The Signalling System in Satellite Personal Communication Networks

by

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Summary

Recent advances in both satellite and terrestrial mobile communications technologies are now leading to the realisation of the dream of the global personal communications within a few years. Satellite systems, as a complement to terrestrial cellular systems, are introduced into the future Personal Communication Networks (S-PCN) to provide global coverage and to allow global roaming. The inter-working and the integration between the satellite and the terrestrial cellular systems (e.g. GSM system) are the key issues in developing the network architecture and designing the control functions and signalling protocols of satellite systems. This thesis focuses on the design of a satellite signalling control system.

The coverage and link properties of ICO10 and LE066 satellite constellations, the representatives of low earth orbit (LEO) and medium earth orbit (MEO) satellite systems, are considered. A satellite specific network architecture is proposed to accommodate the requirements of satellite dynamics and resource control function. The physical layer of satellite signalling links are designed to cope with the specific features of LEO or MEO satellite air-interfaces.

In order to overcome problems specific to LEO or MEO satellite systems and to provide call set-up control function, three important signalling protocols are proposed for the S-PCNs. The priority based fast access scheme is designed for the satellite random access channel allowing low access delay for the call set-up related access packets, even when the channel load is high. The satellite diversity based paging approach is proposed to optimize the paging performance. The modified selective retransmission (M-SRT) and Go-Back-N (M-GBN) protocols are proposed to cope with the transaction type transmission on the dedicated control channel. Simulation results have shown significant improvement of the M-SRT and M-GBN protocols in call set-up delay. Two protocols are also compared in the aspects of implementation complexity and call set-up performance.

Finally, the integration scenarios between satellite and GSM system have been examined for S-PCN in the call handling related functions and associated signalling protocols. The GSM higher layer signalling protocols are tailored to provide the call control related functions. The optimum integration scenario is derived under the criterion of minimum modifications to the GSM higher layer signalling protocols and minimum complexities of the control functions.
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Acronyms

ACCH: Associated Control Channel
AFD: Average Fade Duration
ARFCN: Absolute RF Channel Number
AFSP: Accuracy of predicted First Step Paging area
AGCH: Access Grant Channel
AMSC: American Mobile Satellite System
ARQ: Automatic Repeat Request
AuC: Authentication Centre

BCCH: Broadcast Channel
BCF: Base Control Function
BCR: Boundary Crossing Rate
BEC: Backward Error Control
BER: Bit Error Rate
BPSK: Binary Phase Shift Keying
BSC: Base Station Controller
BTS: Base Transceiver Station
BSS: Base Station System
BSSAP: BSS Application Part
BSSMAP: BSS Management Application Part

CC: Call Control
CCCH: Common Control Channel
CDF: Cumulative Distribution Function
CDMA: Code Division Multiple Access
CM: Call Management
CSL: Component Sub-Layer
CW: Continuous Wave

DA: Diversity Assignment
DAMA: Demand Assignment Multiple Access
DCAS: Diversity Channel Assignment
DCCH: Dedicated Control Channel
DLCI: Data Link connection Identification
D: signalling channels at radio interface
DPC: Destination Point Code
DTAP: Direct Transfer Application Part

EIR: Equipment Identity Register
ES: Earth Station
ESC: Earth Station Controller
EST: Earth Station Transceiver
EXC: gateway Exchange

FA: Fast Access
FACCH: Fast Associated Control Channel
FCH: Frequency Channel
FE: Function Entity
FEC: Forward Error Control
FPLMTS: Future Public Land Mobile Telecommunication System
FN: Frame Number

GBN: Go-Back-N
GCA: Guaranteed Coverage Area
GCT: Good Channel Transmission
GEO: Geostationary Earth Orbit
GMSC: Gateway Mobile service Switching Centre
GOS: Grade of Service
GPS: Global Positioning System
GSM: Group Special Mobile
GT: Global Title

HDLC: High Level Data Link Control
HLR: Home Location Register
HSN: Hopping Sequence Number

IA: Immediate Assignment
IAP: Initial Address Message
IAR: Inter Arrival Rate
ICC: Inclined Circular Constellation
ICO: Inclined Circular Orbit
IMSI: International Mobile Subscriber Identity
IN: Intelligent Network
ISDN: Integrated Service Digital Network
ISUP: ISDN User Part
IWF: Inter-working Function

L1: Layer 1 (physical layer)
L2: Layer 2 (data link layer)
L2ML: Layer 2 Management Link
L3: Layer 3 (network layer)
LA: Location Area
LAI: Location Area Identity
LAPD: Link Access Protocol for the D channel
LAPDm: Modified Link Access Protocol for the Dm channel
LCR: Level Crossing Rate
LE: Local Exchange
LEO: Low Earth Orbit
LI: Length Indicator
LOS: Line of Sight

MA: Mean Anomaly
MAIO: Mobile Allocation Index Offset
MAP: Mobile Application Part
MCC: Mobile Country Code
MEO: Middle Earth Orbit
MFO: Multiple Frame Operation
M-GBN: Modified Go-Back-N
MM: Mobility Management
MNC: Mobile Network Code
MS: Mobile Station
MSC: Mobile Service Switching Centre
MSIN: MS Identification Number
MSISDN: Mobile Station ISDN number
MSRN: Mobile Station Roaming Number
M-SRT: Modified Selective Re-Transmission
MTP: Message Transfer Part

NC: Network Code
NCS: Network Control Station

OA&M: Operation Administration and Maintenance
OML: Operation and Maintenance Link
OSI: Open System Interconnection

PA: Paging Area
PBFA: Priority Based Fast Access
PCM: Pulse Code Modulation
PCN: Personal Communication Network
PDF: Probability Distribution Function
PER: Packet Error Rate
P/F: Pull/Final
PGCH: Paging Channel
PLMN: Public Land Mobile Network
PD: Protocol Discriminator
PSPDN: Packet Switched Public Data Network
PSTN: Public Switched Telephone Network

QPSK: Quaternary Phase Shift Keying
QOS: Quality of Service

RA: Random Access
RACH: Random Access Channel
RER: Receiver Ready
RR: Radio Resource
RNR: Receiver Not Ready
REJ: Reject
RSL: Radio Signalling Link

SA: Slow Access
SABN: Set Asynchronous Balanced Mode
SACCH: Slow Associated Control Channel
SAINT: Satellite INTEGRATION
S-ALOHA: Slotted ALOHA
SAP: Service Access Point
SAPI: Service Access Point Identifier
SAW: Stop And Wait
SB: Spot Beam
SCH: Synchronisation Channel
SR: Satellite Resource
SCCP: Signalling Connection Control Part
S-HLR: Satellite Home Location Register
SIO: Service Information Octet
SLS: Signalling Link Selection
SMS: Short Message Service
S-MSC: Satellite Mobile Service Centre
SP: Service Point
SPC: Service Point Code
S-PCN: Satellite Personal Communication Network
SPOC: Simulation Package of Coverage
SRT: Selective Re-Transmission
SS: Supplementary Service
SS7: Signalling System No7
SSN: Sub-system Number
STE: Segment Tracking Entity
S-VLR: Satellite Visitor Location Register

TC: Transaction Capability
TCAP: Transaction Capability Application Part
TCH: Traffic Channel
TDMA: Time Division Multiple Access
TEI: Terminal Equipment Identifier
TI: Transaction Identifier
TMSI: Temporary Mobile Subscriber Identity
TN: Time-slot Number
TPB: Terminal Position Based
TS: Time Slot
TSC: Training Sequence Code
TSL: Transaction Sub-Layer
TRX: Transmitter/Receiver
TUP: Telephone User Part
TX: Transmitter

UA: Unnumbered Acknowledgement
UMTS: Universal Mobile Telecommunication System
USCH: User Specific Channel

VLR: Visitor Location Register

WS: Window Size
Notation

\( \alpha_t \)  
right ascension angle of orbits as they pass through the equator

\( \Lambda \)  
a factor defined as the percentage of the occurrence of shadowing

\( \Lambda(\text{erlangs}) \)  
telecommunication traffic in erlangs

\( \beta_n \)  
the nadir angle for the cells of a given tier-n

\( \beta_3dB \)  
the satellite antenna 3dB beam-width

\( \sigma^2 \)  
variance of the power level due to shadowing

\( c \)  
the light speed

\( c_j \)  
the half street width of coverage

\( C \)  
Rice factor, the direct to multipath signal power ratio

\( G/N_0 \)  
carrier to noise power spectral density ratio

\( \delta \)  
the earth central angle subtended by the cells of given tiers

\( d \)  
the distance between an MS and a satellite

\( d_{thr} \)  
a threshold of mobiles’ travelling distance from last updating location

\( D \)  
average access delay

\( D_s \)  
satellite antenna diameter

\( D_0 \)  
the fading duration

\( D_g \)  
inter-fading duration

\( \text{erfc} \)  
complementary error function

\( E \)  
Elevation angle

\( E_{\text{link}}/N_0 \)  
satellite link to noise power spectral density ratio

\( \phi \)  
the lower latitude limit of the coverage

\( G \)  
channel load

\( G_{\text{sat}} \)  
satellite antenna gain

\( G_m \)  
mobile antenna gain

\( G/T_{\text{sat}} \)  
figure of merit of the satellite

\( H \)  
satellite altitude

\( I_0(*) \)  
modified Bessel function of order zero

\( \lambda \)  
wavelength of propagation signal

\( L \)  
a length of the coverage area boundary

\( \mu \)  
mean power level decreased in dB

\( m \)  
harmonic factor for the rosette satellite constellation

\( n \)  
the number of spot-beam tiers

\( n_p \)  
packet length in bits

\( n_r \)  
the random back-off re-transmission parameter

\( N \)  
re-transmission times

\( \bar{N} \)  
average number of transmissions per delivered packet

\( N_e \)  
the number of equal cells

\( N_{ch} \)  
the maximum number of traffic channel allocated to a spot beam area

\( N_s \)  
total number of satellite

\( N_u \)  
number of users in a spot beam coverage

\( N(S) \)  
the sequence number of sent I-frame

\( N(R) \)  
the sequence number of received I-frame

\( O \)  
the number of orbits

\( p_g(>n) \)  
the probability that a good state lasts longer than n bits

\( p_{xy} \)  
the probability that channel state transits from x to y
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_e$</td>
<td>the packet error probability under multipath fading effect</td>
</tr>
<tr>
<td>$P_{su}(n)$</td>
<td>the success probability of an $n$-bit packet which remains in good state</td>
</tr>
<tr>
<td>$P$</td>
<td>transmitting power</td>
</tr>
<tr>
<td>$p(S)$</td>
<td>the overall density of the received signal power</td>
</tr>
<tr>
<td>$P_{LN}(S_0)$</td>
<td>the probability density of the mean received power $S_0$ which obeys a log-normal distribution</td>
</tr>
<tr>
<td>$p_{Ray}(S/S_0)$</td>
<td>the probability density of the received power which is assumed</td>
</tr>
<tr>
<td>$p_{Rician}(S)$</td>
<td>the probability density of the received power which obeys a Rician distribution</td>
</tr>
<tr>
<td>$p_{sh}(S)$</td>
<td>the probability density of the received power during shadowing</td>
</tr>
<tr>
<td>$P(k)$</td>
<td>the probability that $k$ packets are transmitted in one time slot</td>
</tr>
<tr>
<td>$P_{loss}$</td>
<td>the probability of packet loss</td>
</tr>
<tr>
<td>$P_s$</td>
<td>the success probability for a transmitted packet</td>
</tr>
<tr>
<td>$\rho$</td>
<td>a density of mobile user population</td>
</tr>
<tr>
<td>$Q_i$</td>
<td>the maximum calls per hour per cell</td>
</tr>
<tr>
<td>$Q(P,L)$</td>
<td>distributions of the mobile transmitting power ($P$) and the slant range ($L$) from mobiles to the satellites</td>
</tr>
<tr>
<td>$r$</td>
<td>the radius of a guaranteed coverage area</td>
</tr>
<tr>
<td>$\gamma_i$</td>
<td>initial phase angle of satellites in the $i$th orbit at $t=0$, measured from the point of right ascension</td>
</tr>
<tr>
<td>$R_{LH}$</td>
<td>the location updating rate</td>
</tr>
<tr>
<td>$R$</td>
<td>Earth radius</td>
</tr>
<tr>
<td>$R_b$</td>
<td>the bit rate</td>
</tr>
<tr>
<td>$s$</td>
<td>number of satellites in the same orbit</td>
</tr>
<tr>
<td>$S$</td>
<td>received signal power</td>
</tr>
<tr>
<td>$S_0$</td>
<td>a short term mean received power</td>
</tr>
<tr>
<td>$S_i$</td>
<td>new generated traffic for an RACH</td>
</tr>
<tr>
<td>$S_i^{(opt)}$</td>
<td>new generated random access traffic where the maximum throughput can be achieved</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Earth central angle</td>
</tr>
<tr>
<td>$t_{RA}$</td>
<td>the duration between adjacent random access time slots</td>
</tr>
<tr>
<td>$T$</td>
<td>average calling time</td>
</tr>
<tr>
<td>$T_c$</td>
<td>collision timer</td>
</tr>
<tr>
<td>$T_{prop}$</td>
<td>round trip propagation delay</td>
</tr>
<tr>
<td>$T_{RA}$</td>
<td>the transmission delay of random access packets</td>
</tr>
<tr>
<td>$T_{SR_{RA}}$</td>
<td>Random access time slot</td>
</tr>
<tr>
<td>$\psi$</td>
<td>the largest great circle range between an observer anywhere on the Earth’s surface and the nearest sub-satellite point</td>
</tr>
<tr>
<td>$v$</td>
<td>the mobile velocity</td>
</tr>
<tr>
<td>$v_{sat}$</td>
<td>the satellite velocity</td>
</tr>
<tr>
<td>$v_{sh}$</td>
<td>the moving speed of the shadowing front taking into account the satellite and mobile velocity</td>
</tr>
<tr>
<td>$V(A)$</td>
<td>acknowledge state variable</td>
</tr>
<tr>
<td>$V(R)$</td>
<td>receive state variable</td>
</tr>
<tr>
<td>$V(S)$</td>
<td>send state variable</td>
</tr>
<tr>
<td>$W$</td>
<td>number of active users reside in a guaranteed coverage area</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

1.1 BACKGROUND TO SATELLITE PCNs

The rapid expansion of cellular telephone networks has heralded the demand for personal mobile communications that allows mobile personal communications from any location in the world with a single hand-set. This is not possible with the current cellular infrastructure because, firstly, many of the existing systems are incompatible as far as a single hand-set is concerned, and secondly, large areas of the globe can not be covered economically by these terrestrial systems.

The unification of all terrestrial cellular systems has been envisaged within the Future Public Land Mobile Telecommunications System (FPLMTS) in which a single-standard hand-set will operate in any area covered by the system. It is realized that terrestrial systems can not provide global roaming because many areas of the world will still remain outside the coverage. Satellite systems are well suited to filling the coverage gaps left by the terrestrial networks. It is, however, unlikely that satellite systems will replace terrestrial networks because of the difficulty for satellite systems to reuse frequencies sufficiently to meet user demands in the highly populated areas.

With the widespread or global coverage provided by satellite system, global roaming will be provided by the integration of satellites in future personal communication networks (PCN). The satellite systems based on this concept are known as the satellite-PCNs (S-PCN). The S-PCNs aim to provide services to the mobile users in a seamless manner.

Various satellite constellation options exist, which are well documented in the literature [AN95/1]. Geostationary (GEO) satellites, as used for most commercial mobile communications applications (Inmarsat, Aussat(OPTUS), American Mobile Satellite System (AMSC), etc.), could also be used for the S-PCNs. However, the high path loss will lead to increased cost and complexity to both satellites and mobile terminals. The geostationary satellites also suffer from long transmission delays, specially in the case of a mobile to mobile call. To provide acceptable quality of service in terms of delay, the switching and necessary processing functions must be installed in the satellite to allow one hop connection between mobiles. This will increase the complexity of the satellite payload. Low elevation angles at high latitudes, a feature for all geostationary orbits, will also affect the service quality in these regions due to blockage and shadowing.
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<table>
<thead>
<tr>
<th>Iridium</th>
<th>ICO</th>
<th>Globalstar</th>
<th>Odyssey</th>
<th>Ellipso</th>
</tr>
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<tbody>
<tr>
<td>Number of satellites</td>
<td>66+6(^1)</td>
<td>10+2(^1)</td>
<td>48+8(^1)</td>
<td>12+2(^1)</td>
</tr>
<tr>
<td>Number of planes</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Number of satellites per orbit</td>
<td>11</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Type of orbit</td>
<td>LEO</td>
<td>ICO</td>
<td>LEO/ICO</td>
<td>MEO/ICO</td>
</tr>
<tr>
<td>Inclination (degree)</td>
<td>86</td>
<td>45</td>
<td>52</td>
<td>50</td>
</tr>
<tr>
<td>Orbit altitude (km)</td>
<td>780</td>
<td>10354</td>
<td>1410</td>
<td>10350</td>
</tr>
<tr>
<td>Minimum elevation angle (degree)</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Orbit period</td>
<td>100 minutes</td>
<td>6 hours</td>
<td>114 minutes</td>
<td>6 hours</td>
</tr>
<tr>
<td>Range of footprint (km)</td>
<td>4386</td>
<td>12913</td>
<td>5850</td>
<td>7400</td>
</tr>
<tr>
<td>Propagation delay (ms)</td>
<td>2.6-8.2</td>
<td>34.5-48</td>
<td>4.63-11.5</td>
<td>34.6-44.3</td>
</tr>
<tr>
<td>Satellite multiple access mode</td>
<td>FDMA/ TDMA</td>
<td>FDMA/ TDMA</td>
<td>FDMA/ CDMA</td>
<td>CDMA</td>
</tr>
<tr>
<td>Frequency band</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Mobile uplink (MHz)</td>
<td>1616-1626.5</td>
<td>1980-2010</td>
<td>1610-1626.5</td>
<td>1610-1626.5</td>
</tr>
<tr>
<td>• Mobile downlink (MHz)</td>
<td>1616-1626.5</td>
<td>2170-2200</td>
<td>2483.5-2500</td>
<td>2483.5-2500</td>
</tr>
<tr>
<td>• Feeder uplink (GHz)</td>
<td>29.1-29.3</td>
<td>5</td>
<td>5.091-5.25</td>
<td>29.5-30</td>
</tr>
<tr>
<td>• Feeder downlink (GHz)</td>
<td>19.4-19.6</td>
<td>7</td>
<td>6.875-7.05</td>
<td>19.7-20.2</td>
</tr>
<tr>
<td>Satellite crosslink</td>
<td>Ka band</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Number of SBs</td>
<td>48</td>
<td>163</td>
<td>16</td>
<td>37</td>
</tr>
<tr>
<td>Cell coverage (km)</td>
<td>400(minimum)</td>
<td>862</td>
<td>2254</td>
<td>1100</td>
</tr>
<tr>
<td>Coverage</td>
<td>Global</td>
<td>Global</td>
<td>Within ± 70° latitude</td>
<td>Major land mass</td>
</tr>
<tr>
<td>Number of ESs</td>
<td>15-20</td>
<td>12</td>
<td>100-210</td>
<td>10-11</td>
</tr>
<tr>
<td>Satellite capacity</td>
<td>1100</td>
<td>4500</td>
<td>2000-3000</td>
<td>3000</td>
</tr>
<tr>
<td>(Number of voice grade channels)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dual satellite visibility</td>
<td>multi-satellite visibility at high altitude</td>
<td>2 or more satellites</td>
<td>2 or more satellites</td>
<td>2 or more satellites</td>
</tr>
<tr>
<td>Satellite diversity exploited</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Satellite output power (W)</td>
<td>–</td>
<td>–</td>
<td>1000</td>
<td>37*25W S-band transmitters</td>
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<tr>
<td>Satellite mass (kg)</td>
<td>689</td>
<td>1925</td>
<td>450</td>
<td>2000</td>
</tr>
</tbody>
</table>

---

\(^1\) Spare satellites

**Table 1-1 Overview of proposed non-GEO satellite-PCN constellations**
Chapter 1 Introduction

Satellites in non-geostationary orbits, such as low earth orbit (LEO) and middle earth orbit (MEO), could overcome these problems. These orbits have much shorter transmission delays and lower requirements for satellite power, which make the mobile terminal design simple. A high elevation angle can be provided for a particular geographical area by choosing appropriate orbit as the satellites are no longer fixed in the equatorial plane.

Non-GEO satellite networks become more important as the demand for a truly global seamless PCN increases. If there are sufficient number of satellites in such orbits, one will always be visible at any geographical location. Thus PCN subscribers will be reached from any point on earth at any time. The advantages of using non-GEO networks have inspired many commercial companies and consortia to invest heavily in their design and operation.

The major proposed S-PCNs are listed in Table 1-1, together with their primary system specifications. Of these, the best known are Iridium, Globalstar, ICO and Odyssey all of which are planned to provide service by the end of this century.

1.2 OBJECTIVES

Since the satellite segment of a S-PCN is used mainly to provide a global roaming feature, it must be compatible with the terrestrial cellular systems. Amongst the various cellular systems, the Group Special Mobile (GSM) system is the most successful and has been adopted virtually world-wide. Many wireless systems worldwide now use the GSM standard and network concept as their baseline system architecture. The use of the GSM standard, especially the signalling system, in the design of S-PCNs is beneficial to both the users and the operators. Some of the advantages are low development cost, smooth interworking and easy integration between satellite systems and the GSM system.

In order that satellite systems provide a complementary service to global roaming users, a satellite specific network architecture and possible modifications to the GSM signalling protocols are necessary. These are needed because satellite systems are different from cellular GSM systems in their resource management, physical and data link controls. Modifications to the GSM network layer are also needed in order to adapt to the global coverage of satellite systems, as the GSM cellular systems are basically local systems contained within the boundary of an operator-owned Public Land Mobile Network (PLMN). Moreover, the inclusion of the satellite segment in a PCN will increase the complexity of the system. Modeling and performance evaluation are therefore critical in the design and operation of such a S-PCN. These issues are the main concerns of this research, and will be addressed separately in different chapters.
1.3 STRUCTURE OF THIS THESIS

This thesis focuses on the call set-up signalling activities in S-PCNs. The study is divided into two parts: the call set-up signalling protocols at the satellite air-interface and the call set-up related signalling transactions between network entities via the CCITT No7 signalling system. For the call set-up signalling at the satellite air-interface, we need to consider the dynamics of the satellite constellation and the channel. Suggested modifications are made to the GSM protocols, such as the Slotted-ALOHA (for random access channel-RACH) and the Stop-and-Wait HDLC protocol (for dedicated control channel-DCCH) by considering the characteristics of the satellite links (e.g. long propagation delay and large path loss, etc.). Performance of paging signalling which is part of the call set-up procedure can be improved via user assistance. The call set-up signalling delay and the signalling load are evaluated for both the LEO66 and ICO10 systems as examples. These are presented in Chapters 3, 4 and 5. For the signalling transactions between network entities, modifications to the GSM functions and signalling protocols are made in order to provide call set-up related functions in the integrated satellite and cellular GSM systems. This part of the research, including a comprehensive review of the GSM signalling system, is in Chapters 6 and 7.

The chapters of this thesis are summarized as follows:

Chapter 2 reviews the design techniques of non-GEO satellite constellations: the street of coverage and the rosette patterns. Two representative satellite constellations, LEO66 (66 satellites on the low earth orbit) and ICO10 (10 satellites on the inclined circular middle earth orbit), have been selected as examples. The coverage statistics of the two satellite constellations along with other important attributes, such as the spot beam configuration, propagation delay and path loss, etc., have been examined. A satellite channel model which forms the basis for the signalling performance study is also introduced. Satellite constellation connectivity data is used in the satellite channel model in order to evaluate the packet error rate at the satellite air-interface.

Chapter 3 proposes a network architecture to accommodate the satellite dynamics. The satellite resource is controlled by earth station controllers (ESC) between which the token for satellite resource control is passed. Conventional GSM logical signalling channels are reused in the S-PCNs. However, different physical layer and data link protocols are defined for the satellite signalling links in order to accommodate the long propagation delay and large path loss. A novel priority-based S-ALOHA random access scheme, based on the good channel transmission and the time capture effect, is proposed for the RACH in order to improve the access delay, in particular, the delay
performance of the delay sensitive random access packets. This approach is shown to effectively reduce the call set-up delay, leading to improved service quality.

Chapter 4 deals with the mobility management signalling in the S-PCNs. The guaranteed coverage area (GCA) \([\text{SAID15}] [\text{AN95/1}]\) approach is selected for the S-PCNs. The advantages of the GCA approach are: a) satellite dynamics which is handled by the network does not affect mobile terminals and b) mobile positioning is not a requirement. The optimum GCA sizes for the ICO10 and the LEO66 systems are determined. The paging channel performance is evaluated for the two systems for both one-step and two-step paging schemes. To counteract the channel fading effect, a new user-assisted-paging scheme is proposed. The performance of the satellite diversity based paging approach is also evaluated and compared with other paging approaches.

Chapter 5 reviews the data link protocols of the GSM DCCH. Problems of using the Stop-And-Wait protocol for the satellite DCCH are addressed. To provide acceptable call set-up delay performance in the S-PCNs, the Go-Back-N and Selective Retransmission protocols are proposed for the Satellite DCCH and necessary modifications to each are made. The call set-up delay and DCCH signalling load for a given traffic load are examined for the LEO66 and the ICO10 systems.

Chapter 6 reviews the GSM network architecture, the signalling system and the higher layer (above layer 3) protocols. It presents the basic framework for the development of a signalling system in an integrated satellite and GSM system.

In chapter 7, the single and split MSC (Mobile service Switching Center) integration scenarios are investigated for an integrated satellite and cellular GSM system. In particular, the higher layer protocols for support of the call control functionality are investigated for satellite specific characteristics. Comparisons of the two integration scenarios are based on the call handling related functions. The study leads to an optimized integration scenario. Additionally, two approaches dealing with the dual-mode terminals’ tracking and location in an integration system have been proposed and analyzed for the completion of the integration study.

Finally, in chapter 8, conclusions and possible directions for the future research work in these related areas are fully discussed.

**1.4 MAJOR ACHIEVEMENTS**

The original achievements obtained during this research are briefly outlined below:

1. A simulation module has been produced for evaluating the packet error rate in the signalling system of LEO66 and ICO10 with real channel conditions. Comparison of
simulation and analytical results has shown good agreement hence validating the module. Using this simulation module, propagation data from practical experiments can be used with real satellite constellations in order to yield the packet error performance on the satellite links. (Chapter 2)

2. A distributed satellite network architecture is proposed for efficient satellite resource management to cope with problems arising from the dynamics of the Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellite constellations. The reuse of the GSM signalling system is desirable for both the users and the operators. Modifications to the GSM signalling system are, however, necessary for the S-PCNs to suit the satellite specific links and the specific control procedures of satellite mobile systems. The concept of GSM logical signalling channels is reused for the S-PCNs. A physical link layer for the satellite air-interface, i.e. the TDMA channel and frame, and the multi-frame structures of a signalling carrier, is defined so that the problems associated with the LEO and MEO based S-PCNs can be taken into account. (Chapter 3)

3. A novel priority-based fast access (PBFA) protocol, based on the good channel transmission (GCT) approach and time capture effect, is proposed for the satellite RACH. The improvement in satellite random access performance achieved by the proposed approach by counteracting the fading effects is significant compared to the conventional Slotted ALOHA protocol used in GSM. In particular, the PBFA scheme optimizes the performance of delay sensitive access packets which affect the call set-up time and the load of other signalling channels (e.g. paging channel). (Chapter 3)

4. A user-assisted paging approach has been proposed for both the one-step and the two-step paging scenarios. Satellite diversity based paging approach, i.e. the user assisted two-step paging scheme, is proved to be superior in terms of the paging delay and the PGCH load. (Chapter 4)

5. Modified Go-Back-N (M-GBN) and Selective Re-transmission (M-SRT) protocols have been proposed and evaluated for the satellite DCCH link layer. The air-interface signalling procedures for mobile originated and terminated call set-up, based on two DCCH link layer protocols, are simulated. The call set-up delay and the signalling channel load for the ICO10 and LEO66 satellite systems are also evaluated. Two protocols are compared in implementation complexity, the call set-up delay, and signalling load performance in different environments (e.g., highway, city) and different satellite constellations. (Chapter 5)

6. Two integration scenarios for S-PCN and cellular GSM, the split Mobile Switching Centre (MSC) and the single MSC, are investigated from the viewpoint of the higher layer protocols that provide the call control related functions. Comparisons of network signalling loads for the two integration scenarios are performed via
Chapter 1 Introduction

simulation. This study results in an optimized integration scenario in terms of minimum modifications to the GSM signalling system and the minimum complexities of the control functions. (Chapter 7)

7. Two approaches, GSM-like and segment tracking entity approaches, performing the mobility management of dual-mode terminals in an integrated satellite and GSM system are proposed and investigated.

The above are all considered to be new and original contributions to the dynamic satellite signalling area.
Chapter 2

Non-Geostationary Satellite Systems

Problems associated with non-geostationary satellites in the provision of personal communication services, such as satellite dynamics, link power limitation, long propagation delay and path delay difference in a coverage zone, are investigated for two non-GEO satellite constellations: LEO66 and ICO10. The satellite connectivity data is combined with the satellite channel model in order to evaluate the packet error rate at the satellite air-interface.

2.1 INTRODUCTION

The technology of geostationary (GEO) satellite communications systems is now mature and well understood since these architectures have been studied, designed and implemented for many different applications. Recently there has been renewed interest in non-GEO satellite systems to provide personal communication services (e.g. Iridium, inclined circular orbit-ICO, Globalstar, etc.). These systems aim at global coverage using satellite constellations in non-geostationary orbits (low earth orbit-LEO, medium earth orbit-MEO). The main reason that non-GEO satellites are favoured is their advantage in link power budget. Also, reduced propagation delay compared to GEO satellites will benefit voice communications.

The design of a non-GEO satellite system is very different from, and often more complicated than, that of a GEO satellite system. In fact, whilst a GEO satellite can be analysed independently, one has to deal with the whole constellation of LEO/MEO satellites in order to calculate link budgets and derive service availability figures.

2.2 SATELLITE CONSTELLATIONS

The operating altitude of non-GEO satellites has been confined to two kind of orbits: LEO and MEO, which are determined by the radiation characteristics of outer space. The Van Allen belt contains two kinds of charged particles (electrons and protons) trapped by the earth’s magnetic field, centred on the equator between altitudes of 2100 to 5300km (inner belt) and 13200 to 19500km (outer) [WHI92a]. To counteract the radiation from the Van Allen belt, radiation hardened components and advanced shielding technology have to be used on board the satellites. As a consequence, the satellite cost will increase. Therefore LEO around 1000km and MEO around 10000km have been selected to provide satellite personal communication services.

Many non-GEO satellite networks have been proposed and studied over the past 20 years for commercial and military applications. Rider [RID85] and Ballard [BAL80]
showed that optimised satellite constellations in polar or inclined circular orbits would give the best world-wide coverage.

Figure 2-1 Geometry of satellite coverage

In the study of satellite constellations, an important geometry parameter, the earth central angle $\theta$, which is related to the instantaneous coverage of a single satellite, is defined. It is determined by the satellite altitude and the minimum elevation angle $E$ of the earth coverage as illustrated in Figure 2-1.

$$\theta = 90 - E - \arcsin(\cos E \times \frac{R}{R + H}) \quad (2.1)$$

As shown in Figure 2-2, a 20° earth central angle corresponds to the Iridium constellation, whereas a 58° earth central angle is adopted by the ICO10 constellation.

Figure 2-2 Elevation angle vs. satellite orbit altitude for various earth central angle
2.2.1 Polar Constellation

Polar constellations consist of a number of satellites that have a common intersection at the polar axis. Satellites with the same altitude are equally distributed around the circular orbits. The satellite density is highest at the poles and lowest at the equator. The orbit separation and satellite spacing on one orbit are adjusted to minimise the number of satellites required to provide a global coverage.

The “Street-of-Coverage” technique applied to polar constellations was first proposed in [LUD61] and studied in [BES78], [RID85] and [ADA87]. The footprints of satellites distributed in a polar orbit overlap to provide a continuous band of coverage along the orbit projection. The half street width of coverage \( c_j \) is given by

\[
c_j = \arccos{\frac{\cos\theta}{\cos\left(j\frac{\pi}{s}\right)}}
\]  

where \( \theta \) is the earth central angle and \( j = 1 \) corresponds to the single street coverage provided by \( s \) satellites in the same orbit.

For an arbitrarily phased constellations, the ascending nodes of the orbits are equally distributed along half the equator. The number of orbits required to provide global coverage is, therefore

\[
O = \frac{\pi}{2c_j}
\]  

To minimise the number of satellites, the optimal inter-orbit phasing is investigated in [BES78] and [ADA87]. The inter-orbit phasing angle is defined as the relative position between satellites in adjacent co-rotating orbits. The maximum spacing between orbits

![Figure 2-3 Street coverage of optimal phasing polar constellation](image)
is achieved by keeping the inter-orbit phasing angle such that a satellite footprint centre of C(2,2) is at the middle of the distance between the other two satellites’ footprint centres A and B which are in the adjacent orbit, as shown in Figure 2-3. Therefore the single coverage from the poles to the lower latitude limit (φ) of the coverage is provided by O orbits (in the case of global coverage, φ = 0°)

\[(O-1)(\theta + c_j) + 2c_j = \pi \cos \phi\]  

(2.4)

The comparison between arbitrary and optimal phasing constellations shows that the phasing approach can significantly reduce the number of satellites required for global coverage [BES78]. For instance, a constellation of 66 satellites (θ = 20°) is designed using the optimal phasing approach with 6 near polar orbits and 11 satellites in each orbit. This constellation (LEO66) is also the optimum among optimal phasing constellations, which requires minimum number of satellites. If arbitrary phasing is used, the number of satellites required is at least 80 (Figure 2-4).

The elevations to the primary (with the highest elevation angle) and secondary (with the second highest elevation angle) satellites in the LEO66 constellation are plotted versus the latitudes (Figure 2-5). The mean elevation angle to the primary satellite is above 20° for all latitudes. The acceptable visibility (elevation angle > 15°) from the second satellite can be observed only when the latitude is above 60°. Therefore diversity is not a viable approach for the polar orbit constellation.

![Figure 2-4 Comparison between optimal phasing and arbitrary phasing polar constellation](image)
2.2.2 Inclined Circular Constellation (ICC)

Since, in polar constellations, satellite visibility improves as the latitude increases, such constellations do not favour the low and medium latitudes. In contrast, the ICC can be optimised for a given latitude where the majority of the traffic is located. The ICC has the beneficial property that orbits remain in a relatively fixed pattern. For single satellite visibility, ICCs are more efficient than polar constellations in terms of the required number of satellites.

The Rosette pattern was adopted by Walker to search for the optimised constellations in the inclined circular orbit [WAL73,77]. He showed, through examples, that constellations for global coverage, which employ either up to 15 satellites for single visibility or up to 25 satellites for optimum multiple visibility, are possible. Ballard [BAL80] extended and generalised Walker’s work by mathematically describing the satellite orbit optimisation process. The key parameter of ICC design is the largest great circle range ($\Psi$) between an observer anywhere on the Earth’s surface and the nearest sub-satellite point. It is a parameter providing more suitable measure of good geometry coverage than elevation angle since it is independent of the satellite altitude. $\Psi$ subtends the earth central angle $\theta$ as shown in Figure 2-1. Besides the inclination angle, other orbit orientation angles used to define a Rosette constellation are given as below:

$$\alpha_i = 2\pi i / O, \ i = 0 \ to \ O-1 \quad (2.5)$$

$$\gamma_i = m\alpha_i, \ \ m = (0 \ to \ N_r-1)/s \quad (2.6)$$
The orbits are uniformly distributed in a right ascension angle $\alpha_i$ as they pass through the equator, and $\gamma_i$ is the initial phase angle of satellites in the $i$th orbit at $t=0$, measured from the point of right ascension. The shorthand notation $(N, O, m)$ is used in [BAL80] to describe a rosette constellation with $N$ total satellites, $O$ orbit planes and a harmonic factor ‘m’. The denominator ‘s’ in Equation 2.6 is the number of satellites in an orbit.

Three inclined circular constellations have been proposed for global coverage: ICO, Globalstar and Odyssey (Table 2-1). The maximum circle range ($\psi$) for ICO, Globalstar and Odyssey are 58°, 26.2° and 47.3° respectively. ICO and Odyssey satellites are deployed in MEO, whereas the Globalstar is a LEO satellite system.

Both ICO and Globalstar will use satellite diversity to improve the channel performance. As shown in Figure 2-6 for the ICO constellation, whilst the mean elevation to the primary satellite is kept above 20°, the mean elevation to the second best visible satellite is above 14° for all latitudes. It can also be observed that the mean elevation angles to the two satellites (primary and secondary satellites) are above 40° and 20° respectively when the latitude is below 50°. The mean elevation angle distribution of the Globalstar constellation is plotted in Figure 2-7. Coverage is not available above 75° latitude owing to the use of inclined orbits and to the low altitude. The mean elevation to the second satellite is above 15° when the latitude is below 60°.

![Figure 2-6 Mean elevation distribution of ICO10 constellation](image)
2.3 PROPOSED SATELLITE CONSTELLATIONS

The primary features of Iridium and ICO satellites have been listed in Table 1-1. In this section, two satellite constellations, LEO66 and ICO10, as representative of LEO and MEO systems respectively, are further investigated. Many parameters, such as the delay difference, the free space loss and the satellite antenna gain, are dependent on the geometry of the satellite constellation, and in particular the spot beam (SB) structure.

2.3.1 Geometry of a Multi-beam Satellite Coverage

To increase the link availability, satellite mobile systems use multi-spot-beams providing the coverage. The number of SBs deployed in a satellite coverage is determined by the following factors: the maximum capacity that a beam can support; the total available bandwidth; the SB size which needs to be small enough to increase the satellite antenna gain which leading to a saving of the power consumption at both the satellite and the mobile terminals. However, small SB size leads to a short visibility time owing to the satellite dynamics. This problem can be solved by electronically steering a satellite antenna as it passes over [TUC93], so that the SB’s coverage can be fixed during the satellite visible period.

The geometry of a multi-beam satellite coverage area is addressed in Ref. [MAR91]. It is assumed that the satellite SBs have the same size. Actually the outer-tier SBs are enlarged due to the curvature of the earth. The number of SBs $N_e$ is given by

$$N_e = 1 + \frac{6n(n+1)}{2} \quad (2.7)$$
where \( n \) is the number of tiers. Hence for \( n=1, 2, 3, \ldots \) and 7, a satellite multi-beam structure consists of 7-, 19-, 37-... and 169-beams respectively. The nadir angle of SBs for a given tier \( n \) is expressed as

\[
\beta_n = \tan^{-1} \left[ \frac{R \sin \left( \frac{(2n+1)\delta}{2} \right)}{H + R - R \cos \left( \frac{(2n+1)\delta}{2} \right)} \right] - \sum_{k=1}^{n-1} \beta_k - \frac{\beta_n}{2} \tag{2.8b}
\]

where \( \delta \) (Figure 2-1) is the earth-centre angle subtended by the SBs. \( \beta \) is the nadir angle for a given spot beam. Because of the equal size assumption for the SBs, \( \delta \) of different tiers is assumed to be equal and given by:

\[
\delta = \frac{2\theta}{2n+1} \tag{2.9}
\]

\( \delta \) is only an approximation of the spot beam configuration. In fact, the practical spot beam is larger than that given in above equation due to the spot beam overlapping.

\[2.3.2 \text{ Satellite Antenna}\]

The selection of SB numbers is closely related to the earth central angle \( \theta \), as well as to the satellite antenna size. For a given \( \theta \), the greater the number of SBs, the smaller the SB nadir angle (\( \beta_n \)). Therefore the satellite antenna gain can be increased. The satellite antenna 3dB beamwidth is inversely proportional to the antenna diameter

\[
\beta_{3dB} \equiv 70 \frac{\lambda}{D_a} (\circ)
\]

and the antenna gain at the edge of SB coverage is expressed as [MAR93]:

\[
G_{sat} = 10 \log \left( \frac{\pi D_a}{\lambda} \right)^2 - 3 \left( \frac{\beta_n}{\beta_{3dB}} \right)^2 (dBi) \tag{2.11}
\]

Since the multi-beam coverage is formed by one antenna reflector with an array of feeders, the nadir angle of the central SB (where the sub-satellite point is located) is wider than that of the outer layer’s SB for a given equal size of beam coverage. If the nadir angle of the outermost SB is assumed as \( \beta_{3dB} \), the gain variation inside the central SB coverage might be very large (>3dB). The satellite antenna diameter of 2.18m has been selected for an ICO10 like system, balancing between the satellite antenna gain and the nadir angles of the different SB tiers. As shown in Figure 2-8, the maximum antenna gain is at the centre of each SB. The gain is reduced to the lowest point (-3.5dB) at the boundary of central SB because the nadir angle exceeds \( \beta_{3dB} \). The gain variances in the outermost SBs are only 0.12dB. The differences of gain variation in
different SB tiers make the receiving power at the boundary of the inner SBs similar to that of the outermost SBs because of the free space loss differences (2.87dB for ICO satellite) between sub-satellite point and the boundary of the footprint (Figure 2-9).

2.3.3 Iridium Multi-beam Satellite

Iridium satellites adopt a 48-beam pattern that constitutes four-layers of circular SBs with different SB sizes (Table 2-1). Because the LEO66 has low orbit altitude and
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fewer SBs, compared to the ICO satellites, the SB nadir angle is much wider for Iridium SBs. The choice of a wider 3dB beamwidth which will yield smaller satellite antenna size (1.35m as selected) will reduce the gain variance inside the SB. The difference between satellite antenna gain at the boundaries of the outermost and the inner SBs is as high as 8dB. However, the difference in free space loss between them is also about 8dB. Therefore the receiving power at the boundaries of different SB tiers tends to be at the same level. This is the properties of isoflux antenna.

<table>
<thead>
<tr>
<th></th>
<th>ICO satellite (E &gt; 10°)</th>
<th>LEO66 satellite (E &gt; 8°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of layers</td>
<td>8</td>
<td>1st 2nd 3rd 4th</td>
</tr>
<tr>
<td>The number of SB</td>
<td>163</td>
<td>3 9 15 21</td>
</tr>
<tr>
<td>One SB diameter (km)</td>
<td>862</td>
<td>529 422 463 789</td>
</tr>
<tr>
<td>One SB pass duration (minutes)</td>
<td>7.72 1.32 1.05 1.16 1.97</td>
<td></td>
</tr>
<tr>
<td>One satellite pass (minutes)</td>
<td>115.7</td>
<td>10.96</td>
</tr>
<tr>
<td>One satellite coverage range (km)</td>
<td>12913</td>
<td>4386</td>
</tr>
<tr>
<td>Satellite 3dB beamwidth (°)</td>
<td>4.4</td>
<td>9.6</td>
</tr>
<tr>
<td>Satellite antenna(m)</td>
<td>2.18</td>
<td>1.35</td>
</tr>
</tbody>
</table>

*Table 2-1 ICO10 and LEO66 multi-beam systems*

Owing to the low orbit altitude, call handover is very frequent in a LEO system, especially when multi-beam satellites are used. As shown in *Table 2-1*, one satellite pass takes approximately 11mins and the SB pass duration of the Iridium system is merely 1-2 min.

2.3.4 *Other Features of Multi-beam Satellite Coverage*

The maximum delay differences \((d_{\text{max}}-d_{\text{min}})/c\) (in this case \(d\) is the distance between an MS and a satellite) in the SBs of both ICO10 and LEO66 satellites is of the same order of magnitude, as shown in *Figure 2-10*. The maximum delay difference in a SB is an important parameter that affects the performance of random access channels. *Figure 2-11* illustrates the elevation angle of each tier of SBs. The elevation angle to an ICO10 satellite is increased in the order of 10° from the outermost tier of SBs to the central SB. In the Iridium system, the elevation angles in the different tiers of SBs are not uniformly distributed. The elevation angle of the central tier of SBs is in the range of 50° to 90°, whereas the elevation change of the outermost tier of SBs is only 10°.
2.4 SATELLITE CHANNEL MODEL

As in mobile radio channels, satellite channels are not ideal. The signal received at a mobile antenna includes a direct component from the satellite, a ground-reflected component and a diffuse component coming from the surrounding environment. Owing to the movements of the mobiles and of non-GEO satellites, the channels are time-variant. The effect of time variance can be subdivided into fast fading caused by the
destructive or constructive superposition of multipath signals, and slow fading caused by shadowing.

### 2.4.1 Methods of Counteracting the Fading Effect

Shadowing process poses the major threat to accurate data transmission. When the line of sight signal from the concerned satellite is blocked, it is highly likely that errors will occur and that data packets will have to be re-transmitted.

The shadowing phenomenon on satellite channels is a function of the elevation angle. The lower the elevation angle to a mobile, the worst the shadowing condition will be. Encountering a low elevation angle is unavoidable owing to the constant motion of non-GEO satellites. When a satellite in communication approaches the horizon, the channel condition deteriorates and it may become completely unavailable. The problem is alleviated by using satellite diversity in order to counteract the shadowing and to solve the satellite handover problem.

Diversity techniques have been used in the RAKE receiver in the CDMA cellular mobile system [KOH92] in order to solve the interference problem at cells’ boundary caused by frequency reuse. Qualcomm [QUA92] are proposing a LEO satellite CDMA system (Globalstar) based on their experience in the CDMA cellular mobile systems. Satellite diversity is an important measure for the Globalstar system in order to improve received signal performance and to realise a soft handover. Although it uses TDMA, the ICO10 system, which was initially proposed by Inmarsat, will also provide the advantage of satellite diversity. The ICO10 constellation is designed to provide dual diversity coverage (Figure 2-6). Indeed the diversity approach can improve the service performance under shadowing conditions. However the drawback is that it would increase the complexities of terminals and network.

Slow fading can be compensated by power control which requires a higher transmitting power in order to provide the shadowing margin. Iridium’s low earth orbits can provide about 10dB fading margin on the mobile link (Table 2-4).

In addition to slow fading, fast fading results in more or less noticeable fluctuations of the received signal power. Such fluctuations are harmful to the error performance of the received signal because of the non-linear relation between signal-to-noise ratio and error probability. In our study of the signalling performance at the satellite air-interface, the fading effect is an important factor that needs to be taken into account.

### 2.4.2 Satellite Channel Model

Many studies, mostly based on the mobile radio channel models and the experimental statistics, have looked at satellite channel fading effects. Loo first proposed a statistical
model for a land mobile satellite channel [LOO85]. The model assumes that the line-of-sight (LOS) component is shadowed with a lognormal distribution and the multipath component is Rayleigh distributed. The expressions for level crossing rate (LCR) and average fade duration (AFD) are derived from the above assumptions.

Refs. [FAR85] and [CAS92] focus on satellite channels impaired by the multipath fading effects. The received multipath signal consisting of the LOS component and a fading component that is assumed to be Rician distributed. The fade margin is determined [FAR85] as a function of signal to noise ratio for different bit error rates (BER) when the coherent detection of binary phase shift keying (BPSK) or quaternary phase shift keying (QPSK) signals is considered. The optimum packet size is resolved in [CAS92] by applying an analytical Rician channel model.

Another important contribution was made by Lutz [LUTZ91]. Lutz’s model is based on the experimental results using a MARECS satellite. The measurement results were recorded for elevation angles between 13° to 43° using different mobile antennas and in city and highway environments. A channel model describing combined Rician fading and lognormal shadowing was developed. The switching process between the good and bad channel states was approximated by two-state Markov model. Our study on the signalling performance at satellite air-interface is mainly based on the use of Lutz’s channel model which will be introduced in the next section.

### 2.4.3 Lutz’s Satellite Channel Model

#### 2.4.3.1 First order probabilistic model

Lutz’s model can accommodate both unobstructed and shadowed situations. In the unobstructed case where the mobiles have a direct view of satellites, the received power $S$ obeys a Rician distribution

$$p_{\text{Rician}}(S) = Ce^{-C(S^+)}I_0(2C\sqrt{S})$$

(2.12)

where $C$ is the direct to multipath signal power ratio (Rice factor) and $I_0(\bullet)$ is the modified Bessel function of order zero.

When the LOS signal is shadowed, the model is more complex. No direct component exists and the multipath signal is assumed to be Rayleigh distributed with a short term mean received power $S_0$

$$p_{\text{Rayl}}(S/S_0) = (1/S_0)\exp(-S/S_0)$$

(2.13)

The mean received power $S_0$ is a time-varying factor and is assumed to be characterised by a log-normal distribution

$$P_{\text{LN}}(S_0) = \frac{1}{\sqrt{2\pi}\sigma\ln10} \frac{1}{S_0} \exp\left[-\frac{(10\log S_0 - \mu)^2}{2\sigma^2}\right]$$

(2.14)
where $\mu$ is the mean power level decrease in dB and $\sigma^2$ is the variance of the power level owing to shadowing. Therefore the probability density of the received power during shadowing is given by

$$P_{sh}(S) = \int_{0}^{\infty} p_{Rayl}(S/S_0) \cdot P_{LN}(S_0) dS_0$$  

(2.15)

The overall density of the received signal is a combination of the densities of the shadowed and unshadowed components, weighted by a factor $A$ which is defined as the percentage of the occurrence of shadowing:

$$p(S) = (1 - A) p_{Ray}(S) + A \int_{0}^{\infty} p_{Rayl}(S/S_0) P_{LN}(S_0) dS_0$$  

(2.16)

The mean reduction of received power is calculated by

$$E(S) = (1 - A)(1 + \frac{1}{C}) + A \cdot 10^{ln10\%b^2/2+\mu/10}$$  

(2.17)

From Table 2-2, it can be observed that shadowing is negligible at a high elevation angle. Thus the packet errors will mainly be due to the multipath effect.

2.4.3.2 The Markov Model

The most important parameter in Lutz’s model is the time sharing parameter, $A$, which is related to the fading and interfading duration $D_g$ and $D_b$:

$$A = \frac{D_b}{D_g + D_b}$$  

(2.18)

The mean values of $D_g$ and $D_b$ are given in [LUTZ91] and we list them along with other parameters, $A$, $C$, $\mu$ and $\sigma$ in Table 2-2. The measurement results given in [LUTZ91] are limited to the low elevation angles (Max. 43°). The propagation experiment conducted by University of Surrey gives the measurement results in the suburban area at the high elevations [PAR93].

![Figure 2-12 Markov channel model](image)

To simplify the problem, the switching process, characterised by the factor $A$, is approximated by a two-state Markov model [LUTZ91], as shown in Figure 2-12. The
transition probability $P_{gb}$ is related to the bit duration for a given speed $v$ and the bit rate $R_b$ (b/s)

$$D_g (bits) = \frac{1}{P_{gb}} = \frac{R_b}{v} \cdot D_g (m) \quad (2.20)$$

The probability that a good channel state lasts longer than $n$ bits is

$$p_g (\geq n) = P_{gs} = (1 - P_{gb})^n \quad (2.21)$$

The probability of a packet starting in the good state is $(1 - A)$ [CAS92]. Therefore, the probability of an $n$-bit packet transmitted in a good channel state is the probabilities of it starting and remaining in the good state for the whole duration of the packet [CAS92]

$$P_{ss} (n) = (1 - A) \cdot p_g (\geq n) \quad (2.23)$$

So, from the combination of Equations (2-20) to (2.23), the probability of an $n$-bit packet without encountering a bad channel state is given by

$$P_{ss} (n) = (1 - A) \left( 1 - \frac{v}{R_b \cdot D_g} \right)^n \quad (2.24)$$

where $v$ is the mobile velocity. For non-GEO satellite systems, however, both the satellite and mobile velocities should be taken into consideration. In this case, instead of using the mobile speed $v$, we use the moving speed (relative to the mobile) of the shadowing front (point S as shown in Figure 2-13), $v_{sh}$, in Equation (2.24).

$$v_{sh} = v \pm D_g / t_{gs} \quad (2.25)$$

where $t_{gs}$ is the time needed for a fixed mobile to be shadowed because of satellite movement.

$$t_{gs} = \frac{D_g}{v_{sat}} = \frac{D_g \cdot (S_s - S_g) / S_B}{v_{sat}} \quad (2.26)$$

Assuming that the mobile velocity is 90km/h, the shadowing speeds for ICO10 and LEO66 satellites are 90.2 km/h and 93.7 km/h respectively if the satellites move in the same direction as the mobiles. Clearly, the satellite moving speed has very little effect on the channel state transition probability. In particular, the MEO satellite velocity can be ignored as far as the channel state transition probability is concerned.
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Figure 2-13 Satellite and mobile velocity related to the duration of good channel state

<table>
<thead>
<tr>
<th>Elevation (°)</th>
<th>Environmental category</th>
<th>$A$</th>
<th>$10\log C$ (dB)</th>
<th>$\mu$(dB)</th>
<th>$\sigma$ (dB)</th>
<th>$D_r$ (m)</th>
<th>$D_b$ (m)</th>
<th>$E(S)$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>city</td>
<td>0.89</td>
<td>3.9</td>
<td>-11.5</td>
<td>2</td>
<td>9</td>
<td>70</td>
<td>-6.48</td>
</tr>
<tr>
<td>24</td>
<td>city</td>
<td>0.66</td>
<td>6.0</td>
<td>-10.8</td>
<td>2.8</td>
<td>27</td>
<td>52</td>
<td>-3.07</td>
</tr>
<tr>
<td>34</td>
<td>city</td>
<td>0.58</td>
<td>6.0</td>
<td>-10.6</td>
<td>2.6</td>
<td>24</td>
<td>33</td>
<td>-2.32</td>
</tr>
<tr>
<td>43</td>
<td>city</td>
<td>0.54</td>
<td>5.5</td>
<td>-13.6</td>
<td>3.8</td>
<td>42</td>
<td>49</td>
<td>-2.05</td>
</tr>
<tr>
<td>60</td>
<td>suburban</td>
<td>0.224</td>
<td>13.23</td>
<td>-6.1</td>
<td>2.8</td>
<td>--</td>
<td>--</td>
<td>-0.55</td>
</tr>
<tr>
<td>70</td>
<td>suburban</td>
<td>0.03</td>
<td>14.68</td>
<td>-6.1</td>
<td>2.2</td>
<td>--</td>
<td>--</td>
<td>0.05</td>
</tr>
<tr>
<td>80</td>
<td>suburban</td>
<td>0.007</td>
<td>17.7</td>
<td>-6.4</td>
<td>3.2</td>
<td>--</td>
<td>--</td>
<td>0.51</td>
</tr>
<tr>
<td>13</td>
<td>highway</td>
<td>0.24</td>
<td>10.2</td>
<td>-8.9</td>
<td>5.1</td>
<td>90</td>
<td>29</td>
<td>-0.48</td>
</tr>
<tr>
<td>24</td>
<td>highway</td>
<td>0.25</td>
<td>11.9</td>
<td>-7.1</td>
<td>6</td>
<td>188</td>
<td>62</td>
<td>-0.34</td>
</tr>
<tr>
<td>34</td>
<td>highway</td>
<td>0.008</td>
<td>11.7</td>
<td>-8.8</td>
<td>3.8</td>
<td>1500</td>
<td>12</td>
<td>0.26</td>
</tr>
<tr>
<td>43</td>
<td>highway</td>
<td>0.002</td>
<td>14.8</td>
<td>-12.0</td>
<td>2.9</td>
<td>8300</td>
<td>17</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Table 2-2 Fading channel statistics measured using C3 antenna [LUTZ91] [PAR93]

2.4.4 BER of Signalling Packet

2.4.4.1 $C/N_0$ Threshold

Considering the coherent detection of $\pi/4$ QPSK signals, the bit error rate (BER) is the complementary error function of the $E_{\text{int}}/N_0$

---

1 The channel statistics measured at 13°-43° elevation angles are the average of measurements obtained under various cases.
BER = $\frac{1}{2} \text{erfc}\sqrt{E_{\text{link}} / N_0}$ \hspace{1cm} (2.27)

Figure 2-14 shows the link BER plot versus the link C/N₀ threshold. The carrier bit rate is assumed 50kb/s and the modem implementation loss is 1.5dB. To achieve a satisfactory service quality (BER=$10^{-3}$), the link C/N₀ threshold is 55.3dB Hz.

![BER vs. link C/N₀ threshold](image)

### 2.4.4.2 BER Evaluation

In order to consider the effect of mobile velocity and packet length on the transition probability of channel states, we separately evaluate the mean BERs for the good and bad channel states with the probability density function $p_{\text{Rician}}$ and $p_{\text{sh}}$ given previously (Equations 2.12, 2.13):

\[
\begin{align*}
BER_g &= \int_0^\infty BER(S) \cdot p_{\text{Rician}}(S) dS \hspace{1cm} (2.28a) \\
BER_b &= \int_0^\infty \int_0^\infty BER(S) \cdot p_{\text{Rician}}(S/S_0) p_{\text{LN}}(S_0) dSdS_0 \hspace{1cm} (2.28b)
\end{align*}
\]

When fading effect is considered, the Equation (2.27) becomes

\[
BER(S) = \frac{1}{2} \text{erfc}\sqrt{S \cdot E_{\text{link}} / N_0} \hspace{1cm} (2.29)
\]

The BER (mobile uplink) can be considered as a function of the mobile transmitting power ($P$) and the slant range ($d$) from mobiles to the satellites

\[
BER(S,d) = \frac{1}{2} \text{erfc}\sqrt{S \cdot Q(P,d)} \hspace{1cm} (2.30)
\]

where $Q(P,d)$ is given by
where $G_m$ is the mobile antenna transmitting gain assumed 0dBi, $G/T_{sat}$ is the figure of merit of the satellite assumed 5.4dBiK and $R_b$ is the channel bit rate assumed 50kb/s. For simplicity, we assume that the slant range $d$ is an uniform distribution. Hence according to Equation (2.28a), the mean BER is

$$BER = \frac{1}{d_{max} - d_{min}} \int_{d_{min}}^{d_{max}} BER(S, d) \cdot p_{fid}(S) dS d\dd$$

(2.31)

The mean BER from Equation (2.31) is plotted in Figure 2-15 (dash line), which is about $10^{-2}$ when the fading effect is present and mobiles’ elevation angle is in the range of 10°-20° for the mobile transmitting power (peak) of 3W. We have also obtained the BER (solid line in Figure 2-15) via simulation approach. The simulation model is as shown in Figure 2-16. The connectivity statistics and the fading attenuation (in the form cumulative distribution file (CDF)) are fed into a BONeS Satcom model (Up/Down channel model primitive). The output C/N\textsubscript{0}(S) and the fading value probability $p(S)$ are used in the BER model with Equation (2.32) to calculate the mean BER which is obtained by averaging over 40 individual BER samples. Figure 2-15 shows the agreement between two results.

This simulation model can be used to co-operate with the propagation data from the practical experiments. As has been introduced, only two fading data files are required, CDF and PDF. This is left for the future work. In this research, the CDF and PDF of fading values used is calculated from Equations (2.13) to (2.15).
The elevation angle from users to a best visible satellite in non-GEO satellite systems changes continuously over time. The users’ channel condition is, therefore, also time-varying. To evaluate the call set-up signalling performance in practical satellite systems, we have simulated the BER performance at different elevation angles for two representative satellite systems, ICO10 and LEO66 (Figures 2-17 to 2-20).

Figure 2-17 shows the BER performance in the bad channel state for the LEO66 satellite system, the propagation parameters of high elevation angles in suburban environment being used. It can be observed that the signalling transmission in the bad channel state is almost impossible even though the LEO66 provides a high propagation margin.
The BER performance in the good channel state for the LEO66 satellite system is plotted in Figure 2-18. The signal transmission (BER) at a high elevation angle in the suburban environment exhibits much better performance. The BER values are in the range of $10^{-2}$ to $10^{-10}$ when the elevation angle is changed from $10^\circ$ to $80^\circ$ with 0.5 W transmitting power. Because the same frequency band on the up and down links are used, the mobile and satellite transmitting powers, as well as the BER performance for the up and down links, will be identical.
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![Figure 2-20 ICO10 mobile downlink BER (good channel) vs. satellite TX power](image)

Figure 2-19 and 2-20 display the BER performance for up and down links in the ICO10 satellite system. Due to a higher orbit altitude compared to that of the LEO satellites, ICO10 requires higher transmitting powers to obtain a satisfactory BER performance. The BER values (mobile uplink) are in the range $10^{-2.2}$ and $10^{-3.2}$ in the city and suburban environment when the mobile transmitting peak power is 3W. The obvious differences between the BER plots are due to different surroundings and elevation angles. The BER performance for the up and down links shows slight differences because of the use of different frequency bands.

In order to increase the packet success probability, packets are normally protected by forward error correction (FEC) or a cyclic redundancy check (CRC) coding scheme. When good channel state is present, it can be assumed that the bits in a transmitted packet are uncorrelated because the fast fading is much slower than the packet duration. Using FEC, the packet error probability $P_e$ is given by [PRA94]

$$P_e = 1 - \sum_{i=0}^{t} \binom{n_p}{i} BER^i (1 - BER)^{n_p-i} \quad (2.33)$$

where $n_p$ is the packet length and $t$ is the number of error bits which can be recovered.

An example of packet success probability for the random access packets under the multipath fading effect in the ICO10 satellite system is plotted as shown in Figure 2-21. The relevant parameters are given in Appendix C1.
Figure 2-21 The error probability of random access packets - good channel state (ICO10)

2.4.5 Simulation of Signalling PER

The simplified simulation flow chart is as shown in Figure 2-22. The simulation libraries, SATCOM and SATLAB, provided within the BONeS network simulation package have been used along with the implementation of Lutz’s channel model in order to determine the packet success probability. For the given satellite constellations and the mobile instantaneous positions, SATLAB outputs satellite connectivity related data which includes the elevation angle, the distance between the visible satellite and the user, etc. When more than one satellite is visible, the one with the highest elevation angle is selected.

For the purpose of evaluating the call set-up signalling performance, a two-state Markov channel model was used with the occurrence percentage of shadowing A and transition probability $p_{gb}$. The latter is dependent on the signalling packet length, the moving speed of the shadowing front end, the visibility of a satellite, as well as the roaming environment of the mobiles.

The probability that a signalling packet is transmitted in the good channel state is determined by the user’s elevation angle and factors included in Equation (2.24). If a packet encounters a shadowing during the transmission, it most likely that it has to be re-transmitted because the bit error rate is unacceptable (Figure 2-17). If a packet is transmitted in the good channel state, the packet’s BER is evaluated using the simulation module given in Appendix C1. The packet error rate (PER=$P_e$) under the good channel state is determined by the Binomial distribution as given in Equation
The PER of different signalling packets, e.g. random access, paging and dedicated control packets, are evaluated later in the signalling performance simulation (Chapters 3, 4 and 5).

Figure 2-22 Generalised flow chart in evaluation of packet success probability

2.5 SATELLITE LINK BUDGET

In this section, we present the forward and return link budgets for the signalling channel in the ICO10 and LEO66 satellite systems in Table 2-3 and 2-4 respectively. The satellite RF power requirements for the signalling links are also included.
In the ICO10 satellite system, only 2.5dB fading margin on the mobile uplink is available to cope with the C/N₀ threshold (55.3dBHz, which corresponds to BER=10⁻³ using QPSK modulation scheme). The mobile transmitting peak power is 3W in a time slot (TS). The average power of continuous wave (CW) is 0.5W, assuming 6 TSs in a TDMA frame. The simulation results show that the mean BER is only 10⁻².² at 10° elevation angle with 3W transmitting power (peak). The high fade margin (7dB) is allowed in the mobile downlink by increasing the satellite transmitting power to 10W per carrier.

<table>
<thead>
<tr>
<th>Return link</th>
<th>Forward link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile to satellite</td>
<td>ESC to satellite</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
<td>2.01</td>
</tr>
<tr>
<td>MS elevation (degree)</td>
<td>10</td>
</tr>
<tr>
<td>Pₘₛ (W) (peak power/TS)</td>
<td>3</td>
</tr>
<tr>
<td>Gₘₛ (dBi)</td>
<td>0</td>
</tr>
<tr>
<td>Path loss (dB)</td>
<td>-181.7</td>
</tr>
<tr>
<td>Satellite G/T (dBK)</td>
<td>6.47</td>
</tr>
<tr>
<td>Propagation margin (dB)</td>
<td>-2.5</td>
</tr>
<tr>
<td>C/N₀</td>
<td>55.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satellite to LES</th>
<th>Satellite to MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>7</td>
</tr>
<tr>
<td>ESC elevation (degree)</td>
<td>10</td>
</tr>
<tr>
<td>Satellite TX Gain (dB)</td>
<td>9.41</td>
</tr>
<tr>
<td>Satellite EIRP (dBW)</td>
<td>0</td>
</tr>
<tr>
<td>Path loss (dB)</td>
<td>-192.5</td>
</tr>
<tr>
<td>ESC G/T (dB/K)</td>
<td>30.7</td>
</tr>
<tr>
<td>Propagation margin (dB)</td>
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<td>C/N₀</td>
<td>73.21</td>
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<td>55.56</td>
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<td>55.3</td>
</tr>
<tr>
<td>Link margin (dB)</td>
<td>0.26</td>
</tr>
<tr>
<td>Satellite feeder link TX</td>
<td>Satellite mobile link TX</td>
</tr>
</tbody>
</table>

Table 2-3 ICO10 signalling links

In the LEO66 satellite system where the transparent transponder is assumed, 10dB fading margin is available on the mobile links because of the low orbit altitude. The mobile and satellite transmitting power is 3W and 2W respectively. High attenuation is caused by rain at the feeder link that uses a frequency band of 20/30GHz [MAR93].
### Table 2-4 LEO66 signalling links

<table>
<thead>
<tr>
<th>Return link</th>
<th>Forward link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile to satellite</td>
<td>ESC to satellite</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
<td>1.626</td>
</tr>
<tr>
<td>MS elevation (degree)</td>
<td>8</td>
</tr>
<tr>
<td>$P_{MS}$ (W) (peak power/TS)</td>
<td>3</td>
</tr>
<tr>
<td>$G_{MS}$ (dBi)</td>
<td>0</td>
</tr>
<tr>
<td>Satellite G/T (dB/K)</td>
<td>-2.6</td>
</tr>
<tr>
<td>Propagation margin (dB)</td>
<td>-10</td>
</tr>
<tr>
<td>$C/N_0 \mid_{up}$ (dBHz)</td>
<td>56.27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satellite to ESC</th>
<th>Satellite to MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>19.6</td>
</tr>
<tr>
<td>ESC elevation (degree)</td>
<td>10</td>
</tr>
<tr>
<td>Satellite Gain (dB)</td>
<td>27</td>
</tr>
<tr>
<td>Satellite EIRP (dBW)</td>
<td>20</td>
</tr>
<tr>
<td>Path loss (dB)</td>
<td>-189.6</td>
</tr>
<tr>
<td>ESC G/T (dB/K)</td>
<td>26.9</td>
</tr>
<tr>
<td>Propagation margin (dB)</td>
<td>-15</td>
</tr>
<tr>
<td>$C/N_0 \mid_{down}$ (dBHz)</td>
<td>70.9</td>
</tr>
<tr>
<td>$C/N_0 \mid_{total}$ (dBHz)</td>
<td>56.12</td>
</tr>
<tr>
<td>$C/N_0 \mid_{threshold}$ (dBHz)</td>
<td>55.3</td>
</tr>
<tr>
<td>Link margin (dB)</td>
<td>0.82</td>
</tr>
<tr>
<td>Satellite feeder link TX power</td>
<td>0.2W/carryer</td>
</tr>
</tbody>
</table>

#### 2.6 SUMMARY

In this chapter, the design techniques for non-GEO satellite constellations: the street of coverage and the rosette pattern, was presented. The street coverage technique is suitable for the polar orbit constellation types. Optimisation can be obtained by properly phased inter-orbit satellites. The rosette pattern is suitable for the inclined circular orbit constellation types that can provide good visibility to areas of low and medium latitude where most populations reside. Another advantage of the rosette constellation is that fewer satellites are required to provide global coverage as compared to the polar constellation.

The two satellite systems, the LEO66 with polar orbit and the ICO10 with inclined circular orbit, and their coverage statistics along with other important attributes have been analysed. For the ICO10, not only is the high elevation angle to the best visible satellite observed at the low latitude area, but also the moderate elevation angle to the second best visible satellite is observed. For the LEO66, diversity satellites or multiple satellite visibilities are only observed at the high latitude area.
The geometry of a multi-beam satellite was investigated to determine the SB pass duration, the satellite antenna size, the elevation angle for different tiers, the path delay difference and the propagation loss difference in a SB. These satellite related parameters are required in the later work, the signalling performance evaluation.

Another important issue addressed in this chapter is the satellite channel model. Lutz’s probabilistic channel model and the two-state Markov model along with the satellite connectivity statistics, which are time-varying parameters, will be used to derive the packet success probability. This provides a means for the later work (Chapters 3, 4, 5) to evaluate and improve the signalling performance at the satellite air-interface. Finally, the link budgets for the signalling links in the ICO10 and LEO66 satellite constellations in the worst case, i.e. at the edge of the satellite coverage area, were presented. The satellite RF power consumption for the satellite signalling channels was also evaluated.
Chapter 3

Signalling Channel at Satellite Air-Interface

A network architecture is proposed for the S-PCNs which exploits advantages of both the satellite and the terrestrial mobile systems. Problems related to the reuse of the GSM lower layer protocols on S-PCN air-interface are examined. The satellite specific physical layer configuration are defined for two satellite systems, LEO66 and ICO10. A novel priority-based Slotted-ALOHA random access scheme is proposed for the satellite RACH in order to counteract the channel fading effect. This measure is aimed to reduce the call set-up delay, leading to better service quality.

3.1 SATELLITE NETWORK ARCHITECTURE

3.1.1 Background

The network architecture of the first generation of satellite mobile systems is different from that adopted by the cellular systems. For example, 3-4 GEO satellites can provide the large landscape coverage and the satellite channel resources are managed by the appointed earth station (ES), generally referred to as the network control station (NCS) in the Inmarsat system. Besides the NCS, there are a number of ESs distributed inside the satellite coverage in order to provide the interface between the satellite network and public telecommunication networks. Due to the distributed ESs, a shortest terrestrial path can be realized.

Because of the limitation of satellite resource, the channels are allocated according to instantaneous demands and, are released and given back to the NCS when the calls are finished. In some systems, e.g., the Inmarsat system, a pair of signalling channels are allocated to each ES. In others, such as the American Mobile Satellite System (AMSC) [WHI92b], no fixed channels are allocated to ESs.

In cellular mobile systems the basic coverage unit is a cell which is limited in coverage by radio wave attenuation. A base station (BS) resides in each cell and is semi-permanently allocated a set of traffic and signalling channels. A number of BSs are connected to a Mobile service Switching Centre (MSC) which is a key point to access data bases, perform the mobility management function, connect to other parts of the network, and to inter-work with other public networks (ISDN, PSTN and other PLMNs).
The rapid expansion of PCNs will eventually allow flexible, wireless, person-to-person communications on a worldwide basis. PCNs might evolve as hybrid networks that combine the resources of several communication media. The new S-PCNs are expected to reuse the terrestrial cellular technologies as much as possible to profitably integrate with the cellular networks. The hand-held terminals that are the essential elements of future PCNs will be characterized by low cost, long battery life, modest antenna gain and low power transmitters. For S-PCNs, different design concepts are needed due to the power constraint (of hand-held terminals) especially if the system is designed based on GEO systems. Non-GEO satellite systems have advantages since they can more easily provide the link power needed to operate with the handheld terminals.

Compared with terrestrial cellular systems, the power constraint in a GEO systems, remains a problem even in the non-GEO satellite systems. To solve this problem and to reuse the frequency resource on the mobile link, the next generation of satellite systems will adopt the umbrella structured multiple spot beams (SB). The SB coverage can be thought of as the counterpart of the cells in the cellular mobile systems. A global beam is still used for the feeder links to the ESs. This satellite configuration extends the coverage area of an ES and resolves to some extent the power limitation problem on the mobile links.

A satellite provides channel resources and has a similar role to the BS of the cellular GSM system. However, to simplify the satellite payload, the resource management function is moved to the ground - earth stations (ES). Due to the satellite movement, the visibility from ESs to a non-GEO satellite are constantly changing. Theoretically, a mobile can access any ES if it is in the instantaneous coverage of the same satellite. However, due to satellite movement and frequency reuse, fixed allocation of a set of carriers to each ES as signalling and traffic channels may cause either severe interference or poor utilization of spectrum resources. Coordination between ESs is thus necessary. To solve this problem, a standard satellite network structure is considered. The satellite resource management is performed by a designated ES, known as the earth station controller (ESC). Due to the constant movements of non-GEO satellites, an ESC is, in a given period of time, responsible for the resource management functions. The resource control function for a given satellite is always handed-over between designated ESCs following the movement of the satellite along its orbit.

The proposed network architecture for a non-GEO satellite system is depicted in Figure 3-1. The principal functions performed by the key network elements are summarized as follows.
The functionality of an ES supports a dedicated resource function, terrestrial connection function, coding and modulation, synchronization and radio sub-system control, etc. The ESC, on the other hand, has full control of all the signalling and traffic channels of the satellite(s) under its control. This control task is to manage the resource configuration within the whole satellite coverage and to perform the channel allocation in each cell. The common signalling function is only performed by an ESC. The ESs are allowed to access traffic channels (TCH) and dedicated control channels (DCCH) only when they receive the command from the ESC. An ES is selected to act as a relay node if:

- it has the shortest terrestrial tail to the called party for a mobile originated call;
- it is the user’s preference, or
- the satellite diversity feature is used to provide a better service quality, one or two appropriate ESs are chosen to establish the connection to the concerned mobile.
The satellite mobile service center (SMSC), which has a similar role to a MSC in a GSM network, acts mainly as a mobility management entity. It coordinates the satellite resource management when a controlled satellite is handed over between two ESCs. It is also involved in the call handling process by performing the call routing inside the land-line networks during the life time of a call. Since each SMSC is associated with a geographic area, defined as a location area (LA), a satellite visitor location register (S-VLR) is always co-located with a SMSC.

3.2 SIGNALLING CHANNELS AT THE SATELLITE AIR-INTERFACE

The signalling system in S-PCNs should have sufficient capability to support basic and enhanced services. For a specified quality of service (QOS), the signalling load on the satellite air-interface and in the public network has to be designed to be minimum. This is one of the major objectives in this study, to improve the signalling performance and minimize the spectrum requirement.

3.2.1 Logical Control Channels

The classification of logical control channels at the satellite air-interface is shown in Figure 3-2. The common control channels (CCCH) are point-to-multipoint channels, whilst the user specific channels (USCH) are the point-to-point channels.

The broadcast control channel (BCCH) is unidirectional from a ESC to the MSs within a SB coverage. The system information sent via the BCCH includes the identities of LA/satellite/SB, the configuration of CCCH and the access related parameters.

The random access channel (RACH) is a unidirectional channel on the return link, the rest of the CCCHs are on the forward link. The frequency correction channel (FCCH)
and the synchronization channel (SCH) are used for mobiles to acquire the synchronization in both frequency and time domain. The paging channel (PGCH) is used to broadcast the call announcement. In order to save the mobile battery power, paging sub-groups are formed. Mobiles only listen to the PGCH which is assigned to their paging group. The response to the random access (RA) signalling, referred to as the immediate assignment, is sent via the access grant channel (AGCH). To reduce the call set-up delay, a number of channels can be reserved for the AGCH. However, the PGCH messages have higher priority than the AGCH messages for the unreserved channels. Thus, the immediate assignment signalling may be conveyed by the PGCH if there is no scheduled paging signalling. Therefore a mobile has to monitor both the AGCH and PGCH after sending a RA packet. The RACH allows the mobiles to transmit their access requests to the network in an uncoordinated manner, therefore collisions may occur. The RACH performance is critical in assessing the system performance. The study on the RACH performance will be addressed later in this chapter.

The user specific signalling channel (USCH) includes dedicated control channel (DCCH) and associated control channel (ACCH). DCCH conveys the call set-up and call release information. It is also allocated for the mobility related signalling exchanges between mobiles and ESCs. The call associated information is transmitted via the ACCH. The slow associated control channel (SACCH) with very low bit rate is used mainly to convey the channel measurement data. The fast associated control channel (FACCH) makes use of traffic channels if there are demands for transmitting call associated signalling, such as messages to command a handover, to authenticate a subscriber, or to modify the channel mode for different service requirements, etc.

3.2.2 Mapping of Logical Control Channels

3.2.2.1 Basic Assumptions

To benefit both the users and the network operator, the modifications to the GSM radio signalling channel for the integration of the satellite services need to be minimized. However, because of the large free space loss, the transmission bit rate of a carrier at the satellite air-interface has to be reduced in order to maintain the required C/No. Furthermore, the GSM signalling channel structure cannot be used in the satellite system due to the long propagation delay and the large path delay difference. It is noticed that:

a) a GSM time slot (15/26ms long and 200kHz wide in the time/frequency domain) cannot accommodate the delay difference in a satellite SB coverage. To efficiently utilize the expensive satellite spectrum resource, the satellite RACH will not use the
GSM physical layer (L1) design. Otherwise a RACH has to occupy a whole TDMA carrier;

b) the guard time provided in the GSM TCH and DCCH signalling channel (only 29μs) is not sufficient to accommodate the mis-alignment of a packet. The GSM timing advance message conveyed by the SACCH packet is transmitted twice per second. Failing to receive a SACCH packet will cause the overlapping of the packets with the adjacent TSs due to satellite movement. Therefore, the SACCH performance is critical to the transmission performance. There are two methods to avoid packet overlapping: a) to increase the guard period (GP) allocated in each TS and b) to increase the SACCH capacity allocation. The latter is not desirable because little performance improvement can be made with substantial increase of the signalling. Increasing the GP in a TS means that the GSM channel structure cannot be reused in S-PCNs.

To solve the above problems, we define a new TDMA channel structure specially designed for S-PCNs. The carrier capacity (assumed 50kb/s for both ICO10 and LEO66 satellite systems) is far less than that of the GSM system (271kb/s). The basic unit, time slot (TS), in the satellite TDMA system is assumed to be 6.67ms long. A TDMA frame includes 6 TSs. This assumption is derived from a 40ms speech block using 4.8kb/s speech coding rate and 2/3 channel coding rate. This gives 270μs for the guard time which is sufficient to tolerate a maximum of 16 successive error SACCH packets. The common and dedicated signalling channels adopt the same TS and frame structure as the TCHs.

Since both ICO10 and LEO66 satellite system adopt the TDMA scheme as GSM system, only the TDMA assumption has been considered in this thesis. Other possibilities such as CDMA scheme, even though the physical layer structure of signalling channels is different from that of GSM system, the modified GSM higher layer signalling protocols can be used in the S-PCNs.

3.2.2.2 Signalling Channel Structure

Considering the above assumptions regarding the TDMA channel structure and the characteristics of the satellite constellations, the combination of two types of signalling channels, CCCH and DCCH, is given in Figure 3-3. A 480ms and a 320ms multi-frame structure (signalling repetition duration) are assumed for the signalling channels of ICO10 and LEO66 systems respectively, considering the signalling response delay at the ESCs and the MSs (148ms/51ms are specified for BS/MS processing time in the GSM system), the space propagation delay, and the packet transmission delay. The signalling transmission time division in a multi-frame duration is depicted in Figure 3-4.
Since the messages transmitted at the satellite air-interface are confined to a TS, long messages must be segmented into message units to be delivered to the physical layer (L1). To avoid congestion at the L1, only a limited number of message units (frame blocks) from the data link layer can be handed over to L1 in a fixed time interval (block recurrence time). The frame block lengths and the recurrence time for different logical control channels in the ICO10 and LEO66 systems are listed in Table 3.1.

The recurrence time of a RA packet depends on the collision timer \( T_c \) and the random back-off re-transmission parameter \( (n_r) \). Normally, a MS, following a timer drop out, initiates the re-transmission after waiting for a randomly selected back-off period. The collision timer \( T_c \), as shown in Figure 3-4, is 400ms (10 frames) and 240ms (6 frames) for ICO10 and LEO66 RACHs respectively. The DCCH recurrence time can
be between 1 to 12 frames, depending on the window size specified for the DCCH. The normal L1 signalling packets (BCCH, AGCH, PGCH and DCCH) include 18-octets information that is protected by 1/2 rate channel coding and is appended with a 32-bit header as shown in Figure 3-5. A RA packet has a special format which will be introduced in the next section.

![Figure 3-5 Signalling packet format](image)

**NB:** The 26-bit training sequence used in GSM system may be reduced in the S-PCN due to reduced delay spread.

**Table 3-1 Recurrence time and signalling block length of control channels**

<table>
<thead>
<tr>
<th>name of channels</th>
<th>recurrence time (TDMA frames)</th>
<th>information block length(bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCCH</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>FCCH</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>SCH</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AGCH</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>PGCH</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>RACH</td>
<td>10+(1..nr)</td>
<td>6+(1..nr)</td>
</tr>
<tr>
<td>DCCH</td>
<td>1-12</td>
<td>1-8</td>
</tr>
</tbody>
</table>

\(^{*n_r : upper bound of uniform back-off re-transmission distribution.}\)

The signalling conveyed by the FCH using the specially defined bit sequences allows the mobile receivers to be frequency synchronized. The time synchronization between mobiles and a BS in the GSM system is achieved through setting up a time-base counter at the mobiles by receiving the SCH [STE94]. The same synchronization mechanism can be used at the S-PCNs’ air-interface. The TS number is conveyed by the synchronization burst which is always transmitted in the TS1 of every other frame (Figure 3-3). The information field in the synchronization burst also conveys the ES ID and frame number (FN) which is used mainly for the encryption algorithm.

**3.3 S-ALOHA RACH USING PBFA SCHEME**

**3.3.1 Random Access Channel**

To cope with the low traffic cycle in mobile systems, a demand assignment multiple access (DAMA) scheme is widely used. When mobiles have communication needs,
they have to access the network through a common channel-RACH without co-
ordination between them.

The slotted-ALOHA (S-ALOHA) protocol is usually used on the RACH in most
mobile communication systems due to its simplicity. Even though S-ALOHA can
improve the throughput performance of pure ALOHA, its maximum throughput \((1/e)\)
is still very low. This is because of the packet collision. The throughput performance
will deteriorate still further if the signal goes via a fading channel.

The format of satellite RA (S-RA) packet needs to be different from that of the GSM-RA
packet [STE94]. As shown in Figure 3-6, a 13-bit random reference is used to distinguish
the users competing for the same channel. Due to using the time capture effect, the packets
transmitted in the same channel can be correctly received by an ESC if they are not
overlapped. To avoid the same reference number used by these collision-free packets, we
increase the allocation to the random reference element (13bits instead of 5bits). The S-RA
packet has 99-bits including 16 information bits.

![Figure 3-6 RA burst format](image)

As a result of the large coverage of satellites, the delay difference between packets
emanated by two MSs which compete for the same channel can be very large even if
the coverage is divided by its multi-beam antenna footprint. To use the S-ALOHA
protocol, mobiles are required to synchronize to the beginning of an RA slot. To avoid
the interference to the other channels, a minimum GP which is twice the maximum
path delay difference \((2(d_{\text{max}}-d_{\text{min}})/c)\) in a SB coverage is necessary. The path delay
difference in a SB area is, at its worst, 2.76ms for an ICO10 satellite which has 163
SBs. Therefore the maximum mis-aligning of RA packets in the same random access slot
could be as much as 5.52ms (GP). Because the normal TS is 6.67ms, a RA burst needs
to occupy two TSs in order to accommodate the GP. Therefore, the RA slot, \(TS_{\text{RA}}\), is
2\times6.67ms. Obviously, the transmission efficiency of the RACH is very low because of
the long GP. The channel capacity of a GSM-RACH is about 7.8kb/s (coded informa-
tion), whereas the Satellite-RACH (S-RACH) capacity is only around 1.3kb/s
assuming one random access slot in each frame.
Since the actual RA packet length is only 2ms, it is possible that two packets competing for the same channel can be captured by the receiver due to the geographic separation between users. This phenomenon is called the time capture effect which can be exploited to improve the RACH performance.

The RACH collision timer is determined by three factors: the propagation delay, the RA and the access grant (AG) packet transmission delays and the earth station processing delay. The collision timer of the GSM-RACH is around 175ms considering the processing time of the BS (148ms) and the AG packet transmission delay (four GSM frames due to packet interleaving). The propagation delay in terrestrial systems is negligible. However the collision timer for satellite systems must be longer than that of the GSM system due to the sizable propagation delay of the former, which is no longer negligible. As shown in Table 3.1, we assume that the collision timer for ICO10 and LEO66 satellite systems is 10 and 6 TDMA frames (400ms and 240ms) respectively based on above three factors.

3.3.2 RACH Throughput and Delay

In mobile systems, Poisson distribution can be assumed for the RACH with channel load $G$ (including new and re-transmitted RA packets) if the total number of users is large. Hence the probability that $k$ packets are transmitted in one TS is given by

$$P(k) = \frac{G^k}{k!} \exp(-G)$$ (3.1)

At the satellite air-interface, the random access packets suffer not only from the collisions but also from the channel fading effect. The success probability ($P_s$) for a transmitted packet is expressed as

$$P_s = \exp(-G)P_{ss}(n)(1 - P_e)$$ (3.2)

where $\exp(-G)$ is the probability that a packet transmitted without collision. $P_{ss}(n)$ and $P_e$ are respectively the probability that an $n$-bit packet is transmitted in the good channel state (Equation 2.24) and the packet error probability due to multipath fading effect (Equation 2.29). The RACH throughput is given by

$$S = G \cdot P_s = G \cdot \exp(-G)P_{ss}(n)(1 - P_e)$$ (3.3)

The channel throughput versus the channel load is plotted in Figure 3-7 for an elevation angle of 10°. For the S-ALOHA plot, only the collision probability is considered. The other two plots are the RACH throughput in the highway and city environment. Clearly, the channel throughput is severely reduced due to the channel fading effect, especially in the city environment.
The probability of packet loss depends on the allowed re-transmission times (N):

\[ P_{\text{loss}} = (1 - P_s)^N \]  

(3.4)

Due to packet re-transmission, new generated traffic load \( S_i \) is different from the channel load \( G \) which consists of both re-transmitting and new generated traffic load [WHI92b]
where $N$ is the re-transmission times. It is well known that the S-ALOHA RACH reaches the maximum throughput when the channel load $G=1$ (Figure 3-7). Hence for given $N$, the maximum throughput is reached at $S_i^{(opt)} = P_s / (1 - (1 - P_s)^N)$ as shown in Figure 3-8 where $S_i^{(opt)}$'s are 0.113 and 0.253 packet/slot for the city and highway environment respectively. The low $S_i$ (new generated access load) in the city environment is because $P_s$ in the city is much lower than that in the highway. When $G$ increases beyond 1, re-transmissions caused by collision dominate the channel load. Therefore the $S_i$ in both city and highway environments tend to be the same. We will use the $S_i$ as the channel load parameter in our study because it reflects the actual supportable traffic load for the allocated channel capacity and the adopted access controls.

The average number of transmissions per delivered packet is given by

\[
\bar{N} = \frac{G - N \cdot S_i \cdot P_{total}}{S_i}
\]  

(3.6)

If the access packet is correctly received, the ESC sends an acknowledgment (access grant-AG packet) which grants a DCCH to the mobile. If an access user does not receive the AG packet until the collision timer expires, it re-transmits the RA packet. To avoid further collision, the re-transmission is randomly deferred by a number of slots. Assuming a uniform distribution of back-off re-transmissions, the average access delay can be calculated by the following equation:

\[
D = T_{prop} + T_{RA} + \bar{N}\left(T_c + \frac{n_r + 1}{2}\right)
\]

(3.7)

where $T_c$ is the collision timer which has been discussed previously. $T_{prop}$ is the propagation delay (round trip) and $T_{RA}$ is the RA packet transmission delay. $n_r$ is the maximum back-off parameter (in $T_{RA}$, the duration between adjacent random access time slots). The $T_{RA}$, as shown in Figure 3-10, is one TDMA frame. The duration of a random access time slot is two normal TSSs in the outermost SB coverage. The mean RA delay in both city and highway environments are plotted versus channel load in Figure 3-9.
3.3.3 A Priority-Based Random Access Scheme

In cellular GSM systems, the S-ALOHA protocol, although low in throughput, has been adopted on the RACH for its simplicity. To overcome the disadvantage of low throughput, more channels have to be allocated as the channel load increases. However, some form of dynamic congestion control is still required in order to accommodate the peak channel load or cope with the situations where the channel load requires more channels than the channel capacity can support. The GSM-RACH’s congestion control mechanisms is to broadcast three RACH related parameters: the maximum number of allowed re-transmissions, the average time between repetitions, and the access classes forbidden from accessing the system [MOU94]. Mobiles schedule their random access attempts according to these three parameters. Hence acceptable RACH performance can be achieved.

Mobile satellite systems suffer from fading and shadowing at low elevation angles. Thus the S-RACH performance is affected not only by the collisions but also the channel fading effect. In the cellular mobile communication systems, the power capture effect can be used to improve the RACH performance. It can be conceived that the stronger signal of two collided packets can be captured by the receiver if the other one is shadowed. However, if one of two collision packets is partly shadowed, there is no benefit from the capture effect. The shadowed packets only increase the channel load. The S-RACH has, as discussed previously, lower channel capacity and a longer collision timer than the GSM-RACH. To tackle these problems, an Good Channel Transmission (GCT) approach [JAH93] has been proposed. The GCT method requires
mobiles to estimate their link quality before transmission. The access attempts are postponed if a shadowing channel condition is detected. The GCT approach effectively reduces the RACH load, hence the collision probability, by eliminating the invalid transmissions. With the GCT approach, the RA packets are only transmitted in the “good” channel state (i.e. line-of-sight signal is available). However, even though the channel is in a good state at the beginning of transmission, the transmitted packets might still be partially shadowed and have non-correctable errors due to the channel dynamics. If a transmission error is encountered, the delay-sensitive RA packets, e.g. paging response and channel request, could suffer long delay due to long re-transmission cycle.

Since the access delay of the delay-sensitive RA packets is the most critical factor that affects the call set-up delay and the signalling load, its reduction will significantly improve the signalling load. To this end, we proposed a novel random access method known as the priority based fast access (PBFA) scheme based on the GCT approach.

In this approach, as shown in Figure 3-10, the RA packets are classified into two groups, fast access (FA) and slow access (SA), according to their delay constraints: The FA group includes paging response and channel request packets; and the SA group includes location updating and registration packets.

The copies of FA packets are transmitted in two consecutive RA time slots in order to increase the success probability of the fast access packets. For the SA packets, the length of transmission cycle depends on the channel load.

The PBFA is simple in implementation and effective in reducing the delay of call set-up related RA packets. The reduction of the access delay is at the expense of transmission redundancy which increases the channel load. Even though the capacity of the S-RACH is lower than that of the GSM-RACH, the minor increase of the channel load due to redundant FA packets will not degrade the channel performance when the total channel load is low. If the total channel load reaches the peak point, the load increment caused by the FA redundancy can be balanced by the reduction of the channel load for SA packets using a long re-transmission cycle.
3.3.4 RACH Performance Evaluation

In section 3.3.2, the RACH performance parameters $S$, $Si$, $G$, $P_{\text{loss}}$ and $D$ have been given in analytical expressions. However, due to the large coverage of a satellite SB, the access users may come from different environments and their propagation delays differ considerably causing a phenomenon known as the time capture effect which has been introduced previously. Therefore to evaluate the S-RACH performance a complex simulation model is required for simulating the practical fading environments, the satellite constellations and the users' random distribution.

Having obtained the satellite constellation statistics and the packet success probability $P_s$ from the channel simulation, we perform extensive RACH simulations in a SB coverage in which MSs are randomly distributed. More specifically, the MSs are located inside a concentric circle, thus providing the possibility to emulate the access collisions and derive all relevant statistics associated with a RACH in a SB.

The advantage of the proposed PBFA approach has been demonstrated through the RACH performance improvement relative to the S-ALOHA protocol in the fading channel and the GCT scheme. The RACH performance in terms of delay, capacity and failure access rate
(the ratio of the number of failed RA packets in a unit time-TS to the $S_i$) are evaluated for both the ICO10 and LEO66 satellite systems.

### 3.3.4.1 Assumptions

In the evaluation of the RACH performance, we have made the following assumptions:

- Mobile users, of which 70% are from highway and 30% are from city environment, are uniformly distributed in an outermost SB coverage for both the ICO10 (E: $10^\circ$-$18.5^\circ$) and LEO66 (E: $8.2^\circ$-$20.8^\circ$).
- The inter-arrival rate (IAR) of the FA packets is 1/3 of the $S_i$.
- $\pi/4$ QPSK modulation and (2,1,7) convolution coding scheme are assumed for a RACH with 400 b/s un-coded bit rate. One third of one carrier capacity (50kbps) is allocated to the RACH in a SB coverage.
- The re-transmission time (N) is assumed to be 10; the back-off parameter $n_r$ is assumed to be 7 (in $t_{rad}$); the processing time of a RA packet at earth stations is assumed to be 0.15 second; the collision timers are 0.4 and 0.24 seconds for the ICO10 and the LEO66 systems respectively.
- The channel parameters are given in Table 2.3. The mobile velocity is assumed to be 90km/h.

### 3.3.4.2 Results and Discussions

*Figure 3-11* shows that the throughput of S-ALOHA RACH in ICO10 is reduced from the theoretical value of $1/e \approx 0.368$ to less than 0.20 due to channel fading. This does not agree with the analytical results shown in *Figure 3-7*, mainly due to the time capture effect and the mixed traffic (30% and 70% of the users are respectively from the city and highway environments). It can be observed in the *Figure 3-11* that the peak throughput of the PBFA plot is 0.42, which is higher than $1/e$. Part of the throughput improvement is attributed to the time capture effect which is caused by the path delay difference between the geographically separated users. For a fair comparison, the time capture effect has also been included in the S-ALOHA throughput.

Since the GCT and PBFA approaches are specialized for counteracting the shadowing, they have a significant throughput improvement compared to the S-ALOHA protocol used in the fading environment. For the PBFA approach, in order to balance the load increase caused by the redundancy of the FA packets when the channel load is increased to saturation point, we increase the timer for the SA packets to three times of the length of the normal timer from the channel load 0.45 packets/slot upward. The PBFA approach shows the higher throughput than the GCT approach at the high channel load. Due to throughput improvement, the maximum supportable channel load (0.55 packet/slot) using the PBFA scheme is also increased compared to that of using the S-ALOHA protocol (0.3 packet/slot) and the GCT approach (0.45 packet/slot).
In Figure 3-12, the throughput improvement due to the time capture effect is plotted. It can be observed that the higher the channel load, the higher the throughput improvement due to the time capture effect. The maximum throughput of the time capture effect in the outermost SB coverage of the ICO10 can be as much as 0.21 packets/slot. The capture throughput in LEO66 is considerably lower than that of the ICO10. This is because the path delay difference in the LEO66 SB area is smaller than that in the ICO10 SB coverage. Therefore, in S-PCNs, the low transmission efficiency of S-RACH due to the long GP can be improved by using the time capture effect.
Chapter 3 Signalling Channel at Satellite Air-Interface

Figure 3-13 RACH throughput in LEO66 satellite system

The throughput plot for LEO66-RACH shows (Figure 3-13) that the maximum 0.38 throughput can be achieved using the PBFA approach. Comparing the plots in Figure 3-11 and 3-13, the RACH throughput in the LEO66 is lower than that in the ICO10. Since the shorter collision timer used in the LEO66 than that in the ICO10, lower channel load (new generated access load) can be supported in the LEO66 than that in the ICO10 with the same channel allocation.

Figure 3-14 Mean RACH delay vs. IAR in ICO10 system

The main objective of the PBFA is to reduce the access delay of the delay-constrained RA packets. This has been achieved as shown in Figure 3-14 for ICO10 system. With the PBFA scheme, the fast access packet delay is respectively, in the extreme case, 177ms and
1.66 second less than those of the GCT and the S-ALOHA approaches before the RACH load exceeds 0.35 packets/slot. If we reduce the SA load by increasing the timer’s length when the total channel load is near to the peak, the fast access delay is further reduced compared to the delay of using the GCT scheme. But the delay of slow access packets is increased.

The delay performance of the S-ALOHA, GCT and PBFA approaches used in the LEO66 system are compared and shown in Figure 3-15. Compared to the GCT approach, a maximum of 210ms delay reduction (before the percentage of packet loss exceeds 1%) for the FA packets can be achieved by using the PBFA scheme. To balance the increased channel load due to the redundancy of fast access packets, we increase the timer length of slow access packets at high access load. Even though there is a sudden increase of slow access delay owing to the increase of timer length, the channel saturation point is shifted upward (Figure 3-13). Therefore the delay reduction of the fast access packets relative to the access delay of using the GCT approach is further increased.

Figure 3-16 shows the packet loss probabilities of the S-ALOHA and the PBFA schemes for the ICO10 system. The PBFA approach exhibits a significant improvement compared to the former. Because the system allows the communication channel blocking probability to be as low as 1%, the probability of signalling loss should be lower than 1%. In our study, we have found that the maximum $S_f$ of 10 access per second can be supported by allocating one third of the carrier capacity to the RACH in ICO10 outermost SB coverage. In the LEO66 system, the maximum supportable RACH load ($S_f$) is 8 packet/sec which is slightly lower than that in the ICO10 system (Figure 3-17).
The offered traffic load in a SB coverage is related to the call arrival rate $Q_i$ (call setup related access signalling load) and the calling time \[ A(\text{erlangs}) = \frac{Q_i \cdot T}{60} \] where $T$ is the average calling time assumed to be 3 minutes and $Q_i$ is the maximum calls per hour per cell. Traffic load $A$ can be calculated according to the Erlang B formula.
Chapter 3 Signalling Channel at Satellite Air-Interface

\[ GOS = E(A, N_{ch}) = \frac{A^{N_a}}{N_{ch}!} \sum_{i=0}^{N_a} A^i/i! \]  

(3.9)

where \( N_{ch} \) is the maximum number of TCH allocated in a SB area. The Erlang result calculated from Equation 3.9 is used in Equation 3.8 to derive \( Q_\ell \). The location updating rate \( R_{LU} \) (non-call related access rate) of a user can be derived for a given number of users \( (N_u) \) in a SB coverage as

\[ R_{LU} = \frac{S_i - Q_\ell}{N_u} \]  

(3.10)

Table 3.2 summaries the division of the RACH load between the call and non-call related accesses. Due to the high mobility of the LEO satellites, the location area in LEO66 should be smaller than that in the ICO10. We assume that the LEO66 RACH supports fewer users in a SB coverage than the ICO10 RACH. Allocation of more RACHs is needed if the call and non-call related access rate exceeds the allocated capacity.

<table>
<thead>
<tr>
<th></th>
<th>ICO10</th>
<th>LEO66</th>
</tr>
</thead>
<tbody>
<tr>
<td>RACH IAR ((S_i)) (packet/sec)</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Call loss probability</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Number of TCH ((N_{ch}))</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>(A) (Erlangs)</td>
<td>425</td>
<td>425</td>
</tr>
<tr>
<td>Call related access rate ((Q_i)) (packet/sec)</td>
<td>2.36</td>
<td>2.36</td>
</tr>
<tr>
<td>Number of user ((N_u))</td>
<td>180,000</td>
<td>90,000</td>
</tr>
<tr>
<td>A user' location updating rate ((R_{LU})) (access/hour)</td>
<td>0.15</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Table 3-2 RACH load in ICO10 and LEO66 satellite systems

Finally the RA delay distribution in ICO10 and LEO66 systems are shown in Figure 3-18 and 3-19 respectively. We have found that the delay of RA packet which is received in the first attempt is within 0.3 second in the ICO10 system, whereas it is within 0.1 second in the LEO66 system. Due to using the PBFA approach, more than 80% of fast access packets sent by the users from open and urban areas respectively can successfully access the network within 0.5 and 1 second in both ICO10 and LEO66 systems. Even though the propagation delay is long in the ICO10 system, the similar RACH performance can be achieved in the ICO10 system as that in the LEO66 system due to the use of the PBFA approach. Moreover, we also observe that the PBFA approach is more useful for the RA packets transmitted in the bad channel condition.
3.3.5 Conclusion

The performance of the S-ALOHA RACH in the practical satellite environment is unacceptable because the loss probability is more than 10% even for low channel load. Using the GCT approach, the channel performance can be significantly improved. The proposed PBFA approach based on the GCT approach can further improve the delay performance for the delay sensitive packets even when the channel load is high. The PBFA scheme is thus useful in satellite systems where the propagation delay is long. Additionally, the time capture effect can be utilized to improve the RACH performance. The higher the channel load, the more the throughput improvement due to the time capture effect.
3.4 SUMMARY

In this chapter, a satellite network architecture is proposed to tackle the problems associated with the satellite movement. Designated ESCs are responsible for the satellite resource management when the concerned satellite is visible. The resource control function is handed over between ESCs as the satellite moves. With this network architecture, the satellite common signalling channels are handled by only one ESC. Thus the channel resource utilization is efficient.

In S-PCN, the GSM logical signalling channel concept is reused. Possible problems related with reusing the GSM physical layer in the LEO66 and the ICO10 systems have been identified. We propose the physical layer configuration tailored for the satellite air-interface of these two systems.

Finally, we have investigated the S-ALOHA RACH performance. The GCT scheme has been examined. The results show that it has the potential to counteract the channel fading effect. The throughput, delay and packet loss probability of the GCT approach outperform those of the S-ALOHA protocol in the practical fading environment. To further improve the delay performance for the delay-sensitive RA packets, a novel priority-based random access (PBFA) scheme based on the GCT approach is proposed. The PBFA approach further improves the delay performance of the call setup related random access packets compared to the GCT approach. The performance improvement is at the price of the transmission redundancy. To obtain the equivalent throughput performance as that of the GCT approach, the increased channel load can be balanced by reducing the channel load generated by the location updating accesses. This can be realized by increasing the length of the collision timer for the slow access packets.

Moreover the channel throughput can be improved by exploiting the time capture effect. In fact, as far as the time capture effect is concerned, a large GP in a SB coverage can be advantageous for improving the RACH performance.
Chapter 4

Mobility Management Signalling Performance

The guaranteed coverage area approach in which satellite dynamics does not affect the mobile location update signalling load is selected to perform mobility management in the S-PCNs. The optimum size of the GCA is determined for ICO10 and LEO66 systems. This chapter deals mainly with the evaluation of paging channel performance which is affected by the satellite dynamics. We compare the one-step and two-step paging schemes to show the trade-off between the paging delay and signalling load. To counteract the channel fading effect, a user assisted paging method is proposed. The performance of a satellite diversity based paging approach is evaluated and compared with other paging techniques.

4.1 MOBILITY MANAGEMENT

User mobility management in the second generation cellular mobile systems is realized by two signalling procedures at the radio interface, i.e., location updating and paging.

4.1.1 GSM Mobility Management Function

In the GSM system [MOU94], each Mobile service Switching Center (MSC) is associated with a location area (LA). A mobile initiates location updating signalling procedures when it enters a new LA, therefore, the network can effectively deliver the mobile terminated calls. To accept the registration request from a new user, a MSC and its associated Visitor Location Register (VLR) interrogates the mobile’s Home Location Register (HLR). The HLR determines whether to accept the mobile’s registration in the new MSC/VLR by checking any subscription constraints for the user. If the result of this procedure is positive, the HLR will update its database and inform a new MSC/VLR to accept the registration request. At the same time, the HLR will cancel the mobile’s registration with the old MSC/VLR.

When an incoming call is delivered to a Gateway MSC (GMSC), the address of the visiting MSC/VLR can be obtained by interrogating the HLR. The call is then routed to the visiting MSC/VLR from the GMSC. The mobile is notified by the MSC, via a paging channel (PGCH). When a mobile enters a new location area whose identity (LAI) is obtained via the BCCH, it sends location updating signalling to the visiting MSC which stores the LAI in the VLR. Receiving a mobile terminated call, the visiting MSC extracts the LAI from the VLR. The paging signalling is broadcast in the area identified by the LAI, know as paging area (PA), via an associated BS.
The critical task in the mobile system design is to find an optimum PA size which allows to balance the paging signalling load (which increase when a PA includes more cells) and location update signalling load (which increases when a PA includes less cells).

### 4.1.2 S-PCNs Mobility Management Function

In non-GEO satellite mobile systems, the mobility management becomes more complex due to the dynamic movement of the satellites. Obviously, the cell-based location area concept used in the GSM system is not applicable for the S-PCNs. A number of location updating methods have been proposed in recent research to cope with satellite dynamics [SAI15]:

1. Guaranteed Coverage Area (GCA) approach; and
2. Terminal position based (TPB) approach.

The terminal position based approach requires the mobile terminals to have positioning capability (e.g. GPS-Global Positioning System). If a mobile's traveling distance since its last location update exceeds a threshold \(d_{thr}\), it should initiate the location updating procedure. Different traveling thresholds are broadcast via the BCCH to accommodate different user mobility classes. The TPB approach is not considered here as the positioning requirement will impose an additional complexity to the terminals.

![Figure 4-1 Guaranteed coverage area in S-PCNs](image)

The GCA is defined as the fixed geographical area around an satellite mobile service center (SMSC) where the coverage is guaranteed by the connected ESCs at any time (Figure 4-1). The LA identity (LAI) is broadcast over the coverage area via the BCCHs of the spot beams (SB) (possibly from more than one satellite) which overlap the GCA. The mobiles will not initiate a location updating until a new LAI is received through the selected satellite (with best visibility). The GCA approach excludes the effect of satellite dynamics in the
location updating procedure. Therefore, the location updating rate only depends on the size of the coverage area and the velocity of the mobiles. The GCA is thus similar to the LA defined in the GSM system. Hence the mobility model [MOH94] given for cellular mobile systems can be reused herein. Assuming that the mobile users are uniformly populated with a density of \( \rho \) (user/km\(^2\)) and the coverage area boundary has a length of \( L \), the boundary crossing rate - BCR (crossing/second) is given by

\[
BCR = \frac{\rho v L}{\pi}
\]

(4.1)

where \( v \) (km/second) is the mobile velocity. If there are \( W \) users in a GCA with radius of \( r \), the BCR is inversely proportional to the radius of coverage

\[
BCR = \frac{2\pi W}{\pi r}
\]

(4.2)

A mobile may reside anywhere within a given GCA which is the same as the LA when a mobile terminated call is initiated. If the time interval between the last location updating and the incoming call arrival is short, the position uncertainty can be determined by taking other information, such as the mobile’s mobility class, into account. Since the satellite movement is predictable, the paging area in terms of paging satellite/SBs can be determined. When the time stamp is invalid, the whole GCA has to be paged. The larger the coverage radius \( r \), the more the cells (SB) have to be paged. The PA size in terms of paging satellite/SBs will be different at different latitudes for different constellations.

A study of the satellite constellation and SB configuration performed within the research group at University of Surrey ([SAM94] and [SAI15]) has given the number of SBs paged for different coverage radius \( r \). This provides a basis on which the optimum GCA size can be found. The following assumptions have been made in performing the analysis:

- 200,000 active users reside in a GCA for ICO10 and LEO66;
- Average mobile velocity is 90 km/h;
- The mobile terminated call arrival rate is 0.7 call/sec which is one third of the traffic load (425 Erlangs and 3 minutes of call holding time).

The paging and location updating signalling load generated within a GCA (50° latitude) versus the coverage radius \( r \) is plotted in Figure 4-2, 4-3 respectively for two satellite systems, LEO66 (61SBs) and ICO10 (163SBs). The optimum GCA size, in terms of minimizing both the location updating and the paging signalling load, is 400km and 600km for LEO66 and ICO10 satellite systems.

Comparing the LEO66 and the ICO10 systems, With the increase of LA size, the paging signalling load in the ICO10 system has a slower increase than that in the LEO66 system. Therefore, the larger LA can be selected in the ICO10 system. There is only a slight increase of signalling overhead when the radius of the LA increased from 600km to 1000km. However, for the LEO66 system, the LA size must be carefully chosen as the signalling load is very sensitive to the change of the LA size. For both systems, the radii of
LA smaller than 400km should be avoided since the location updating signalling dominates the signalling load. The above conclusions are derived based on the traffic assumptions made previously. To perform a specific system design, a realistic traffic load estimation is required to find the optimum size of the GCA.

![Figure 4-2 Mobility signalling load vs. location area radius in LEO66 system](image)

![Figure 4-3 Mobility signalling load vs. location area radius in ICO10 system](image)

### 4.2 Paging Scenarios

#### 4.2.1 One-step Paging

Using a one-step paging scheme, the whole GCA is paged in first and subsequent paging steps. The PGCH performance in terms of delay and load is determined mainly by the channel fading effect. It is well known that the line of sight (LOS) signal is critical in S-
PCNs and a signal is deemed lost if it encounters a shadowing situation. To provide a satisfactory paging performance, the mobiles' cooperation is very important since it is impossible for the network to know whether the channel is shadowed. If a mobile can always select a satellite with best visibility from which the LOS signal is available, the paging performance can be improved even though the elevation angle to this satellite might be very low. The prerequisite for this method is to have satellite diversity which exists in most areas for ICO10, but only at high latitudes for LEO66.

As far as mobiles are concerned, the SB re-selection procedure is described as follows. We tailor the GSM cell re-selection procedure to cope with the specific link features of the S-PCNs. Let us start with a mobile being in good visibility to a satellite. From the currently monitored BCCH, a list of beacon frequencies is broadcast indicating where to look for the beacon channels of the neighboring SBs. As soon as the LOS signal from the current monitored satellite is lost, the mobile must locate the beacon channels in those SBs from other satellites in view. The received signal levels are measured and the satellite with best visibility is chosen. In the next step, the mobile should obtain the synchronization in the selected SB in order to decode the broadcast information carried by the BCCH which repetition cycle is four multiframes (one multiframe is 0.48 second and 0.32 second for ICO10 and LEO66 satellite systems respectively). The transmission rate of BCCH messages directly impacts the cycle of a paging sub-group. To avoid a systematic masking of the SB selection information in BCCH messages by a paging sub-channel, the cycle of a paging sub-group is specified by at least two multiframes (0.96 second and 0.64 second for the ICO10 and LEO66 respectively). Therefore, a paging channel may mask half of the BCCH messages in the worst case.

4.2.2 Two-step Paging

Normally a location area consists of a number of SBs. Using the one-step paging approach, the entire LA is paged. Since a mobile only decodes the messages received from the PGCH of one SB, the larger the LA, the higher the waste of paging resource. To reduce the paging signalling load, thus leading to a more efficient use of channel resources, the PA which is a part of the GCA must be minimized. In terrestrial cellular systems, intelligent paging schemes (also known as the two-step paging strategy) are proposed. The main idea behind the intelligent paging strategy is to define a PA using the paging related information (e.g., recent interaction information, high mobility flags, etc.) [LYB95] or the user mobility profile [TAB95] which records the most probable mobility patterns.

In S-PCNs, it is assumed that a SB with the highest probability is selected as a PA in the first paging step. This is achieved by implementing a satellite intelligent paging algorithm and using satellite constellation ephemeris as well as other paging related information stored in a satellite VLR (S-VLR). However, the accuracy of a predicted PA is an uncertain parameter since it depends on a number of uncertain factors, such as the dynamics of coverage overlapping and the users' mobility, etc.
Chapter 4 Mobility Management Signalling Performance

There are 11 and 12 SBs covering the optimum GCA of ICO10 (600km) and LEO66 (400km) at 50° altitude separately [SAI15]. A mobile only listens to one SB. Obviously, the paging signalling load can be significantly reduced using the two-step paging approach if the first-step paging success rate is high. However, the two-step paging scheme will increase the paging delay and paging load in the case that the paging fails in the first step. This delay could degrade the service quality in terms of call set-up delay. Additionally, if no paging response is received before the paging timer expires, the paging command has to be sent to the entire GCA in the second step.

The first step paging success rate depends not only on the accuracy of the predicted first-step paging area (AFSP) but also on the satellite channel condition. For a given AFSP, improving the capability of counteracting the channel fading effect, especially the shadowing effect, will increase the paging success rate. Therefore, it can be envisaged that the first step paging success rate is the key parameter affecting the paging delay and signalling load. To increase the first-step success rate by counteracting the channel fading effect, we propose a satellite diversity based paging scheme.

Using the satellite diversity based paging approach, two SBs, each from one of two diversity satellites, are chosen to issue the paging command in the first paging step. The satellite diversity based paging is the same concept as the user assisted paging approach discussed in the section on the one-step paging scheme. The only difference is that only two SBs rather than the whole GCA are paged in the first paging step. Because the availability of LOS signal is improved with user assistance, the first-step paging success rate can be increased.

4.3 PGCH PERFORMANCE

The performance of satellite diversity based and two-step (without user assistance) paging schemes are evaluated and compared with the one-step paging schemes (with and without user assistance).

The impacts of the channel fading effects, the paging timer and the delay of paging response have been considered in the simulation. The channel fading affects both the PGCH load and the paging delay. The paging timer will influence the paging delay. The delay of the paging response packet affects the PGCH load. If a mobile receives a paging command but the paging response is not received within a cycle of paging sub-group, the paging command will be re-transmitted over the whole GCA. The paging response is transmitted through the random access channel (RACH) and the access delay can be very long if consecutive re-transmissions are incurred. In Chapter 3 we have proposed the PBFA approach which improves the delay performance of delay-sensitive packets including the paging response. The results are included in the paging performance simulation in order to evaluate the effect of the paging response delay on the PGCH load.
4.3.1 Assumptions

In the PGCH performance simulation, the following parameters have been assumed:

- The mobile terminated call arrival rate is 0.7 page/sec;
- A paging packet transmitted over the satellite PGCH contains 18 octets of information and 32 overhead bits. (2,1,7) convolution coding scheme is used;
- Paging transmission time is 6.4ms (320bits/50kbps);
- The channel fading parameters are given in Table 2-2;
- Table 4-1 lists parameters which are different for LEO66 and ICO10 satellites.

<table>
<thead>
<tr>
<th></th>
<th>LEO66</th>
<th>ICO10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle of paging sub-group(sec)</td>
<td>0.64-2.88</td>
<td>0.96-4.32</td>
</tr>
<tr>
<td>Free space propagation delay (ms)</td>
<td>2.6-8.2</td>
<td>34.5-48</td>
</tr>
<tr>
<td>Mean paging response delay - city environment (sec)</td>
<td>0.41</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Table 4-1 Simulation parameters for different satellite constellations

4.3.2 Simulation Results and Discussions

4.3.2.1 One-step Paging Signalling Performance

The paging performance of the one-step paging approach has been evaluated through simulation. The results presented in Table 4-2 show that user assisted paging is very useful in the city environment if satellite diversity is provided. Both paging delay and load are significantly reduced for the ICO10 system. For the LEO66 system, the paging delay improvement is not significant using the user assisted paging scheme, whereas the high paging load caused by the high density of satellite coverage overlapping at high latitude can be reduced to some extent. Intuitively, the paging delay in the ICO10 system should be longer than that in the LEO66 system due to the longer propagation delay of MEO satellites. However, since the satellite diversity is provided with ICO10 constellation, the paging delay in ICO10 system becomes 200ms shorter than that in the LEO66 system when the user assisted paging scheme is adopted.

<table>
<thead>
<tr>
<th></th>
<th>LEO66</th>
<th>ICO10</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGCH bit rate</td>
<td>0.5 kbits</td>
<td>0.333 kbits</td>
</tr>
<tr>
<td>Pagng with user assistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGCH load (kbits)</td>
<td>8.9</td>
<td>3.37</td>
</tr>
<tr>
<td>Delay (sec)</td>
<td>1.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Pagng without user assistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGCH load (kbits)</td>
<td>11.74</td>
<td>3.81</td>
</tr>
<tr>
<td>Delay (sec)</td>
<td>1.17</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table 4-2 PGCH performance for one-step paging strategy

1 The cycle of paging sub-group can be 2-9 multiframes in GSM [MOU94].
We also observed that there is little performance improvement for paging scheme with user assistance compared to those without user assistance if users are in the highway environment.

4.3.2.2 Two-step Paging Signalling Performance

In this section, the evaluation of two-step paging signalling performance is performed in the city environment. For the ICO10, the satellite diversity based paging scheme (Figure 4-4) exhibits better paging delay performance than that of the two-step paging scheme (without user assistance). The paging delay reduction is about 215ms. With the increase of the AFSP, the paging delay of the satellite diversity based paging scheme is comparable to that of the one-step paging scheme.

![Figure 4-4 Paging delay vs. AFSP (ICO10)](image)

For the LEO66, in comparison with the two-step paging scheme, the paging delay reduction due to the satellite diversity paging scheme is higher at low AFSP than at high AFSP (Figure 4-5). This is because the LEO66 constellation does not provide satellite diversity feature. For areas of 40°-50° latitude, the elevation angle to the second best visible satellite is lower than that in the ICO10 constellation. Therefore the satellite diversity paging scheme is less effective to counteract the shadowing effect for the LEO66 system than for the ICO10. When the AFSP is low, the first-step paging success rate is also low. Consequently, the satellite diversity paging can increase the first step paging success rate, hence reducing the paging delay. With the increase of AFSP, the first step paging success rate increases. Therefore the improvement due to the user assistance paging scheme diminishes.
To save mobiles power, paging sub-groups are adopted in the GSM system. The long cycle of a paging sub-group is preferred as far as the power saving is concerned. Its disadvantage is an increased paging delay. Nevertheless, the satellite diversity based paging scheme can be adopted to improve the delay performance when the cycle of a paging sub-group is increased (Figure 4-6, ICO10). For the LEO66 constellation, satellite diversity paging scheme can not provide significant delay reduction when AFSP is high.
The one-step paging scheme guarantees the shortest paging delay (Table 4-2) as there is no uncertainty about the paging area. With high AFSP (90%), the paging delay of the satellite diversity based paging scheme is slightly higher (0.086 second) than that of the one-step user assisted paging scheme. Compared to the one-step paging strategy, the two-step paging schemes generate much less paging load, especially when the AFSP is high (Table 4-2, Figure 4-7). The saving of the paging signalling is more than 35% in ICO10 systems. For the LEO66 satellite (Table 4-2, Figure 4-8), the satellite diversity based paging scheme can also provide 23% signalling saving compared to the user assisted one-step paging scheme.
In comparison with the two-step paging scheme, the paging load reduction due to the satellite diversity paging scheme is slightly higher at low AFSP than that at high AFSP (Figure 4-7, 4-8). This is because the channel fading effects become the critical factor in determining the PGCH performance when the AFSP is low. The satellite diversity based paging scheme is designed to counteract the shadowing effect. Therefore, the first step paging success rate is attributed mainly to the satellite diversity rather than the AFSP. With the increase of the first-step paging success rate, the probability of paging re-transmission in the whole GCA can be reduced. This leads to the reduction of the paging load. Therefore we can concluded that the satellite diversity paging scheme generates less paging load when AFSP is low.

**4.4 SUMMARY**

In this chapter, the GSM mobility management signalling procedures [MOU94] and satellite mobility management approaches proposed in the SAINT project [SAI15] were reviewed. The guaranteed coverage area approach was a preferred option considering the following three advantages, a) it inherits the GSM mobility management approach, b) the mobile location updating rate is not affected by the satellite dynamics, and c) positioning is not a requirement for the mobiles. The size of GCA in ICO10 and LEO66 has been optimized by minimizing both the location updating and paging signalling.

The satellite mobility in the GCA approach is managed by the network. The satellite dynamics and coverage overlap are shown to be the cause of the PGCH load problem when using the one-step paging approach. In this chapter, we also investigated a number of paging schemes: namely the conventional one-step paging and the two-step paging approaches. The corresponding PGCH performance was evaluated. To reduce the channel fading effect, a user assisted paging approach was proposed for both the one-step and the two-step paging schemes. The simulation results show that the satellite diversity based paging approach can significantly reduce the paging delay and the PGCH load.
Chapter 5

Evaluation of call Set-up signalling performance

In this chapter, we evaluate the performance of the call set-up signalling procedure at the satellite air-interface. The work is focused on the study of the data link layer protocols used on DCCH. The call set-up delay performance of reusing the GSM LAPDm protocols is examined. The modified Go-Back-N and Selective Re-transmission ARQ protocols are proposed for the satellite DCCH data link layer control. The call set-up delay and the DCCH signalling load for a given traffic load is examined for both the LEO66 and the ICO10 satellites. These performance parameters are important in the system design.

5.1 GSM LINK LAYER PROTOCOL

In the GSM system, the link access protocol (LAP) for the D channel (LAPD) and for the Dm\(^1\) channel (LAPDm) are used at the A-bis interface and the radio interface respectively ([GSM04.05,06]). The layer 2 of the message transfer part (MTP2) is used for the rest of the network interfaces. All of the three protocols are derived from the high level data link control (HDLC [BUX80]) scheme with minor differences.

The prime functionality of a link layer is to structure the information in the frame blocks that are the basic units to be transmitted on the channel. In HDLC, the frame delimitation is provided by flags at the start and the end of a frame (Figure 5-1). This is the case in the LAPD and the MTP2. In the LAPDm, the flags can be eliminated due to the transmission constraints imposed by the physical layer of the radio interface. The length of a frame block at the radio interface is limited to 23-octets including the frame control. Higher layer messages that are longer than this have to be segmented before transmission. The segmentation function is provided by the link layer. Due to the high capacity of the network links, the frame lengths of the LAPD and the MTP2 are up to 260-octets of the upper layer information. The segmentation and re-assembly mechanism are not necessary for the signalling exchanged between network entities because most of them can be accommodated in one frame block.

As far as error detection is concerned, both LAPD and MTP2 adopt the HDLC scheme using redundant bits to check the residual errors in a frame. The LAPDm does not provide this function at the radio interface. The error detection must be combined

\(^1\) Dm is the collective name of all control channels at the radio interface.
with the backward error correction (BEC). All three data link protocols use the HDLC-like BEC, depending on the choice of operation modes, acknowledged and unacknowledged. At the radio interface, both operational modes are applicable to the DCCH, FACCH and SACCH, whereas the BCCH and CCCH work only on the unacknowledged mode. In the unacknowledged mode, the messages are transmitted only once regardless of the transmission results. Hence transmission errors are not correctable under this operational mode. To improve the transmission performance, the acknowledgment mechanism is provided by the HDLC protocol. At the radio interface, the forward error correction (FEC) capability is provided by the physical layer.

The functions provided by the data link layer include [GSM04.05]:
1. Discrimination between data link connections of different Dm channels by means of a data link connection identifier (DLCI). (DLCI consists of the service access point identity (SAPI) in the address field and identity of physical channel. The latter is managed locally in each end system and is carried in primitives between the layers);
2. Recognition of frame types (Information or Supervisory frames);
3. Notification of unrecoverable error to the Layer-3 (L3 primitive);
4. Support of sequence control to maintain the sequence order of the Layer-2 (L2) peer-to-peer data units (control field);
5. Segmentation and concatenation of L3 messages (address and control fields);
6. Flow control (control field).

**5.1.1 LAPDm Peer-to-Peer Communication**

In this chapter, we focus on the LAPDm protocol used for the DCCH acknowledgment operation because the DCCH signalling exchanges are the main contributor for the call set-up signalling procedures. The study of the GSM LAPDm
protocol ([GSM04.05,06]) will provide a prerequisite for the design of a link protocol for the satellite control channels.

As shown in *Figure 5-2*, the LAPDm peer-to-peer communications are carried out through the Dm channels between a MS and an ESC. The signalling messages are exchanged between the data link layers of the MS and the ESC according to a pre-defined procedure.

### 5.1.1.1 Elements of Procedures

The elements of procedures contain the commands and responses. Three types of messages, the information frame (I-frame) and the supervisory frame (S-frame) as well as the un-numbered frame (U-frame) are defined for the message transfers. The S-frame includes the receiver ready (RER), the receiver not ready (RNR) and the reject (REJ) frames. Each point-to-point data link connection endpoint has three state variables: acknowledgment state variable \( V(A) \), receive state variable \( V(R) \) and send state variable \( V(S) \).

The control field in a frame includes a receive sequence number \( N(R) \) and a transmit sequence number \( N(S) \) as shown in *Figure 5-1*. The \( N(R) \) in an I-frame or S-frame is used to acknowledge the reception of an outstanding I-frame. Thus the \( V(A) \) in the I-frame transmitter is renewed and the link layer timer is canceled. The \( N(S) \) in the I-frame indicates the sequence number of the I-frame being sent. If an error free and in-sequence I-frame is received, the \( N(S) \) is used to renew the \( V(R) \) in the receiver.

In the acknowledgment mode, the information frames are numbered cyclically which enables the link layer in the receiver to detect whether the received frame is a retransmission or the frame loss occurs and to acknowledge an error-free reception of the frame. To reduce the frame header, the LAPDm adopts the modulo 8 numbering cycle. Therefore, both \( N(S) \) and \( N(R) \) can be coded with 3 bits.

The repetition of an I-frame can be triggered by the REJ S-frame or the link layer timer (T200 in GSM LAPDm). The value of T200 shall be chosen such that the repetition of a frame can take place at the earliest possible opportunity and it does not time out before the response frame from the opposite direction is received and processed. The T200 for DCCH is 220ms and the repetition delay of DCCH messages is 51 TDMA frames (235.4ms).

### 5.1.1.2 Peer-to-Peer Procedures

The peer-to-peer procedures apply to all signalling and data transfer procedures between L3 entities. The multiframe operational procedures which are mainly used by the DCCH are outlined as follows [BUX80]:

---

70
1. To enter the acknowledgment operation mode, the multiple frame operation (MFO) is set by exchanging a pair of command/response messages, the SET ASYNCHRONOUS BALANCED MODE (SABM) and the UNNUMBERED ACKNOWLEDGMENT (UA), between peers. The information transfer commences after the MFO mode is successfully established.

2. Error-free operation: An error-free, in sequence I-frame is acknowledged either by a S-frame or an I-frame with the N(R) set to the sequence number of the received I-frame.

3. P/F-bit (Pull/Final) recovery: This is also called check-point function [BUX80]. As the P- and F-bits are always exchanged as a pair, the P cannot be issued until the previous P has been matched with an F. The N(R) count contained in a frame with the F-bit set to 1 can be used to detect the I-frame sequence error.

4. REJ recovery: The REJ S-frame is used to initiate an early re-transmission following the detection of a sequence error. The REJ method is quicker than the checkpointing approach.

5. Timer recovery: In case an I-frame cannot be recovered by either REJ S-frame or the P/F-bit, a timer will trigger the re-transmission. For every re-transmission the counter is increased by one. To avoid achieving the deadlock, an error will be reported to L3 when the re-transmission counter reaches a maximum number of re-transmission.

To simplify the protocol implementation, the window size (WS) is set to 1 in the GSM LAPDm case [BOH94]. Because most of the L3 signalling messages can be included in one frame block and the transmission on the DCCH is of transaction type, this simplification does not cause any performance degradation. However, when the L3 messages need to be segmented, the processing in the receiver has to wait until all the segments are correctly received. Hence the signalling performance is degraded by long L3 messages exceeding 20-octets, such as the SET-UP (152-octets), the ALERTING (43-octets) and the CONNECTION (43-octets) messages.

5.1.2 Layer-to-Layer Operation

In the layered signalling system, the L2 provides services to the L3 and uses the services provided by the Layer-1 (L1). The communications between layers are accomplished by means of primitives. There are four types of primitives, i.e., REQUEST, INDICATION, RESPONSE and CONFIRM, as shown in Figure 5-2.

The service access point (SAP) is where the data link layer services are provided by the L2 to the L3 entity (Figure 5-2). The SAP identifier (SAPI) included in the address field of a L2 frame allows 8 SAPs to be specified. Amongst them, SAPI=0 is defined for the call control, mobility management and radio resource management purposes. The SAPI=3 is defined for the short message service.
Table 5-1 shows the primitives conveyed between L2 and L3. Two main parameters, the message unit and the channel type, are included in the primitives. The message unit conveyed by the primitives are of two types, the peer-to-peer messages transferred through the data link connection, and the layer-to-layer information concerning the actions and results related to the REQUEST primitives. The channel type (BCCH, CCCH, DCCH) is indicated in the L3 primitives enabling the data link layer to correctly distribute L3 messages on appropriate physical channels.

<table>
<thead>
<tr>
<th>Operations</th>
<th>Primitives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledged mode</td>
<td></td>
</tr>
<tr>
<td>Data transfer</td>
<td>DL-DATA-REQUEST/INDICATION</td>
</tr>
<tr>
<td>Establishment of MFO using SABM</td>
<td>DL-ESTABLISH-REQUEST/INDICATION/CONFIRM</td>
</tr>
<tr>
<td>Suspension of MFO</td>
<td>DL-SUSPEND-REQUEST/CONFIRM</td>
</tr>
<tr>
<td>Resumption of MFO</td>
<td>DL-RESUME-REQUEST/CONFIRM</td>
</tr>
<tr>
<td>Termination of MFO</td>
<td>DL-RELEASE-REQUEST/INDICATION/CONFIRM</td>
</tr>
<tr>
<td>Unacknowledged mode</td>
<td></td>
</tr>
<tr>
<td>Data transfer</td>
<td>DL-UNIT DATA-REQUEST/INDICATION</td>
</tr>
<tr>
<td>Random access</td>
<td></td>
</tr>
<tr>
<td>Data transfer</td>
<td>DL-RANDOM ACCESS-REQUEST/INDICATION/CONFIRM</td>
</tr>
</tbody>
</table>

Table 5-1 Data link layer primitives for providing services to L3
Table 5-2 Physical layer primitives for providing services to L2

There are three groups of primitives exchanged between L2 and L1, as shown in Table 5-2. The functions of LAPDm are applied only to the peer-to-peer messages, i.e., the data transfer. To the random access and the unacknowledged type of messages, the link layer is transparent. As shown in Figure 5-3, the data link layer in a BS simply passes the information received in a primitive PH (physical)-RA indication to the L3 in a primitive DL (data link)-RA request. The information carried in the primitives includes the content (8 bits) of the random access burst and an indication of the time slot in which the burst was received. An indication of the type of the channel used is also included in the primitives.

Figure 5-3 Random access procedures

5.2 LINK LAYER PROTOCOL FOR DCCH of S-PCNs

In S-PCNs, the signalling transactions on the DCCH will incur longer delay than that in the GSM system for the following reasons:
1. Re-transmissions of signalling packets, due to the channel fading and power constraint, which results in a long call set-up delay,
2. The long repetition duration (480ms/320ms assumed for MEO/LEO satellite systems respectively) due to the long propagation delay in the satellite systems;
3. Increased signalling exchanges due to the involvement of a second BS, in addition to the ESC, in the call set-up procedure.

5.2.1 Modifications of GSM Timer T200

In the GSM system, the repetition delay of a DCCH frame block is 235.4ms and the DCCH timer (T200) is 220ms. These parameters are determined mainly by two factors, the DCCH signal processing delay at the Base station/Mobile station which is
148ms/51ms and the transmission delay (mainly the interleaving delay) of command and response packets which is about 37ms. The propagation delay in terrestrial systems is negligible. Due to the long propagation delay in satellite systems, the value of GSM-T200 is not appropriate for the S-PCNs. We suggest 480ms and 320ms the frame repetition cycle for ICO10 and LEO66 satellite systems respectively.

5.2.2 Data Link Layer Protocols for DCCH of S-PCNs

The use of a stop and wait (SAW) scheme in S-PCNs may cause unacceptably long call set-up delays due to the channel fading. Two ARQ techniques, Go-Back-N (GBN) and Selective Re-transmission (SRT) ([LIN84] and [IYE93]), are considered since they have been widely used in data communication systems to counteract the transmission errors and the long propagation delay. Both protocols can provide higher channel throughput efficiency than the SAW scheme. To be adopted in S-PCNs, the GBN and SRT ARQ schemes need to be modified in order to cope with the transaction type transmission on the DCCH.

In S-PCNs, the DCCH transmission data rate is low because of the long propagation delay (ICO10: 320/0.48 = 667b/s). It can be increased by increasing the window size (WS). The window size refers to the number of pending frame blocks allowed to be sent before the response frames from the opposite direction are received. The DCCH load will be increased by X times if the window size is increased from 1 to X.

As shown in Figure 5-4, the long L3 messages (exceeding 15-octets in S-PCNs) will be segmented into a number of frame blocks and placed in a transmit buffer in sequence. WS frame blocks are input to a send buffer according to their sequence number. If the number of frames in the transmit buffer is smaller than the WS, frame copies are filled in successively. When the window slots become available, the pending frames in the send buffer are sent. The frames will be kept in the send buffer until the acknowledgment (N(R)) is received. Before the next transmission interval begins, the unacknowledged frames are re-scheduled. If some frames are successfully received in the previous transmission, the number of unacknowledged frames is reduced. Thus, more windows are available for the redundant frames.

![Figure 5-4 The message sending peer (WS=5)]
5.2.2.1 Modified Go-Back-N Protocol

As shown in Figure 5-5, a transmission is deemed successful and is acknowledged only if the received frame is both error free and in sequence in the GBN case. The N(R) in the S-frames is set to the highest sequence number of the successful frames. When an out-of-sequence frame is detected, the receiver sends a REJ frame which indicates the sequence number of the next expected I-frame. Then the transmitter initiates retransmission starting from the frame immediately after the last successful frame. If the REJ frame is lost, recovery is achieved via a time-out mechanism. A timer is set whenever an I-frame is sent. If a positive acknowledgment is not received within the time-out interval, then the transmitter re-transmits all the frames following the last positively acknowledged frame. When the whole L3 command is correctly received and processed, a responding L3 message is generated. The transmit buffer is only cleared when the first I-frame of a L3 response is successfully received at the peer entity from which the L3 command is issued.

The numbering ambiguity problem which exists for the SRT protocol (discussed later) can be avoided by using the GBN protocol. If we keep the WS smaller than 8, it will not be possible for different frames with the same sequence number to be sent in the same transmission cycle in the GBN protocol.

![Diagram of M-GBN protocol (WS=5)](image)

Figure 5-5 M-GBN protocol (WS=5)

5.2.2.2 Modified Selective Re-transmission Protocol

In the SRT case (Figure 5-6), the receiver stores the error-free I-frames even if those frames may not be in sequence. Because the REJ S-frame only indicates the sequence error, it can be eliminated from the SRT protocol operation. Only the positive acknowledgments (RR S-frame) which indicate the sequence number of I-frame received are sent back to the transmitter. It will simplify the protocol implementation
and increase the protocol efficiency. For those unacknowledged I-frames, recovery is achieved via a time-out mechanism. The SRT protocol requires multiple timers for those out-standing I-frames, which number exceeds the number of timers (WS) used in the GBN scheme.

In data communication systems, the SRT protocol gives better throughput performance compared to the GBN, because unnecessary re-transmissions can be avoided by storing the out-of-sequence but error-free I-frames in the receiving buffer. The disadvantages of the SRT is its an infinite buffering and the complex logic required at both transmitter and receiver [LIN84].

When an M-SRT ARQ scheme is applied to the DCCH, the buffering requirement is not a problem since the maximum length of a L3 message is 260-octets (equivalent to 18 frame blocks).

To reduce the frame header, the GSM LAPDm protocol specifies the sequence number modulo 8. It will not cause any problem in the LAPDm case because there is only one outstanding frame. If we adopt the modulo 8 sequence numbering in the M-SRT case, ambiguity of sequence numbering may occur. When there are more than eight segmented frames, the ninth frame that follows the frame No.7 is numbered as No.0. If the first I-frame (No.0) is still unacknowledged when the ninth I-frame is sent, the link layer in the receiver cannot restore the L3 message. The only solution to this problem is to increase the maximum sequence number in the SRT case. Therefore the length of the control field has to be increased to 2-octets (1-octet is used in the GSM LAPDm case), then the maximum sequence number can be increased to 128. This will reduce the transmission efficiency due to the increase of the frame header.

![Figure 5-6 M-SRT protocol (WS=5)](image-url)
Chapter 5 Evaluation of Call Set-up Signalling Performance

5.3 MOBILE ORIGINATED AND TERMINATED CALL SET-UP

5.3.1 Call Set-up Signalling Procedures

The mobile originated call set-up procedure is as shown in Figure 5-7. When an ESC receives an access request on RACH, a DCCH is allocated through AGCH for call set-up related signalling exchanges.

Messages are exchanged between a mobile and an ESC in order to verify the mobile’s registration and to route the call through an appropriate ES in the range. The information exchanged at this stage includes the authentication message, destination of called party and required services, mobile location and diversity information, etc. After an appropriate ES is selected, a channel assignment command is issued from the ESC to both MS and ES.

Both MS and ES synchronize to the allocated DCCH. To begin the signalling transactions, the multiple frame operation (MFO) mode is established by the MS sending a SABM and the ES responding with a UA frame. After the MFO is successfully established, the next step is to exchange the cipher command/response. Once entering the cipher operation mode, the MS sends a set-up message to the ES. The ES checks the service compatibility between the called user’s network and the S-
PCN to determine the appropriate interworking function for the required service. Figure 5-7 shows the called user is an ISDN subscriber. Hence the ISUP call set-up related signalling procedure is applied for the rest of the signalling procedure. To save the valuable satellite resource, the TCH can be allocated after the called user answers the call.

**Figure 5-8 Mobile terminated call set-up procedure**

Figure 5-8 shows the mobile terminated call set-up signalling procedure. By interrogating the S-HLR, a gateway exchange (EXC) (corresponding to the GSM-GMSC) which is the entrance point of a mobile terminated call retrieves the address of a SMSC/S-VLR. In the case where the ISDN interfaces the SMSC, the ISUP *initial address message* (IAM) is sent from the EXC to the SMSC. Having received the call set-up request, the SMSC initiates the paging process that has been introduced in Chapter 4. The *paging* signalling is broadcast by the ESCs via appropriate satellite/SBs that are selected according to an intelligent paging algorithm. Once the *paging* message is received, an MS will send a *paging response* on the RACH as early as possible. When an ESC receives the *paging response* from the MS, an *immediate assignment* command is sent on the AGCH. A number of preliminary call set-up related signalling exchanges take place between the ESC and the MS before an appropriate call routing point is selected. Firstly, the authentication procedure is performed to verify the user’s profile. Then the mobile and service related information, such as the mobile’ location, the ES preference, the type of service required, is exchanged. The *additional assignment* command is sent to both MS and the selected ES. Then the call is propagated from the EXC to the determined access point-ES. The
rest of the call set-up signalling procedure is similar to that in the mobile originated call set-up signalling procedure. Exceptions are that the set-up message is sent by the ES and the call confirm, alerting and connect messages are received from the MS.

5.3.2 Evaluation of Call Set-up Signalling Performance

Mathematical analysis of ARQ protocols usually requires some simplifications. For instance, the S-frame is assumed error-free [BUX80]. The analysis is difficult without these assumptions. Our evaluation of the ARQ protocols is carried out using a complete simulation of the satellite channel, taking into account errors in both the I- and S-frames.

As discussed in Chapter 2, the signal transmitted at the satellite air-interface is subject to multipath fading as well as shadowing. The satellite fading channel is approximated by a two-state Markov channel model [LUT91]. Because the bit error rate (BER) performance of the shadowed link is very poor, it can be assumed that the transmission link is virtually blocked when a shadowed channel condition is encountered. This is referred to as the “bad” channel state in the Lutz model. Likewise, a “good” channel state refers to the un-shadowed condition. The probability of a packet being transmitted in the good channel state \( P_{\text{g}(n)} \) is the combination of the probability of a packet started in the good state \( (1-A) \) and the probability of the good channel state lasting longer than the packet duration \( p_{\text{g}(>n)} \) [CAS92]. When the ‘good’ (multipath fading) channel condition is present, the packet error rate is determined by the coding scheme adopted, the packet length and the BER. The BER of up- and down-links depends on the transmit signal power and the fading parameters and the path loss. Due to the satellite dynamics, the channel fading effect varies with the users’ elevation angle and surrounding environment. The lower the elevation angle, the higher the probability that links are shadowed and the poorer the channel performance (BER). The fading problem is more critical in the city/urban environment than in the open area.

<table>
<thead>
<tr>
<th></th>
<th>ICO10</th>
<th>LEO66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile TX peak power (W)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sat. TX EIRP (dBW)</td>
<td>35</td>
<td>21.4</td>
</tr>
<tr>
<td>Uplink mean BER</td>
<td>(10^{-2.2/-2.4})</td>
<td>(10^{-2.5/-2.9})</td>
</tr>
<tr>
<td>Downlink mean BER</td>
<td>(10^{-2.8/-2.9})</td>
<td>(10^{-3.4/-4.3})</td>
</tr>
</tbody>
</table>

*Table 5-3 Satellite link performance*

The satellite link simulation results are given in Table 5-3. The link BER increases when the elevation angles change from 10° to 50°. Paging delay and random access delay had been evaluated in our previous works (Chapters 3,4) and are given in Table 5-4. In the call set-up simulations, the parameters of up- and down-link BERs, the random access delay (Chapter 3), and the paging delay (Chapter 4) are incorporated in
the forms of cumulative distribution files (CDF) which are given as the simulation input files.

<table>
<thead>
<tr>
<th></th>
<th>RACH</th>
<th>PGCH</th>
<th>Set-up delay (M-SRT, WS=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEO66</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>city/urban (elevation angle: 30°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile term.</td>
<td>0.41</td>
<td>1.06</td>
<td>9.16</td>
</tr>
<tr>
<td>Mobile orig.</td>
<td>0.41</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>open area (elevation angle: 20°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile term.</td>
<td>0.34</td>
<td>0.13</td>
<td>4.18</td>
</tr>
<tr>
<td>Mobile orig.</td>
<td>0.34</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>ICO10</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>city/urban (elevation angle: 30°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile term.</td>
<td>0.52</td>
<td>0.84</td>
<td>13.2</td>
</tr>
<tr>
<td>Mobile orig.</td>
<td>0.52</td>
<td></td>
<td>13.1</td>
</tr>
<tr>
<td>open area (elevation angle: 30°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile term.</td>
<td>0.49</td>
<td>0.2</td>
<td>6.33</td>
</tr>
<tr>
<td>Mobile orig.</td>
<td>0.49</td>
<td></td>
<td>6.07</td>
</tr>
</tbody>
</table>

Table 5-4 Average signalling transmission delay in different environments for LEO66 and ICO10

<table>
<thead>
<tr>
<th>Message type</th>
<th>GSM</th>
<th>S-PCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel request/paging response</td>
<td>8 bits</td>
<td>32 bits</td>
</tr>
<tr>
<td>Paging request</td>
<td>22/21/19 octets</td>
<td>12/11/15 octets</td>
</tr>
<tr>
<td>Immediate assignment</td>
<td>19 octets</td>
<td>7 octets</td>
</tr>
<tr>
<td>Authentication request</td>
<td>19 octets</td>
<td>19 octets</td>
</tr>
<tr>
<td>Authentication response</td>
<td>6 octets</td>
<td>6 octets</td>
</tr>
<tr>
<td>CM service request</td>
<td>17 octets</td>
<td>44 octets¹</td>
</tr>
<tr>
<td>CM service response</td>
<td>2 octets</td>
<td>2 octets</td>
</tr>
<tr>
<td>MS related information (mobile terminated)</td>
<td></td>
<td>17 octets¹</td>
</tr>
<tr>
<td>Addition assignment</td>
<td>18 octets</td>
<td>5 octets</td>
</tr>
<tr>
<td>Cipher mode command</td>
<td>3 octets</td>
<td>3 octets</td>
</tr>
<tr>
<td>Cipher mode complete</td>
<td>2 octets</td>
<td>2 octets</td>
</tr>
<tr>
<td>Set-up, mobile originated/terminated</td>
<td>162 octets</td>
<td>162 octets</td>
</tr>
<tr>
<td>Call processing (mobile originated)</td>
<td>6 octets</td>
<td>6 octets</td>
</tr>
<tr>
<td>Call confirm (mobile terminated)</td>
<td>45 octets</td>
<td>45 octets</td>
</tr>
<tr>
<td>Assignment command</td>
<td>44 octets</td>
<td>39 octets</td>
</tr>
<tr>
<td>Altering, mobile originated/terminated</td>
<td>43/39 octets</td>
<td>41/37 octets</td>
</tr>
<tr>
<td>Connect, mobile originated/terminated</td>
<td>43/39 octets</td>
<td>41/37 octets</td>
</tr>
<tr>
<td>Connect acknowledgment</td>
<td>2 octets</td>
<td>2 octets</td>
</tr>
</tbody>
</table>

Table 5-5 Signalling messages in GSM and S-PCN

¹ Information fields of satellite diversity, ES preference and MS location which are specific for S-PCN are included.
Chapter 5 Evaluation of Call Set-up Signalling Performance

The comparison between the call set-up related L3 signalling message formation in the GSM and that of the S-PCN is given in Table 5.5. Details of the modifications of the GSM signalling used for the S-PCNs are included in Appendix A.

The general assumptions used in the simulation are summarized as follows:

- The traffic load is 425 Erlangs; the average calling time is 3 minutes; then the call arrival rate is 2.36 call/sec;
- 30% of calls are mobile terminated; and 30% and 70% of users are respectively in a the city and highway environment;
- The I-frame (18-octets) and the S-frame (3-octets) transmitted on the DCCH are coded using (2,1,7) convolution coding scheme and the packet lengths of the I-frame and the S-frame are respectively 320 bits and 80 bits;
- The frame repetition cycle for ICO10 and LEO66 satellite systems are respectively 480 ms and 320 ms and the DCCH timers (T200) for the two satellite systems are 460 ms and 300 ms respectively;
- Mobile velocity is 90 km/hour.

5.3.3 Simulation Results and Discussion

Due to the channel fading effects, the call set-up delay is very much dependent on the elevation angles. As shown in Figure 5-9, the lower the elevation angles, the longer the call set-up delay. Both the M-SRT and the M-GBN protocols in this simulation use five window slots in each repetition cycle. The M-SRT protocol exhibits shorter call set-up delay than the M-GBN protocol. This delay difference decreases with the increasing of the elevation angle. When users’ elevation angles are below 20°, the call set-up delay is unacceptable even using the M-SRT protocol. In this case a larger WS will be needed to obtain the desired service quality.
Using the SAW link layer protocol (equivalent to WS of 1 in both SRT and GBN protocols) in the ICO10 system, the average call set-up delay for the mobiles roaming in the city/urban environment will be very long (Figure 5-10, 5-11). It is observed that the delay performance can be significantly improved by applying the M-SRT and the M-GBN protocols (WS>1). The most significant delay improvement is achieved at WS 2. With further increases of WS, the delay reduction is less marked. Compared with the M-GBN protocol, the M-SRT can further reduce the call set-up delay by 8-11 seconds for the city environments and require much less DCCH capacity (Figure 5-12).

**Figure 5-9 Mobile originated average call set-up delay vs. elevation (city/suburban environment)**

**Figure 5-10 Mobile originated average call set-up delay vs. WS (ICO10, E=30°)**
Chapter 5 Evaluation of Call Set-up Signalling Performance

The call arrival rate ($Q_i$) is a function of the offered traffic load ($A$) and the calling time $T$ (Equation 3.8). With the simulation assumptions given previously, the required DCCH capacity is plotted versus the WS in Figure 5-12.

When mobiles reside in open areas, the call set-up delay given by the M-SRT protocol is still shorter than that of the M-GBN protocol (Figure 5-10, 5-11), but the delay reduction is only about 2-3 seconds. This is due to the fact that the packet error probability is low. However, comparing with the SAW protocol, the call set-up delay is still significantly reduced by using the M-SRT and M-GBN (WS>1) protocols. For
example, when WS is 3, the call set-up delay is only 9 second (M-SRT) which is less than one third of that using the SAW protocol.

Figure 5-13 Mobile originated average call set-up delay vs. WS (LEO66)

Figure 5-14 Mobile terminated average call set-up delay vs. WS (LEO66)
Because the power limitation problem in the LEO system is not as critical as that in the MEO systems, improved channel BER can be achieved (Table 5-1). In addition, because of low satellite altitude, the DCCH timer is shorter than that in the MEO systems. Thus, it can be expected that the call set-up delay in the LEO systems is much shorter than that in the MEO systems. However, the propagation delay in LEO satellite systems cannot be ignored. Thus the DCCH timer in the LEO66 is longer than that in the GSM system. In LEO66 satellite system, the M-SRT and M-GBN protocols can still provide much better delay performance than that using the SAW protocol (Figure 5-13,5-14). Since the delay performance is significantly improved, the DCCH load using the M-SRT protocol is also decreased (Figure 5-15).

An example of mobile originated/terminated call set-up delay using the M-SRT protocol (WS of 5) in ICO10 and LEO66 satellite systems is given in Table 5-5.

### 5.4 SUMMARY

In this chapter, the GSM link layer protocol has been reviewed. To simplify the protocol operation, the GSM-LAPDm uses the SAW ARQ scheme in the acknowledgment operation mode.

We have investigated the feasibility of adopting the LAPDm protocol at the satellite air-interface. The long propagation delay and power limitation problems have been addressed. The simulation results show that the call set-up performance is poor using the SAW ARQ scheme. Therefore, modifications to the GSM-LAPDm is necessary to provide the desired link layer functions and a satisfactory QOS at satellite air-interface.
To cope with the transaction type of transmission on the DCCH, two powerful ARQ techniques: GBN and SRT used in continuous data transmission system were investigated and modified for use herein. As a result, the M-GBN and the M-SRT protocols have been proposed in order to reduce the call set-up delay in the S-PCNs. Hence better service quality can be provided and the satellite resource consumption can be minimized. The mobile originated and terminated call set-up delay in the LEO66 and the ICO10 satellite systems are evaluated via simulations. The call set-up delays using the M-GBN and the M-SRT protocols have been examined. The capacity requirements to the DCCH have also been evaluated.

It can be concluded that both the M-SRT and the M-GBN protocols can significantly reduce the call set-up delay. When the channel condition is bad and the satellite propagation delay is long, the M-SRT protocol is better than the M-GBN in reducing the call set-up delay. In addition, the M-SRT protocol has a stable and lower capacity requirement as compared to the M-GBN. Both protocols require larger window sizes compared to the GSM SAW protocol (WS=1). However, compared with the M-GBN protocol, the M-SRT requires more modifications to the LAPDm protocol, such as the number of timers and the control field in the frame header.
Chapter 6

The GSM System Networking

This chapter provides the technical review of the GSM network architecture, and in particular the signalling system and protocols. It also introduces the practice of the CCITT Signalling System No7 and distributed function structure in the GSM signalling system. The GSM signalling system will be used as the basis for developing a signalling structure and protocol set to be applied in the satellite and GSM integration scenario.

6.1 INTRODUCTION

The GSM (Group Special Mobile) system was developed as a second generation mobile radio system. This digital system provides users with automatic boundary-less roaming and allows mobile users to be connected to other users (either fixed or mobile) by accessing the GSM PLMN (Public Land Mobile Network). The first GSM system was in operation in Europe in 1991 and since then has spread to many other countries, such as Australia, New-Zealand, China, the USA, etc.

The GSM system adopts a TDMA multiple access scheme for the mobile access network and makes use of CCITT Signalling System No7 (SS7) to interconnect the network entities. Two fundamental services, teleservices and bearer services, are provided to GSM users. The former requires the implementation of higher level protocols to ensure user to user communication, and the latter exploits only the lower layer protocols of the Open System Interconnection (OSI). The high level protocols providing teleservices in the GSM system are mainly derived from the Integrated Service Digital Network (ISDN). To communicate with users of other wireline networks, e.g. Public Switched Telephone Network (PSTN) and Packet Switched Public Data Network (PSPDN), the protocol adaptation must be provided by the GSM interworking function (IWF). The lower layer protocols are individually designed in order to accommodate radio links.

During the development of the GSM system, much effort has been devoted to the Radio Resource (RR) management and the Mobility Management (MM) functions to provide mobile specific controls apart from providing the traditional transmission control. The RR functions are located in the Base Station Sub-system (BSS) and the Mobile service Switching Centre (MSC). The protocols used between the BSS and the MSC are not standard SS7 protocols because of the unique features of mobile networks. The MM functions are distributed amongst the MSC, Visitor Location
6.2 GSM NETWORK ARCHITECTURE

The architecture of the GSM PLMN is heavily influenced by the control functions required. The control functions include not only the traditional transmission and switching functions, as in the wireline telecommunication networks, but also the radio resource (RR) and mobility management (MM) functions. Because of mobile roaming and the radio resource management requirements, the related network functions are distributed amongst GSM network entities (MSC, BSS, VLR, HLR, GMSC, Authentication Centre (AuC) and Equipment Identity Register (EIR)). Using SS7 to realise the communication between distributed functions can enhance the function management. It is also a viable approach to provide the features and services to be added in the future. We need first to discuss the functionality provided by each network entity before we study the GSM signalling system. Both network entities and interfaces of the GSM system are illustrated in Figure 6-1.

6.2.1 Mobile Service Switching Centre (MSC)

Because of its switching capability, the MSC acts mainly as an ISDN exchange and thus it represents the interface between the fixed and the mobile networks. The MSC requires some IWFs. The services provided by the IWFs depend on the type of user data and the networks to which the MSC interfaces. In the mobile context, CM and MM functions are located in the MSC. The functions performed by an MSC include:
- location registration of a visiting mobile station (MS) in the MSC associated location area (LA);
- locating of a called MS within a LA;
- call routing for both mobile originated and mobile terminated calls;
- co-ordinating the radio resource management, call management and routing management for the inter-BSC and inter-MSC call handover.

6.2.2 Home Location Register (HLR)

The HLR is basically a database in which all relevant data concerning mobiles of a PLMN are permanently stored and updated when necessary. Two kinds of the user data are stored in the HLR. One is the user profile data including user identity (MSISDN-Mobile Station ISDN number and IMSI-International Mobile Subscriber Identity) and registered services. The other is the current roaming position within the network being represented by the SS7 address of an MSC/VLR. A GSM network
entity closely related to the HLR is the AuC (Authentication Centre) where all data relevant to user security are stored for the purpose of authentication.

6.2.3 Visitor Location Register (VLR)

The GSM location updating procedure is designed to cope with the roaming activity of the MSs. A VLR is a database responsible for storing and updating the mobility related information, which is more detailed than that stored in the HLR. A VLR can be integrated with an MSC and associated with a fixed LA.

The location updating procedure is triggered by an MS when a new cell is selected. If the new cell is within the old LA, only the record in the VLR is updated. If the change of LA is detected, the registration procedure with a new VLR is performed. This
procedure includes allocating a roaming number to the MS and signalling to the HLR the routing information (VLR address). This allows a mobile terminated call to be quickly routed to the correct switching point during the call set-up phase.

6.2.4 Base Station Sub-system (BSS)

The BSS is the radio access point to the GSM PLMN for all MS’s positioned within its radio coverage. According to the traffic pattern, every BSS is assigned a semi-permanent set of TDM carriers. The logical radio channels are mapped onto physical TDMA channels for signalling and traffic purposes. The BSS includes two entities: The Base Transceiver Station (BTS) that functions as a radio transceiver and the Base Station Controller (BSC) that performs radio channel control functions. The BTS and BSC are fully co-operative in almost every function: the BTS performs the execution and the BSC the control management functions.

BTS functions include:
- Radio transmission and reception;
- All the signal processing specific to the radio interface.

BSC functions include:
- Radio channel allocation;
- Link supervision and power control;
- Administration of the radio channel configuration;
- Signalling channel management and message scheduling;
- Intra-cell handover;
- Transcoder/rate adapter;
- Transmission network (Pulse Code Modulation (PCM) links between BSC and BTS) management;
- Transparent function for conveying the Direct Transfer Application Part (DTAP) messages related to the call control and mobility management procedures between MSC and MS.

6.2.5 Gateway Mobile Service Switching Center (GMSC)

The GMSC is the access point from fixed networks (e.g., PSTN, ISDN) to the GSM PLMN. The switching function in a GMSC provides call routing between external networks and the GSM MSC. A GMSC also uses the SS7 signalling links to communicate with other GSM network entities (e.g. HLR). When a mobile terminating call arrives at a GMSC, the routing information is fetched from the HLR. The incoming call is then directed to a MSC/VLR to which the call destination party, an MS, is registered.
6.3 GSM SIGNALLING SYSTEM

The GSM network uses the SS7 signalling system to establish the connections between network entities. The OSI 7-layer model adopted in the SS7 signalling system is used to group functions that may be distributed amongst separated network entities in function planes, represented as one plane stacked upon another. Each layer in a network entity (e.g. BSC) is able to communicate with the corresponding layer in another network entity (e.g. MSC) using the services provided by the lower layers. Signalling formats and procedures that are generally designated as signalling protocols are defined to allow communication between corresponding layers.

6.3.1 CCITT Signalling System No. 7

The SS7 is a modern common channel signalling system [KUH94]. A simplified SS7 signalling network architecture [MAN91] is shown in Figure 6-2. The traditional 4-layer structure has been specified for the circuit-related calls, e.g. the telephone user part-(TUP) in the Public Switching Telephone Network (PSTN). The OSI 7-layer model has been specified to support the non-circuit-related applications in addition to the circuit-related calls. The protocols of the Signalling Connection Control Part (SCCP), Transaction Capability Application Part (TCAP) and Transaction Capability (TC) are defined in the OSI model as providing functions supporting non-voice calls, advanced ISDN and Intelligent Network (IN) services.

![Figure 6-2 CCITT signalling network architecture](image)

6.3.1.1 Message Transfer Part

In each signalling point, physical layer (L1), data link layer (L2) and network layer (L3) make up the Message Transfer Part (MTP). The MTP is responsible for reliably transferring messages from one signalling point to another in the circuit-related applications. The L1 defines the physical, electrical and functional characteristics of the signalling link. The L2 is responsible for the reliable transfer of signalling information.
between two directly connected signalling points. The L2 functions can be explained by the fields within the message unit. As shown in Figure 6-3, the flag acts as the frame delimiter, which appears at the beginning and end of each signal unit. The signal information field (SIF) is the only field in an L2 message defined by the L3 function. The fields of sequence numbers and indications (BSN, BIB, FSN, FIB) are used in the error correction procedures. The details of the error correction procedures were discussed in Chapter 5. The length indicator (LI) gives the length of the signal unit. Furthermore, when a message arrives at its destination, the service information octet (SIO) is used by the distribution function in a service point (SP) to determine the user to whom the message is addressed.

L3 provides the network function for circuit-related applications. The L3 functions are classified into two functions: signalling message handling and signalling network management. The latter includes network reconfiguration in response to the status changes in the network. The former consists of the message routing, discrimination and distribution functions. To handle the message routing, a routing label (Figure 6-3) is assigned as a L3 header. The signalling link selection (SLS) field in the routing label is used to indicate the chosen link and perform the load sharing. Signalling routing is performed by analysing the destination point code (DPC).

![Figure 6-3 Format of a L2, L3 signal unit](image)

BSN: backward sequence number  
BIB: backward indicator bit  
FSN: forward sequence number  
FIB: forward indicator bit

### 6.3.1.2 Signalling Connection Control Part (SCCP)

To allow the non-circuit-related transfer of data across the network, the SCCP is added on top of the MTP to provide an equivalent network service in the OSI model. The SCCP messages make use of a local reference number replacing the circuit identity code (used in circuit-related applications, e.g. TUP) to provide services to the non-circuit related applications.
Furthermore, the SCCP offers enhanced addressing capability in addition to the routing label provided by the L3. The called party address (Figure 6-4) included in an SCCP header consists of the signalling point code (SPC), subsystem number (SSN) and global title (GT). The “address indicator” shows the type of address information contained in the address field. The SPC has the same format as the destination point code (DPC) provided in the routing label. The SSN is used to identify the SCCP user functions. The GT is an address plan defined in CCITT E.164 [E164]. Compared to the SPC which is restricted to one network, the GT provides an address mechanism between different networks. The SCCP provides a translation function in the service points that converts a GT into an SPC.

Moreover, two kinds of services are provided by the SCCP: connectionless and connection-oriented services. The former transfers data without establishing a connection, whereas the latter requires that a connection be established and maintained during the transaction.

<table>
<thead>
<tr>
<th>Message type</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol class</td>
<td>1</td>
</tr>
<tr>
<td>Pointers</td>
<td>3 octets</td>
</tr>
<tr>
<td>Parameter length</td>
<td>3 octets</td>
</tr>
<tr>
<td>called party address</td>
<td>4</td>
</tr>
<tr>
<td>calling party address</td>
<td>2</td>
</tr>
<tr>
<td>Data</td>
<td>2 to X</td>
</tr>
<tr>
<td>Address indicator</td>
<td>1 octet</td>
</tr>
<tr>
<td>Signalling point code (SPC)</td>
<td>2 octet</td>
</tr>
<tr>
<td>Subsystem number (SSN)</td>
<td>1 octet</td>
</tr>
<tr>
<td>Global Title (GT)</td>
<td>16-32</td>
</tr>
</tbody>
</table>

*Figure 6-4 SCCP message format*

6.3.1.3 Transaction Capability Application Part (TCAP)

For the non-circuit-related user applications, the transaction capability (TC) is specified to offer general standardised protocol functions establishing communications between distributed network entities. The transaction capability application part (TCAP) provides a general and common protocol for the transfer of information between two nodes. The services provided by the MTP and SCCP are used by the TCAP to transfer messages. The use of the TCAP in the SS7 network is mainly for supporting transactions between databases and exchanges. The Mobile Application Part (MAP) used in the GSM system is an important application of the TCAP to support mobile roaming in the mobile networks.
The TCAP consists of a transaction sub-layer and a component sub-layer as shown in Figure 6-5. The transaction sub-layer is responsible for establishing and maintaining the connection between two nodes. Three message types, begin, continue and end, are defined in the transaction sub-layer. The component sub-layer is responsible for requesting actions at a remote node and reporting the result of such actions. Several components (invoke, return result, return error and reject) defined in the component sub-layer are carried by the transaction messages. TCAP messages consist of information elements which have the general format of tag/length/contents.

6.3.2 GSM Signalling System

The GSM signalling system is based on the CCITT SS7 structure. The L2 protocols were introduced in Chapter 5. The MTP3 and SCCP protocols are employed to implement network layer functions for the carrying of signalling messages related to the mobility management, radio resource (RR) management and call control functions between network entities. To distinguish between the various transactions, the network layer function must maintain the correspondence between physical channels and the SCCP transaction reference. The MAP is an application that makes use of the TCAP to realise mobility management within GSM networks.

We divide the GSM network entities into two groups according to the functionality provided and the signalling protocols adopted (Figure 6-6). The BTS, BSC and part of MSC, referred to as the mobile side network, are mobile specific network (Figure 6-6a) entities as far as the radio resource management function is concerned. The RR management is mainly controlled by the BSC and executed by the BTS. The coordination is the responsibility of the MSC. Signalling protocols, RIL3-RR, GSM08.58 and BSSAP are specified respectively for the Dm (radio interface), Abis and A interfaces. The mobility management (MM) and call management (CM) services can only be provided with the established RR connections. Since the RR connections on different interfaces are established using different protocols, a network function is
required to maintain the correspondence between these connections. The HLR, VLR and the part of the MSC involved in the network side mobility management are known as the SS7 network (Figure 6-6b) which is connected via standard interfaces. The interfaces are specified via the mobile application part (MAP) that uses the transaction capability application part (TCAP) of SS7. In this section, we discuss the network layer functions in the mobile side network and the MAP protocols employed in the SS7 network, as well as the message layer protocols [RAH93]. The latter deals mainly with the radio resource management (RR), mobility management (MM) and connection management (CM) functions. Understanding of these functions and protocols is very important so that we may further investigate the signalling network and protocols used in the integrated satellite and GSM system.

Figure 6-6 GSM signalling architecture
6.3.2.1 Network Layer Function in Mobile Side Network

The network layer is specified to perform the signalling routing and signalling network management functions. A common signalling routing function in the GSM system [GSM04.08] is provided by the protocol discriminator (PD) and transaction identifier (TI) which are mandatory elements in each L3 message transmitted through the $Dm$, Abis and A interface. The purpose of PD is to distinguish messages of different procedures, i.e. that of the call control, the mobility management and the radio resource management, etc. The TI is used to distinguish multiple parallel transactions within one MS.

6.3.2.1.1 Abis Interface

The interface between BTS and BSC is defined as the Abis interface ([GSM08.51,52,54,56,58], [MOU94]). The functional division between BTS and BSC is given so that all the channel control functions are performed by the BSC whilst the BTS provides the channel related parameters for the BSC to make decisions and execute commands received from the BSC. The L1 on the Abis interface will utilise digital transmission at a rate of 2.048Mbit/sec. The signalling stream is transmitted in a 64kbit/sec time slot. The L2 uses the LAPD link protocol. An information field of a L2 message is allowed to include a maximum of 260-octet L3 message.

There are three information elements that provide the addressing mechanism in Abis L3 messages. As shown in Figure 6-7, the "message discriminator" element is one octet long. One bit is used to distinguish between transparent and non-transparent messages. The transparent messages are merely forwarded to L2 on the radio interface, whereas the non-transparent messages are only sent between the BSC and BTS. The remaining seven bits are used to group the messages into four groups: radio link layer management, dedicated channel management, common channel management and transceiver (TRX) management messages. The "Channel number" element supports the distribution of messages to relevant physical radio channels on the TRX. The "Link identifier" element which is only used in the radio link layer management related procedures distinguish the logical signalling links on the radio interface.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message discriminator</td>
<td>1</td>
</tr>
<tr>
<td>Message type</td>
<td>1</td>
</tr>
<tr>
<td>Channel number</td>
<td>2</td>
</tr>
<tr>
<td>Link identifier</td>
<td>2</td>
</tr>
</tbody>
</table>

*Figure 6-7 General format of L3 header at the Abis interface*
To complete the addressing issue, we hereby briefly introduce the addressing methods used by the L2 protocol on the Abis interface. In a BTS, a transceiver (TRX) is an entity supporting transmission and reception on a TDMA carrier. One or more TRXs may be included in a BTS depending on the traffic capacity required. In addition, there is a base control function (BCF) entity handling common control functions like frequency hopping sequences, time base, etc., in a BTS. The Terminal Endpoint Identifier (TEI) in the L2 header is adopted to address different physical entities, such as TRXs or BCF, in a BTS, as shown in Figure 6-8. A physical entity normally has more than one functional entities. The logical links to different function entities are distinguished using the Service Access Point Identifier (SAPI) (Table 6-1).

![Figure 6-8 Layer 2 logical links at Abis interface](image)

<table>
<thead>
<tr>
<th>SAPI</th>
<th>Signalling procedures for different function entities</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Radio signalling</td>
</tr>
<tr>
<td>62</td>
<td>Operation and maintenance</td>
</tr>
<tr>
<td>63</td>
<td>Layer 2 management</td>
</tr>
</tbody>
</table>

*Table 6-1 Distinction of different function entities in a physical entity*

### 6.3.2.1.2 A Interface

The network functions provided by the MTP3 on the A interface ([GSM08.06,08], [MOU94]) have been simplified because of the point to point connection between a BSC and a MSC. The signalling routing function is not supported. The BSC (or MSC) only accepts messages if the destination point code (DPC) in the routing label addresses itself.

The aim of the SCCP function is to achieve the management of the MS references on the A interface. A subset of SCCP functions implemented in GSM is fully compatible with the CCITT SCCP functions. The called party address includes the subsystem number (SSN) to distinguish messages addressed to the applications, such as the...
OA&M function, BSSMAP and DTAP application part. The GT is not necessary because of the point to point connection between the BSC and the MSC. The SCCP supports two methods of signal communication: the connection oriented method and the connectionless method.

The connection oriented mode requires independent connections to be set up with individual MSs. Messages are correlated by using a local-reference number allocated by the nodes involved in the connection. For each call managed by a BSS, a corresponding SCCP connection is established on the A-interface. The BSC manages the one-to-one correspondence between messages (labelled with a given physical channel number) from/to the BTS and messages (labelled with a given SCCP connection) to/from the MSC, while the MSC manages each SCCP connection corresponding to an individual MS.

The connectionless mode enables messages to be transferred between two nodes without establishing a connection. The OA&M messages and the BSSMAP messages that do not pertain to any specific calls are transferred using the connectionless method.

The signalling messages handled by the BSS application part (BSSAP) on the A interface are divided into two groups:

- Direct transfer messages between MSC and MS transparently conveyed by BSC. These are call control and mobility management messages which are handled by Direct Transfer Application Part (DTAP);
- BSS management messages between MSC and BSS. These messages managed by the BSS management application part (BSSMAP) are used to perform resource management and handover control procedures.

<table>
<thead>
<tr>
<th>Discrimination parameter</th>
<th>Data Link Connection Identification (DLCI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0 0 0 0 D</td>
<td></td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 SAPI</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 6-9 The distribution function above the SCCP*

A distribution function above the SCCP is required to discriminate between the two signalling groups. Therefore all the SCCP messages on the A interface contain a distribution data unit, indicating whether the message is a BSSMAP or a DTAP message (*Figure 6-9*). The distribution data unit in the BSSMAP messages only consists of the discrimination parameter (1 octet), which is set to be non-transparent (D=0). Two parameters are defined in the distribution data unit in the DTAP messages. The discrimination parameter is set to be transparent (D=1) and the data link
connection identification (DLCI) parameter (1 octets) gives the SAPI indicating the type of data link connection to be used over the radio interface.

### 6.3.2.2 SS7 Network in GSM System

The signalling messages exchanged between network entities (HLR, VLR, MSC and GMSC, etc.) conform to the standard SS7 protocols because they are not as mobile specific as those between BTS, BSC and BSS side MSC.

#### 6.3.2.2.1 Addressing and Routing

Between the HLR, VLR, MSC and GMSCs, the address and routing functions are provided by the SCCP in SS7. The address information is carried by the SCCP messages. The routing information (SPC or GT) can be derived from either the MSISDN number or the GSM subscriber number (IMSI) using the SCCP translation function. If a signalling transmission is within a national scope, the SCCP will use a SPC to route the messages. When the signalling routing exceeds the national boundary, the global title (GT) translation capability of the SCCP may then be used.

The MSISDN (CCITT E.164) is given as a GSM directory number (Figure 6-10). Its structure follows the same numbering plan as that of the ISDN. The International mobile subscriber identity (IMSI) is used by the mobile when identifying itself to the mobile network. The network code (NC) and mobile network code (MNC) in the MSISDN and IMSI are used to identify the operator. The HLR address can be determined by the analysis of the first digits in the mobile station identification number (MSIN). From the record hold in the HLR, the MS' roaming location can be found.

<table>
<thead>
<tr>
<th>Country Code (CC)</th>
<th>Network Code (NC)</th>
<th>MS Identification Number (MSIN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>6-9</td>
</tr>
</tbody>
</table>

**MSISDN**

<table>
<thead>
<tr>
<th>Mobile Country Code (MCC)</th>
<th>Mobile Network Code (MNC)</th>
<th>MSIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
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**IMSI**

*Figure 6-10 Numbering plan of GSM subscriber*

#### 6.3.2.2.2 TCAP

As mentioned in section 6.3.1, the TCAP provides a common application service to the TC-users (e.g. MAP). The TCAP used in GSM systems is fully compatible with the TCAP defined in the SS7. The two facilities offered to the MAP by the TCAP include the transaction handling and component handling. The transaction portion establishes and maintains the connections between end users. A transaction indicator is added to
each message to distinguish independent message flows, and this indicator enables the other end to relate all the messages of the same transaction to the same context. The component portion correlates the request and the response in each dialogue. Therefore, the messages delivered by the MAP can be simply included in the Invoke request component or the Return result response component. It is the duty of the TCAP to link them within the same dialogue.

6.3.2.2.3 MAP/E

The MAP/E protocol is used between MSCs to perform inter-MSC call handover. The call entry point (an anchor MSC) in the GSM system is assumed stable throughout the call even though a call handover may involve other MSCs (relay MSCs). A relay MSC acts as the transit point connecting a call from/to an anchor MSC to/from an MS.

Because of MAP [GSM09.02] and BSSAP protocols used on the E and A interfaces respectively, a relay MSC has to perform the protocol translation [GSM09.10]. As shown in Figure 6-11, two MAP/E messages, PROCESS ACCESS SIGNALLING (from the relay MSC to the anchor MSC) and FORWARD ACCESS SIGNALLING (from the anchor MSC to the relay MSC), are exchanged between relay and anchor MSCs. Their information field includes the messages sent to or received from the MS. The relay MSC simply translates the messages between MAP/E and DTAP protocols. Additionally, the protocol translation from MAP/E to MAP/B is also required to the relay MSC. The MAP/E PREPARE HANDOVER REQUEST message received in the relay MSC triggers the transaction on the B interface to ask for the handover number allocation from a VLR.

A discrimination function dealing with the distinction between the message flows pertaining to different MSs is fulfilled by the TCAP protocol (transaction handling) on the E interface. The relay MSC is responsible for maintaining the context for each connection with an MS via the connected BSS, and is also responsible for translating back and forth between the SCCP references (towards the BSC) and the TCAP transaction references (toward the anchor MSC).
6.3.2.3 Message Layer Protocols

From the functionality point of view, message layer protocols are grouped into three functional planes. The RR management function is responsible for establishing the transmission links between the network entities and the mobiles. Thus it is located at the bottom of the message layer protocols. Above it, the MM function handles the location updating and the security related procedures, such as authentication. The call management (CM) function co-ordinates call set-up, supervision and release. Both MM and CM are the signalling protocols between the mobile and network entities beyond A interface. The BTS and BSC are transparent to the MM and CM messages (Figure 6-6).

6.3.2.3.1 Radio Resource Management (RR)

The RR has two functions: the one located in the BSS is responsible for radio resource control and managing the cross references between the SCCP connections on the A interface and the physical channels on the MS side; the other located in the MSC co-ordinates paging, call handover and start of ciphering, and maintains a look-up table showing the relationship between different BSCs and the Location Areas.

The function distribution within the RR layer requires various protocols (Figure 6-6) employed on the radio and landline links. The Radio Interface Layer-3 RR (RIL3-RR) protocol is used on the radio link to perform radio resource management between mobiles and a BTS. The GSM08.58 protocol adopted on the A-bis interface is used for a BSC to configure the transmission path to a BTS and for the BTS to report the measurement results to the BSC. The BSSMAP protocol, which is a non-transparent part of the BSSAP protocols, is used to carry the RR related messages on the A interface. The RR related messages sent via the A interface consist of the paging signalling, the transmission mode and channel type messages, and the call handover related messages, etc.

When inter-MSC call handover happens, the RR layer is extended to the E interface. The MAP/E protocol will be included in the RR protocol plane. The two MSCs involved in the handover take different roles. The anchor MSC is responsible for the call control and mobility management of the concerned mobile during the call until the call connection is released. Therefore it is the responsibility of the anchor MSC to initiate and control the handover procedures. The role of the relay MSC is simply to provide the radio resource control within its area and protocol translation between the MAP/E and the DTAP (A interface).
6.3.2.3.2 Mobility Management (MM)

The entities involved in the MM function include the MSC/VLR and the HLR on the network side, and the MS on the mobile side. The MM functions mainly perform the location updating and security management procedures, as well as the procedures to establish, maintain and release an MM connection. The CM entities make use of the MM connections to exchange security related information, whereas the mobility specific procedures, e.g., the location updating procedure, is initiated without the MM connections. Even though the MM connection may or may not be required, the signalling connection provided by the RR layer is definitely required to establish an MM context between an MS and a MSC/VLR.

The RIL3-MM protocol is used to convey MM messages on the radio interface. To the BSS, the RIL3-MM messages are transparent and are conveyed using DTAP protocol on the A interface. The L3 messages pertaining to the MM layer are distinguished using protocol identity (PI).

As shown in Figure 6-6(b), the MAP/D protocol is used between the MSC/VLR and the HLR to exchange location updating and security management related messages. The MAP/G protocol is defined on the interface between the VLRs to enable a VLR to ask for the identity and subscription data from another VLR, before accessing the HLR. The MAP/G protocol is used only under one circumstance, i.e., when an accessing MS identifies itself with a temporary mobile subscriber identity (TMSI) which is allocated by another VLR.

6.3.2.3.3 Communication Management (CM)

Basically, the public cellular networks are access networks to the major fixed telecommunication networks. The CM signalling and protocols adopted as such are very much dependent on existing techniques. This influence exists not only at the interface between the GSM and the public telecommunication networks, but also inside the GSM infrastructure, owing to interworking with various external networks.

Using services provided by the RR and MM layers, the CM layer protocols co-ordinate the call set-up, supervision and release signalling procedures. To set-up a call, the radio connection (RR) to an MS must exist and the authentication procedure (MM connections) as well as the ciphering procedure should be performed before a CM link is established.
**RIL3-CC Protocol**

Services offered by the CM sub-layer consist of the Call Control (CC), the Supplementary Service (SS) and the Short Message Service (SMS). The CC transactions between an MS and a MSC/VLR use the RIL3-CC protocol (Figure 6-6).

The ISDN user part (ISUP) works directly with the RIL3-CC protocol in the MSC since the latter uses the CCITT Q931 protocol that is also the ISDN call control protocol. However, call control protocol in the PSTN has a different mechanism from the one used in the ISDN. The information provided to the users is in the form of audio tone. To establish the link between the GSM and the PSTN users, “progress” message must be provided by the RIL3-CC protocol.

**Call Routing**

Because of user mobility in the cellular networks, the routing approach for mobile terminating calls will be different from that of the public telecommunication networks. The routing function in the GSM network depends upon the PLMN network architecture, and administration regulations, e.g. charging. The routing optimisation may be a less important issue where security about the subscriber’s location is of premium concern. Because of administration reason, a GMSC in a called user’s home PLMN is always selected as an entry point for incoming calls. This may cause inefficient routing in the case that the called user roams outside its home PLMN and happens to be in the same country as a calling user. If the calling party does not know the location of the called user, two international links are inevitable. This phenomenon is called “tromboning”.

For the mobile terminating calls, signalling exchanges use the MAP/C and MAP/D protocols applied between the GMSC and the HLR, and between the HLR and the VLR. As shown in Figure 6-12, according to the dialled directory number (MSISDN), the incoming call can be routed to a GMSC to which the home PLMN of called party is attached. The address of a HLR is derived by the GMSC from the MSISDN. The MAP/C protocol is used between the GMSC and the HLR to get the routing information (MSRN). If only the address of a VLR is stored in the HLR, the HLR has to interrogate the VLR to obtain the routing number. The MAP/D protocol is used between the HLR and the VLR to ask for the provision of the MSRN. After the GMSC gets the routing number, the call is routed to the MSC/VLR where the called subscriber resides. The visited MSC will proceed with the call establishment for the requested service.
The signalling procedure for a mobile-originated call is relatively simple. The MSC analyses the called number and the requested service in order to choose the external network towards which the call will be routed. Then, the MSC and mobile users accessing the external network through the MSC will wait and react according to the available signalling information about the progress of the call. It is not necessary for other GSM network entities beyond the MSC/VLR to get involved in the call control. Therefore, only the RIL3-CC protocol is used for the mobile originating call set-up.

To adapt to the different services for the GSM subscribers, the IWF in the MSC is required to establish the lower layer protocols for transmissions between external and GSM networks. The procedures like establishing the connection-through link to the end users and synchronising two end users in the case of data services are performed by the IWF [GSM09.01,03,07,09]. Sometimes, it is also required to establish the upper layer protocols. For instance, the IWF is involved in a negotiation procedure in the case of fax transmission, which concerns various characteristics of the transmission, in particular, the modem speed.

6.4 SUMMARY

Over the last few years the GSM system has been one of the most successful cellular mobile communication systems. The popularity of the GSM system is attributed to its standardized signalling system which complies with the SS7, and its capability of interworking with other telecommunication networks. To adapt to the mobile environment, modifications are necessary which bring the complexity to the GSM signalling system.

We have briefly reviewed the GSM network entities, system architecture and the network signalling protocols. The success of the GSM system provides us with valuable knowledge and experience to develop new generation of mobile
communication systems. S-PCNs, in particular, can, to some extent, reuse the GSM functions and signalling protocols. This reuse will lead to the integration of satellite and GSM systems at the system/network level. Many network functions, such as mobility management, radio resource management and user security management, addressed in GSM system are also critical issues in the integrated satellite and GSM system. This chapter presents the basis for the development of the signalling system in an integrated satellite and GSM system.
Chapter 7

Call Handling Functions in the Integration of Satellite and GSM Systems

We compare the single and split MSC integration scenarios in an integrated satellite and GSM system. Comparisons are focused on the call handling related functions. A number of issues, such as network architecture, mobility management scheme, etc., have been investigated to see how they cope with the specific requirements of satellite systems. We discuss function distributions, modifications to the GSM signalling and protocols to accommodate the satellite specific function in two integration scenarios. The simulation comparisons of network signalling load related to the call handling functions for two integration scenarios have been performed. The study leads to an optimized integration scenario. Finally, two approaches which deal with the dual-mode terminals' tracking and locating in an integrated satellite and GSM system have been proposed and analyzed for completion of the integration study.

7.1 INTRODUCTION

Satellite systems as part of the future UMTS are viewed as a complementary component to terrestrial mobile systems. However, the deployment of UMTS, the third generation of mobile systems, is the long term goal. Integration and interworking between a satellite system and GSM, a second generation cellular mobile system, can be developed and evolved into the fully integrated UMTS.

Satellite systems, offering broad geographical coverage and a fast deployment, appear to be an attractive solution to the problems of insufficient coverage and spectral resource constraints in current cellular mobile systems. In addition, global roaming is allowed in most satellite systems, thus, integration of satellite and GSM systems will enhance the users' accessibility and roaming area coverage. Generally, integration must be achieved in a way that gives the mobile user convenient access to telecommunications services in a user friendly and seamless manner. Additionally, users should have choice of routing for outgoing and incoming calls.

Integration between satellite and terrestrial mobile systems has attracted attention since the beginning of the 90's, as satellite mobile systems have become a global issue ([PRI93,94], [RE93], [MAT95], [HAR96] and [FIN96]). The level at which the integration of satellite and cellular systems will be implemented is an important issue that affects service, network architecture and mobile terminals. The integration levels discussed in the literature are summarised as follows:
• Network integration: Network infrastructure and functions are shared in order to handle transparent call routing when mobiles are roaming between two segments [CAS94]. Transparent call routing means that a mobile has one unique number regardless of the network to which it is attached. In this case, the same type of services based on certain common design parameters must be provided by all the networks. However from a service quality point of view, the long transit delay and the bit rate limitations inherent in satellite access will create problems for some services [MCF94].

• System integration: Satellite systems are treated as a homogeneous part of total coverage. The full service set provided in terrestrial system may not be possible in the satellite segment but at least a basic service set must be retained in common. The infrastructure of satellite and cellular networks can share some common components. However, the radio link control parts will not be common since specific procedures and techniques are used at the satellite air-interface to accommodate the peculiarities of satellite link and control. [CAS94][PRIS95]

• Terminal integration: Common higher layer protocols would aid the compatibility of the mobile terminals for all the systems owing to the likely emergence of competing technologies and systems [MCF95]. In particular, a call forwarding capability to transfer a call between the two networks is considered in the terminal integration scenario. For this case, it is no necessity of direct signalling links between the two networks in this scenario [INM93].

• Radio interface integration: The commonality between radio interface of the cellular and satellite system should be as high as possible [MCF94]. However this commonality requirement may work against the requirement concerning performance optimization in both satellite and terrestrial mobile systems and thus a trade-off is needed.

The most popular and viable integration approach is the system and network integration scenarios both sharing common network entities, functions and using the same higher layer signalling protocols in satellite and cellular mobile systems. Two practical integration scenarios, split MSC and single MSC, have been proposed for the GSM integrating with satellite system [SAID8]. For the North American cellular systems, two level integration scenarios were also defined [DRU95]. One scenario has a satellite hub station (SHS) connected to a mobile telephone switching office (MTSO) and another has an SHS functioning as a MTSO.

In this chapter, we investigate mainly the call handling related functions in an integrated S-PCN based on the two integration scenarios proposed in the SAINT\(^1\) (satellite integrated system) project. Two integration scenarios will be compared with respect to the signalling load and delay in the network, as well as the modifications to the GSM signalling protocols.

\(^1\)SAINT is a collaborative RACE II project about satellite UMTS between University of Surrey and other European partners.
7.2 ISSUES RELATED TO THE INTEGRATION OF S-PCN AND GSM

In order to define the integration level, a one-to-one correspondence between satellite and GSM network entities is illustrated in Figure 7-1 (single MSC) and 7-2 (split MSC). Two integration scenarios were proposed ([SAID8] and [GUN95]). The single MSC integration scenario implemented at the A-interface indicates that an MSC is shared by the cellular and satellite segments. Most satellite specific functions are located in an Earth Station Controller (ESC) to reduce the modifications to the GSM-MSC. The split MSC integration option, which is integrated at the E-interface using separate MSCs, is tailored to accommodate the requirements of different segments. The mobile application part (MAP) protocols are used between the GSM network entities beyond the A-interface. In S-PCNs, we can reuse these protocols due to similar functionality in the two networks. However, the GSM signalling protocols used on the A-interface may need to be modified to cope with the requirements of satellite call handling functions.

![Figure 7-1 The single MSC integration scenario](image)
To reduce the developing cost and the impact to the GSM system, we must minimize the adaptation of the GSM network needed for the integration of the satellite service. The simplest way to evolve towards an GSM and satellite integration is to use the current GSM network architecture and to enhance it by adding new functions to support satellite services.

Compared to cellular mobile systems, satellite systems have the following features: high propagation loss, long propagation delay, larger coverage areas and a dynamic property of the satellite constellations (non-GEO systems). These features have impacts not only at satellite air-interface but also on the Radio Resource management (RR), Mobility Management (MM) and Connection Management (CM) functions in the network. In the remainder of this section, we will discuss the satellite specific functionality. The issues include the satellite network configuration, the mobility management approach, and the satellite diversity method.

7.2.1 Power Transmission Constraint in S-PCN

The high path loss, in S-PCN, determines that the transmission in satellite systems is power constrained. Thus almost all of the proposed S-PCNs adopt a spot beam approach which increases the complication in mobility and resource management. Even with the use of spot beams, there is little margin available to counter-act the satellite channel fading effects. A satellite diversity approach has been proposed in some S-PCNs, e.g., ICO and Globalstar systems, for improving the transmission performance in the fading channel.
To coordinate the resource allocation from two visible satellites, we require the diversity assignment (DA) functions and corresponding signalling protocols. In the GSM system, the channel allocation protocol is used in the RR function layer (Figure 6-6(a)) and the channel management is mainly performed by the BSC. The MSC will intervene in the resource management function and play a leading role in the inter-BSC or inter-MSC call handover procedure. Basically both the DA and the call handover operation require a second channel allocation. Because of this similarity, the DA protocols in the S-PCNs can use the GSM call handover protocols, either inter-BSC or inter-MSC call handover protocol, depending on the network architecture of the S-PCN. The inclusion of a DA function in the S-PCN may impose modifications to the GSM functionality depending on which level the integration is implemented and also on the network architecture of S-PCN.

7.2.2 Satellite Dynamics

Another complication of the S-PCN, for non-GEO satellite systems is the dynamic movement of the satellite. The consequence is two-fold in the mobility management approach and the network architecture of the S-PCNs.

Firstly, the mobility management approach used in the S-PCN must be able to cope with the satellite dynamics. Two mobility management schemes have been considered herein. One is the terminal position based mobility management (TPB) scheme [SAID8] which relies on the positioning capability of the mobiles. In this scheme, the LA is defined by a set of parameters (latitude, longitude, dthr). Location updating is triggered by the mobile whenever it travels a distance exceeding dthr (traveling distance threshold) from the last reported location. A second scheme is the GSM-type mobility management scheme, known as the GCA approach, that defines a fixed geographic area associated with a Satellite-MSC (SMSC). In this scheme, due to the dynamics of satellite coverage, a SMSC must keep dynamic connections with all of the satellites/SBs within its LA. The need for such dynamic connections definitely brings with it implementation difficulties for the integrated MSC. For this reason, the single MSC integration scenario will use the TPB rather than the GCA scheme.

A further consequence of satellite dynamics is related to the network architecture in the S-PCN. Because of the satellite dynamics, two approaches can be used to control the satellite resource: (1) Centralized, (2) Distributed. The centralized control approach requires only one control center for each satellite resource. A number of ESs are appropriately positioned along the sub-satellite track on the earth surface for the defined satellite. The RR connections are required between the control center and the ESs. For most of the time the satellite resource control will not be local. The consequences of remote control are a longer signalling delay and a larger signalling load on the long distance trunk links. The advantage of the centralized control approach is that the satellite resource control remains in the same location area. Therefore, the signalling related to the handover of resource control functions owing to satellite mobility can be avoided. In a distributed architecture, the
resource control function is handed-over amongst a number of ESs that are also positioned along the sub-satellite track. A ES holding the control token is named ES Controller (ESC). In this system, local control of the satellite resource can be guaranteed. Nevertheless, a function is required to deal with the handover of resource control between successive ESCs and the routing management of those unfinished calls when the satellite handover occurs. The best position for this function is in the satellite MSC (S-MSC). For both of these approaches, modifications to the GSM-MSC are necessary if the integration is to be implemented at the A-interface (single-MSC).

7.3 INTEGRATION SCENARIOS

The main subject in this chapter is the call handling function in the integrated satellite and GSM network. As stated in Chapter 6, the call handling function belongs to the CM function plane which is a complex process using the services of the RR and MM plane. Sometimes, an interworking function (IWF) is called by CM for interfacing with various external networks (PSTN, ISDN, etc.). In this section, we will define the distribution of call handling related function entities (FE) in an integrated network, and identify necessary adaptations to the GSM functionality and signalling protocols, taking the satellite specific functionality into account.

7.3.1 Single MSC Integration Scenario

In this scenario, a single MSC is shared between a GSM PLMN and a S-PCN. In order to minimize the modifications to the GSM network, it is desirable to locate the satellite specific functions in the satellite network entities, such as the ESC. Because an integrated MSC has to interface an ESC, it has to perform some satellite specific functions, such as the satellite handover between ESCs and the channel management for diversity satellites. The single MSC integration scenario will be investigated later based on the following assumptions:

- The satellite specific functions shall be located in the ESCs in order to minimize the modification to the GSM system. However, some modifications to the GSM are inevitable in order to accommodate the satellite specific functionality.
- An integrated MSC is associated with one ESC;
- A terminal position based mobility management scheme (TPB) is adopted.

7.3.1.1 Distributed Network Architecture

The distributed network architecture, as discussed in section 7.2, is adopted for managing the satellite resource. In this architecture, the satellite resource (SR) management function is performed by an ESC within a satellite coverage area. Because of the satellite dynamics, the SR statistics must be down-loaded from the original ESC1 to the new ESC2, called ESC’s handover (Figure 7-2).
Due to the large coverage of satellites, it is most likely that two ESCs are positioned in different GSM-MSC areas or possibly in different PLMNs (Figure 7-2). It is assumed that each ESC is uniquely associated with one MSC in order to minimize the terrestrial distance between them. It can also reduce the complexity of the integrated MSC brought by the satellite dynamics since the satellite dynamic coverage is managed by the ESC.

When an ESC’s hand-over occurs, a routing function is required in the integrated MSC to perform routing management for any unfinished calls using the MAP/E protocol. Additionally, routing “tromboning” may occur as demonstrated in Figure 7-3. In this figure two PLMNs are shown - a home PLMN and a roaming PLMN1. If a mobile station (MS) registers with MSC1/S-VLR1 which is located in PLMN1, a mobile terminated call will be routed from GMSC to MSC1 even when the calling subscriber is in the Home PLMN. According to the GSM specification, an anchor MSC (MSC1) does not change during the life time of a call - a billing requirement. When the concerned satellite is handed over from ESC1 to ESC2, the calls initially landed at MSC1 have to be routed from it to ESC2 through MSC2 which is in the home PLMN.
7.3.1.2 Mobility Management Schemes

As discussed in section 7.2.2, the GCA mobility approach will bring the implementation burden to an integrated MSC. Therefore, a terminal position based mobility management (TPB) scheme is considered here. A prerequisite of this approach is that an MS has the ability to determine its position. A set of mobile location parameters \( (\text{latitude}, \text{longitude}, d_{thr}) \), which is provided by the MS during the location updating, is stored in the S-VLR.

7.3.1.2.1 Paging Function

Paging function is part of call set-up function. It determines the paging satellites and spot beams’ (SB) ID using the ephemeris of a satellite constellation and the mobile location parameters as inputs to a paging algorithm. Because of the visibility’s from multiple satellites, the paging signalling is most likely to be issued from more than one satellite. Hence, the co-operation between paging functions in different ESCs (or different integrated MSCs) is required.

The paging function can be located either in the integrated MSC, just as in the GSM system, or in the ESC which is a satellite specific network entity. In the former case, satellite specific paging function is part of the integrated MSC. The paging signalling is exchanged (RR layer) at the E interface between two integrated MSCs. A MAP/E PAGING message that is not supported in the GSM system needs to be defined for the integrated satellite and GSM system (Figure 7-3).

In the latter case, a MSC provides the paging needed parameters to the associated ESC (Figure 7-3). The paging function in the ESC determines the paging satellites and SBs. To deal with the cooperation of paging functions in different ESCs, a direct signalling channel is required between them. The ESC that issues the paging command to other ESCs is called the master ESC, whereas the ESCs that receive paging signalling are slave ESCs. The slave ESCs simply schedule the paging command on the paging channel and transmit it to the associated satellites. In the GSM system, there is no signalling link between BSCs. To exchange the paging signalling (Figure 7-3) between ESCs, a SCCP signalling link must be established between ESCs. As soon as a dedicated channel is allocated to the concerned MS, the paging transaction is terminated and the SCCP connection between ESCs is released.

Comparing the above two cases, the latter, i.e. the paging functions located in the ESCs, is chosen since it requires less modification to the GSM-MSC.
7.3.1.2.2 Mobile Location Problem

In the single MSC integration scenario, the problem that a mobile may not be directly connected with its register arises due to the satellite movement. Because of the unique relationship between an integrated MSC and an ESC, the S-VLR (collocated with an MSC) must associate itself with an ESC coverage area. With the movement of a satellite, the coverage of an ESC is continuously changing. Therefore it is possible that an MS and its register (S-VLR) via the associated ESC view different satellites at the moment of call set-up.

As shown in Figure 7-3, it is assumed that an MS registers with S-VLR1. When a satellite moves from P1 to P2, it is controlled by ESC2 instead of ESC1. The MS may still be monitoring the same satellite at the moment a call set-up request is triggered because it only updates its location when it has traveled a distance in excess of the threshold. In this case, the signalling procedures for mobile terminated and originated call set-up are described as follows.

A mobile terminated call is landed at the MSC1/S-VLR1 which is the roaming peer for the called MS. The paging command is broadcast by the ESC1 to the mobile via diversity satellites. However, a paging response is received at ESC2, and the MSC1 (anchor MSC) is requested (via ESC2→ESC1→MSC1 signalling link) to redirect the call to the MSC2 (relay MSC). It can be seen that an inefficient routing results in this case simply because an MS is not connected with its register.

As to a mobile originated call, the ESC2 receives a channel request and the register of the MS is connected to the MSC1 (ESC1). The location updating with S-VLR2 must be performed prior to other call set-up signalling being exchanged. Signalling transactions between S-VLR2 and S-VLR1 are required to perform the authentication procedure and fetch the mobile's subscription profile. This results an extended call set-up delay.
7.3.1.3 Diversity Channel Allocation Approach

In a non-GEO satellite environment, overlapping usually exists at the boundary of the coverage area. Some satellite constellations are optimized for maximizing the overlapping areas as satellite diversity can provide a smooth handover in addition to an improved channel performance counteracting the fading effect. According to [BIS96], 99% diversity satellite availability can be guaranteed in the ICO10 and Globalstar constellations, on condition that the distances between user and ES are less than 1200km and 500km respectively.

As claimed in section 7.2, the procedures for allocating channels from two satellites can be similar to the GSM inter-MSC handover procedure. Since the call handover function is governed by the MSC in the GSM system, it is more convenient for an integrated MSC to be in charge of the diversity channel management. In this case, modifications to the functionality of the integrated MSC and related signalling protocols would be inevitable in order to perform the diversity channel management. A new function called diversity channel assignment (DA) is required in it.

![Image of signalling flow](image)

**Figure 7-5 Signalling flow of diversity channel allocation (single MSC)**

The signalling procedure for diversity channel allocation, as shown in Figure 7-4, is described. Although the signalling protocols for diversity channel allocation are similar to the GSM handover signalling protocol, the consequent signalling transactions at the satellite air-interface are different from those for the call handover function. They are considered as different applications. A diversity channel allocation related functions are required in relevant network entities: MS, ESCs and integrated MSCs. In diversity channel allocation related signalling, an information element and a message type must be defined in order to distinguish it from the handover signalling.
7.3.2 **Split MSC Integration Scenario**

In this integration scenario, the satellite system has its own Satellite Mobile Service Center (SMSC) which is separated from the GSM-MSC, and an associated S-VLR. Obviously, the split MSC provides the feasibility for optimizing the satellite network architecture to accommodate the special requirements of the satellite systems. The optimization is realized through:

- Separating the switching function from the SMSC;
- Defining a fixed geographic area as an SMSC’s location area.

![Figure 7-6 The distributed network architecture (split MSC)](image)

### 7.3.2.1 Network Architecture

To attain the call routing optimization, we separate the basic call control (connection control) function from the service control function. The former is performed by the local exchanges (LE) in the backbone network. The latter included in the SMSC support call control and mobility management functions, such as call handover, location updating and mobile location. This separation conforms with the concept of the Intelligent Network that is also the evolution direction to the third generation of personal communication systems
Chapter 7 Call Handling Functions in Integration of Satellite and GSM System

([BLA92] and [BRO93]). The split MSC integration scenario makes this separation feasible in the satellite network.

In order to minimize the effect of satellite dynamics, a fixed LA (Figure 7-6) is allocated to an SMSC. To maintain the connections with all the MSs within the LA, a SMSC must have signalling connections via a number of ESCs to the associated satellites which are visible from the SMSC' LA. The split MSC integration approach makes it viable to have an independent SMSC designed to maintain dynamic connections with a number of ESCs. Another advantage is the fact that the SMSC remains the call control point for mobiles confined within its LA.

The detailed call re-routing procedure due to satellite handover between two ESCs is described as following (Figure 7-6). Owing to the satellite movement, the concerned satellite is handed over from ESC1 to ESC2. Even though the satellite is still visible from the LA1 of the SMSC1 at this position (P2), the SR management function has already been passed to the ESC2. As long as an MS remains in the LA1, the call handover between two ESCs is under the control of the SMSC1. For simplicity, it is assumed that the same satellite channel is used before and after handover. The MS only needs to adjust the timing advance under the network control (ESC2). The call routing is adjusted accordingly in the network segment. The terrestrial channels from a local exchange (LE2) which is nearest to the ESC2 are assigned from the SMSC1 to the ESC2 via the A-interface. The unfinished calls are routed to LE2 by removing the LE1. The inter-MSC handover foreseen in the single MSC integration scenario could be replaced by the inter-ESC handover that is controlled by the SMSC1. In a distributed satellite network architecture, the split MSC integration scenario can avoid the involvement of an extra network entity (SMSC2) in the signalling related to the satellite handover between the ESCs, provided the mobiles remain in the same LA. The call routing is also optimized by separating the connection and call control functions.

7.3.2.2 Mobility Management Scheme

To tackle the mobile location problem envisaged in the single MSC integration scenario, a GSM type mobility management scheme, also known as guaranteed coverage area (GCA) approach, is considered in the split MSC integration scenario.

With GCA approach, a fixed geographic LA (Figure 7-6) is defined for an SMSC. The MSs are required to make a location updating if the detected LAI is different from the original. The independent SMSC can be designed to manage, via associated ESCs, the dynamic connections with the satellites and their SBs which illuminate the LA. The LAI is broadcast by the associated SMSC through all the SBs illuminating the LA. Therefore, the satellite mobility is only managed by the network instead by the mobiles.

The advantages are two fold. Firstly, an MS is always directly connected to its SMCS/S-VLR regardless of the satellite movement. Secondly, an SMSC remains a call control point,
as pointed out in the last section, which makes extra call routing signalling between the two SMSCs unnecessary.

For the GCA approach, the location updating signalling load at the satellite air-interface depends on the LA size. If the LA is large, the paging signalling load will also be very high. For example, the number of paging SBs is 20 and 42 for ICO10 (163SBs), LEO66 (61SBs) respectively in an area (50° of latitude) with radius of 1000km. To improve the paging performance, the size of the LA has to be reduced. The optimum LA size for LEO66 and ICO10 has been found in Chapter 4 by minimizing both the location updating and paging signalling.

The best location for a satellite specific paging FE is in the SMSCs. This is because a) a split SMSC is connected to all the ESCs which control the satellites that illuminate the SMSC's LA, and b) the paging signalling is broadcast through the diversity satellites' SBs. In this case the BSSMAP-paging messages sent through the A-interface to the paging ESCs are the same as those in the GSM system.

### 7.3.2.3 Diversity Channel Assignment Approach

Similar to the integrated MSC in the single MSC integration scenario, a DA function is required in a split SMSC. It is assumed that ESC1 and ESC2 control the primary and secondary satellites respectively. Because SMSC1 has signalling links to both ESC1 and ESC2, the signalling connections to the ESC2 will not involve the relay SMSC2. The call routing to the diversity satellites and associated ESCs can be optimized by selecting the shortest terrestrial links. Compared to the single MSC integration scenario, the signalling procedures for the diversity channel assignment and call routing are simplified.

![Figure 7-7 Signalling flow of diversity channel allocation (split MSC)](image)

The signalling procedure for conducting diversity channel allocation is presented in Figure 7-7. As an anchor point, SMSC1 determines the candidate satellites and SBs based on the
diversity information received from the MS concerned. Due to the direct signalling connection between SMSC1 and ESCs, the MAP/E and MAP/B signalling has been removed. The SMSC1 is the only control point for the connections to the diversity satellites.

7.3.3 Comparing of Two Integration Scenarios

So far we have discussed the distribution of call set-up related functions, such as the paging, diversity assignment and satellite resource control functions. The modifications to GSM functions and signalling protocols for provision of the satellite services in two integration scenarios have also been investigated. The purpose of this study is to minimize the changes in the GSM system needed for the integration of the satellite services. In this section, we will compare the two integration scenarios from two viewpoints: (i) the modifications to the GSM system required, (ii) the signalling load in the network.

7.3.3.1 Summary of Two Integration Scenarios

The comparisons of two integration scenarios are summarized and presented in Table 7-1. In contrast to the single MSC integration scenario, the split MSC integration scenario obviously needs fewer modifications to the GSM network entities and less signalling load at the B/E-interfaces. Since the split MSC integration scenario implements the integration on the E-interface, the communication management function in the integrated components is relatively independent for two segments. This allows the systems to be individually optimized. In addition, the locations of ESCs, and the links between an SMSC and its associated ESCs, can be optimized to accommodate the requirements of a satellite constellation.

The single MSC integration scenario requires close cooperation between the satellite and GSM system operators. Although the cooperation is difficult in practice, it is very attractive because it can reduce the number of network entities and allows more flexible and optimized radio resource allocation strategies. That would lead to system cost reduction.

The required modifications to the GSM functions in two integration scenarios are also investigated. Table 7-2 gives a list of signalling messages used in two integration scenarios, which are either the modified GSM messages or those that are not defined in the GSM system. For instance, all DA related signalling messages are not used in the GSM system. However, they are modified versions of GSM handover messages owing to the similarity between the two kinds of signalling. Diversity assignment and handover signalling are distinguished by message type codes and are used for different functions. As far as the signalling messages are concerned, the split MSC integration scenario requires less modification to GSM messages than the single MSC integration scenario.
## Call Handling Functions in Integration of Satellite and GSM System

### Single MSC integration scenario

- **Call handover between ESs due to satellite dynamics**
  - The routing signalling uses the GSM inter-MSC handover procedure
  - Routing "tromboning"

- **Mobility management approach**
  - Terminal position based mobility (TPB)
  - Guaranteed coverage area (GCA)
  - 1. A Satellite specific paging FE locates in a ESCs:
    - BSSMAP-PAGING PARAMETER message (MSC→master ESC);
    - BSSMAP-PAGING message (master ESC→slave ESCs);
  - 2. An MS may not directly connect with its S-VLR:
    - A mobile terminated call is routed via a relay MSC;
    - Signalling transactions between S-VLRs are required.

- **Diversity assignment** (DA function locates in the integrated MSC or SMSC)
  - GSM inter-MSC call handover procedure

### Split MSC integration scenario

- **Call handover between ESs due to satellite dynamics**
  - The routing signalling uses the GSM inter-BSC handover procedure

- **Mobility management approach**
  - Terminal position based mobility (TPB)
  - Guaranteed coverage area (GCA)
  - 1. A Satellite specific paging FE is in the SMSC:
    - BSSMAP-PAGING message (SMSC→ESCs) is same as that in GSM system;
  - 2. A mobile is always directly connected with its location register.

- **Diversity assignment** (DA function locates in the integrated MSC or SMSC)
  - GSM inter-BSC call handover procedure.

---

*Table 7-1 The summary of comparisons between two integration scenarios*
### Chapter 7 Call Handling Functions in Integration of Satellite and GSM System

<table>
<thead>
<tr>
<th>GSM</th>
<th>Direction</th>
<th>Single MSC</th>
<th>Split MSC</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BSSMAP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paging</td>
<td>MSC→BSC</td>
<td><strong>Paging parameter</strong></td>
<td>Paging</td>
<td>MSC→ESC</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>Paging</td>
<td>N/A</td>
<td>master ESC→slave ESC</td>
</tr>
<tr>
<td>handover(HO)</td>
<td>relay MSC→BSC</td>
<td><strong>Diversity assignment (DA) request</strong></td>
<td>DA request</td>
<td>MSC→ESC</td>
</tr>
<tr>
<td>request</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HO request ack.</td>
<td>BSC→relay MSC</td>
<td><strong>DA request ack.</strong></td>
<td>DA req. ack.</td>
<td>ESC→MSC</td>
</tr>
<tr>
<td>Assignment request</td>
<td>anchor MSC→BSC</td>
<td><strong>First assignment required</strong></td>
<td>First assignment required</td>
<td>MSC→ESC</td>
</tr>
<tr>
<td>Assignment complete</td>
<td>BSC→anchor MSC</td>
<td><strong>First assignment complete</strong></td>
<td>First assignment complete</td>
<td>ESC→MSC</td>
</tr>
<tr>
<td>HO complete</td>
<td>BSC→relay MSC</td>
<td>DA complete</td>
<td>DA complete</td>
<td>ESC→MSC</td>
</tr>
<tr>
<td>HO detect</td>
<td>BSC→relay MSC</td>
<td>DA detect</td>
<td>DA detect</td>
<td>ESC→MSC</td>
</tr>
</tbody>
</table>

### DTAP

<table>
<thead>
<tr>
<th>HO command</th>
<th>anchor MSC→BSC</th>
<th>DA command</th>
<th>DA command</th>
<th>MSC→ESC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### MAP/E

<table>
<thead>
<tr>
<th>N/A</th>
<th>N/A</th>
<th>Paging(1)</th>
<th>N/A</th>
<th>anchor MSC→relay MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perform HO</td>
<td>anchor MSC→relay MSC</td>
<td>Perform DA</td>
<td>N/A</td>
<td>anchor MSC→relay MSC</td>
</tr>
<tr>
<td>Perform HO ack.</td>
<td>relay MSC→anchor MSC</td>
<td>Perform DA ack.</td>
<td>N/A</td>
<td>relay MSC→anchor MSC</td>
</tr>
<tr>
<td>Process access signal request</td>
<td>relay MSC→anchor MSC</td>
<td>Process access signal request</td>
<td>N/A</td>
<td>relay MSC→anchor MSC</td>
</tr>
<tr>
<td>Send end signal request/response</td>
<td>anchor MSC→relay MSC</td>
<td>Send end signal request/response</td>
<td>N/A</td>
<td>anchor MSC→relay MSC</td>
</tr>
</tbody>
</table>

### RIL3

<table>
<thead>
<tr>
<th>HO command</th>
<th>BSC→MS</th>
<th>RR-DA command</th>
<th>RR-DA command</th>
<th>ESC→MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HO complete</td>
<td>MS→BSC</td>
<td>RR-DA complete</td>
<td>RR-DA complete</td>
<td>MS→ESC</td>
</tr>
<tr>
<td>MM-location updating req.</td>
<td>MS→BSC</td>
<td><strong>MM-location updating request (2)</strong></td>
<td>MM-location updating req.</td>
<td>MS→ESC</td>
</tr>
<tr>
<td>MM-location updating accept</td>
<td>BSC→MS</td>
<td><strong>MM-location updating accept</strong></td>
<td>MM-location updating accept</td>
<td>ESC→MS</td>
</tr>
</tbody>
</table>

**Note 1.** Paging FE locates in an integrated MSC.

**Note 2.** The location area identity included in the location updating request and location updating accept messages is replace by the mobile position parameters (latitude, longitude, d_{air}).

*Table 7-2 Summary of signalling messages in GSM system and two integration scenarios*
7.3.3.2 Call Set-up Related Signalling Load

The comparison between two integration scenarios has been conducted via simulation. For simplicity, the simulation does not contain all of the signalling procedures. Only the call set-up related signalling procedures specific to the S-PCN, which have been discussed in the previous sections, are compared between two integration scenarios. The results, shown later, merely contain the components of the call set-up related signalling procedures. They include the diversity channel allocation, the call re-routing, paging and authentication signalling transactions. Therefore, the throughput values cannot be used to configure the capacity of signalling links absolutely but are nevertheless good indication of trends.

**Figure 7-8 Simulation approach for network signalling load in integrated system**

*Figure 7-7* illustrates the simulation diagram of the signalling load for the two integration scenarios. For the single integration scenario, six network entities are included. Due to the satellite handover between ESCs, the network call routing management function controls the signalling exchanges between MSCs and ESCs (thin solid line). To perform the channel allocation from diversity satellites, the signalling is exchanged between MSCs, ESCs and SVLR2 (thick solid line). The authentication procedure between SVLRs (dotted line) is initiated by the satellite movement. Since the satellite handover between ESCs is transparent to the mobiles, a mobile may still register with SVLR1 but accesses the ESC2. In this case, prior to acceptance of the call request by ESC2, SVLR2 needs to get the user's profile from the SVLR1. The paging signalling is broadcast via all of the visible satellites. Because the paging function is located in ESC1, the paging satellites and SBs are...
selected based on the paging related information provided by the MSC/S-VLR. The paging command is then sent to the other ESCs from the master ESC1.

The split MSC integration scenario includes only four network entities, i.e., S-MSC, S-VLR1 ESC1 and ESC2. Due to the signalling connection between an SMSC and all of the ESCs which have instantaneous coverage in the SMSC's LA, the relay SMSC and S-VLR2 are removed from those call set-up related procedures. The satellite dynamics has impact only on the signalling exchanges between the SMSC and the connected ESCs.

We have made the following assumptions in the simulation:

- The call arrival rate is 2 call/sec. 25% of calls use diversity satellite approach. Hence, the request rate for diversity channel allocation is 0.5 call/sec.
- Call re-routing rate is 0.5 call/sec when satellite handover happens.
- 70% of calls are mobile originated and 10% of roaming users are not directly connected with their S-VLRs due to satellite movement. When a mobile originated call set-up request is received, the S-VLR2 that is currently serving the call has to perform an authentication transaction with S-VLR1 from which the temporary roaming number is allocated. The authentication request rate is 0.14 req./sec.
- 30% of calls are mobile terminated. The derived paging rate is 0.6 page/sec.
- The capacity of a signalling link is 64kb/s.

The modified BSSMAP and MAP messages in S-PCNs, which are related to the call handling function, are listed in Tables 7-3 to 7-5. The details containing the message contents and modifications are provided in Appendix B. 25-octet signalling header is added to the MAP messages.

<table>
<thead>
<tr>
<th>Single MSC</th>
<th>Octet</th>
<th>Split MSC</th>
<th>Octet</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTAP DA command</td>
<td>98</td>
<td>DTAP DA command</td>
<td>98</td>
</tr>
<tr>
<td>BSSMAP 1st assignment required</td>
<td>51</td>
<td>BSSMAP 1st assignment required</td>
<td>51</td>
</tr>
<tr>
<td>BSSMAP 1st assignment complete</td>
<td>43</td>
<td>BSSMAP 1st assignment complete</td>
<td>43</td>
</tr>
<tr>
<td>BSSMAP DA request</td>
<td>90</td>
<td>BSSMAP DA request</td>
<td>90</td>
</tr>
<tr>
<td>BSSMAP DA request ack.</td>
<td>91</td>
<td>BSSMAP DA request ack.</td>
<td>91</td>
</tr>
<tr>
<td>BSSMAP DA detect</td>
<td>27</td>
<td>BSSMAP DA detect</td>
<td>27</td>
</tr>
<tr>
<td>BSSMAP DA complete</td>
<td>29</td>
<td>BSSMAP DA complete</td>
<td>29</td>
</tr>
<tr>
<td>MAP/E perform DA request</td>
<td>75</td>
<td>MAP/E perform DA request</td>
<td>75</td>
</tr>
<tr>
<td>MAP/E perform DA response</td>
<td>239</td>
<td>MAP/E perform DA response</td>
<td>239</td>
</tr>
<tr>
<td>MAP/E process access signalling request</td>
<td>230</td>
<td>MAP/E process access signalling request</td>
<td>230</td>
</tr>
<tr>
<td>MAP/E send end signal request</td>
<td>29</td>
<td>MAP/E send end signal request</td>
<td>29</td>
</tr>
<tr>
<td>MAP/B DA number request</td>
<td>23</td>
<td>MAP/B DA number request</td>
<td>23</td>
</tr>
<tr>
<td>MAP/B send DA report</td>
<td>39</td>
<td>MAP/B send DA report</td>
<td>39</td>
</tr>
<tr>
<td>MAP/B send DA report response</td>
<td>32</td>
<td>MAP/B send DA report response</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 7-3 Messages used for diversity channel allocation procedure
### Table 7-4 Messages used in call re-routing procedure

<table>
<thead>
<tr>
<th>Single MSC</th>
<th>Octet</th>
<th>Split MSC</th>
<th>Octet</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSSMAP handover required</td>
<td>91</td>
<td>BSSMAP handover required</td>
<td>91</td>
</tr>
<tr>
<td>BSSMAP handover request</td>
<td>90</td>
<td>BSSMAP handover request</td>
<td>90</td>
</tr>
<tr>
<td>BSSMAP handover request ack</td>
<td>93</td>
<td>BSSMAP handover request ack</td>
<td>93</td>
</tr>
<tr>
<td>DTAP handover command</td>
<td>98</td>
<td>DTAP handover command</td>
<td>98</td>
</tr>
<tr>
<td>BSSMAP handover detect</td>
<td>27</td>
<td>BSSMAP handover detect</td>
<td>27</td>
</tr>
<tr>
<td>BSSMAP handover complete</td>
<td>29</td>
<td>BSSMAP handover complete</td>
<td>29</td>
</tr>
<tr>
<td>BSSMAP clear command</td>
<td>35</td>
<td>BSSMAP clear command</td>
<td>35</td>
</tr>
<tr>
<td>BSSMAP clear complete</td>
<td>27</td>
<td>BSSMAP clear complete</td>
<td>27</td>
</tr>
<tr>
<td>MAP/E perform handover request</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/E perform handover response</td>
<td>239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/E process access signalling request</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/E send end signal request</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/E send end signal response</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/B handover number request</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/B send handover report</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP/B handover report response</td>
<td>32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 7-5 Mobility related call set-up messages

<table>
<thead>
<tr>
<th></th>
<th>Split MSC</th>
<th>Single MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average message size</td>
<td>61</td>
<td>79</td>
</tr>
<tr>
<td>Mean throughput/variance</td>
<td>5.0/0.9</td>
<td>11.7/12.7</td>
</tr>
<tr>
<td>Mean delay for call re-routing (ms)</td>
<td>57.9</td>
<td>103.5</td>
</tr>
<tr>
<td>Mean delay for diversity channel allocation (ms)</td>
<td>38.5</td>
<td>94</td>
</tr>
<tr>
<td>Paging procedure (ms)</td>
<td>20.6</td>
<td>26.5</td>
</tr>
</tbody>
</table>

### Table 7-6 Main simulation results

The main simulation results are presented in Table 7-6. The average message length in both the split and single MSC integration scenarios is about 60 and 80 octets. However, a much higher signalling load is observed in the single MSC integration scenario. This is due to the fact that the MAP signalling which requires more signalling overhead appears in the single MSC integration scenario. Additionally, more network entities are involved in the call setup related functions for the single MSC integration scenario. For the same reason, the signalling delay for the call re-routing and diversity channel allocation procedures is much longer in the single MSC integration scenario than that in the split MSC.
Table 7-7 Singalling load on network links in two integration scenarios

We summarize the mean length of messages and the throughput on the network links in Table 7-7. It can be observed that the traffic load on some signalling links is not balanced for the uplink and downlink. For instance, the differences are obvious on the signalling links between anchor and relay MSC in the single MSC integration scenario. The discrepancy is caused mainly by the messages MAP/E-PROCESS ACCESS SIGNALLING REQUEST and MAP/E-PERFORM HANDOVER RESPONSE, etc.

Figure 7-9 The distribution of message length in two integration scenarios
The distributions of message length in the two integration scenarios are presented in Figure 7-9. The actual message size ranges from 27 to 264 octets in the single MSC integration scenario even though the mean value is about 80 octets. The main reason for the high signalling load in the single MSC integration scenario is the higher number of long messages (250 octets - 10% of total load).

7.4 DUAL-MODE MS TRACKING AND LOCATION

In the integration of the satellite/GSM system (using of single or split MSC integration scenario), tracking and location of a dual-mode MS is an important function that needs to be defined, no matter which integration scenario is used. To avoid parallel signalling connections to both GSM-HLR and S-HLR, we assume that the dual-mode MSs are only registered in the S-HLR. Registering in an S-HLR does not necessarily imply that the satellite tariffs are applied to this group of users. Even though the location address is stored in an S-HLR, a dual-mode MS roaming inside the terrestrial environment will be charged according to the terrestrial tariffs.

Integration of satellite and GSM systems provides for roaming inside both satellite and GSM coverage. The signalling links from S-HLR to both S-VLRs and GSM-VLRs are required to guarantee the access in both segments. Here, we consider two tracking and location approaches, (i) a conventional approach and (ii) a segment tracking entity approach.

7.4.1 Conventional Approach

The conventional approach uses the mobile tracking and location procedure used in the GSM system. Every time a dual-mode MS changes its registered environment, either from the satellite to the terrestrial or vice versa, the location updating message is sent to an S-HLR in which the environment information will be stored. Initially, a dual-mode MS sends an RIL3-MM LOCATION UPDATING REQUEST message to a S-VLR when it switches from the GSM system to a satellite system. Before performing a registration in a satellite system, the S-VLR may have to carry out several checks with the MS as the subscriber data can be different for a dual-mode terminal in different environments. The checking includes:

• the authentication check that verifies MS' identity,
• the environment capability check that determines whether the satellite system is capable of supporting required services,
• the user profile check that confirms the inclusion of the required services in the user profile, and
• the terminal capability check that confirms the capability for the terminal to support the required service.
The check procedures may need to interrogate the S-HLR in case the subscriber data is not stored in the S-VLR. As shown in Figure 7-10, the mobile location record in the S-HLR is updated by the S-VLR. In the meantime, the S-HLR requests the original registered GSM-VLR to cancel the mobile's location record and sends a copy of the user's service profile to the S-VLR.

The signalling procedure for locating a dual-mode MS is illustrated in Figure 7-11. When a GMSC receives a mobile terminated call, it uses the MSISDN number to extract the routing information from an S-HLR. Looking through the data stored, the S-HLR determines where the called MS is registered, e.g. in an S-VLR. Interrogation between S-HLR and S-VLR is invoked for request of the roaming number (MSRN) of the called MS. The MSRN is a temporary number allocated to an MS by an S-VLR as long as the MS stays in the associated LA. Using the MSRN, the GMSC will route the call to the visited S-MSC/S-VLR.

With the conventional approach, no modification is required to an integrated MSC. The currently used GSM location updating and mobile locating signalling procedures can be applied without change. But full interworking between the satellite database and GSM database is required.

In addition, if the environment changing rate is high, the signalling exchanges between VLR (S-VLR/GSM-VLR) and S-HLR will also be very high. Because of the global coverage of the S-PCNs, it is most likely that long distance links are used between an S-HLR and
Chapter 7 Call Handling Functions in Integration of Satellite and GSM System

VLRs. Therefore, the mobility management of dual-mode MSs will impose considerable signalling load on the international links.

### 7.4.2 STE Approach

In order to reduce the signalling load between GSM-VLR/S-VLR and S-HLR, we define a segment tracking entity (STE) in the integrated MSC or SMSC. The signalling procedures for a dual-mode MS tracking and location will be described in this section.

#### 7.4.2.1 MS Location Updating

When a dual-mode MS switches from a terrestrial to a satellite environment, location updating signalling is sent to the STE. If the MS successfully registers with a satellite system, its identity and the register’s (S-VLR) address are stored in the STE. The location of a dual-mode MS stored in the S-HLR is the SS7 address of STE rather than the address of an S-VLR or a GSM-VLR. The size of a STE is related to the coverage area of an integrated MSC or SMSC. If an MS remains in the location area of an integrated MSC or SMSC, i.e., the authority of a STE, there is no location updating message sent from S-VLR or GSM-VLR to S-HLR. In this case, the environmental changing signalling is localized. S-HLR is updated only if STE changing is detected. De-registration in the original GSM-VLR or S-VLR is performed by the STE.

#### 7.4.2.2 MS Location

When there is a mobile terminating call request sent to S-HLR, a number of signalling exchanges are performed before the routing design is done.

The mobile location signalling procedure used in the GSM system has been described in a previous section (conventional approach). Using the STE approach, we will see a different signalling procedure as shown in Figure 7-12. The MAP/D’ and MAP/D” protocols are used between the S-HLR and the STE, and between the STE and the VLR respectively. The S-HLR views the STE and VLR as one unit. When the S-HLR receives a routing request message from a GMSC, it requests the mobile station roaming number (MSRN) from the STE. However, the STE does not allocate the MSRN; it determines the VLR address of the MS concerned and relays the MSRN request to the VLR. The MSRN is allocated by the VLR and is sent by the VLR to the S-HLR via the STE.
Assuming that a STE is co-located with an S-VLR, the internal signalling link between STE and S-VLR is applied. Since the distances between a STE and the various GSM-VLRs are limited by the coverage of the STE, the local links, rather than the long distance links, are used. If mobiles stay inside the boundary of a STE, the signalling load caused by mobiles' changing their registration between satellite and terrestrial networks would not have much effect on the whole network because of the signalling localization. It can be imagined that the registration changing rate is rather higher in an area around the boundary of the PLMNs. If a STE covers this kind of area, the STE approach is obviously superior to the conventional approach. Even though the network signalling load can be reduced, the extra database interrogation in the STE may increase the call set up time for terrestrial originated calls. This influence is dependent on the processing capability of the STE.

7.5 SUMMARY

In this chapter we have proposed new call set-up related functions and signalling procedures to cope with the features specific to S-PCNs, which are based on the modifications to the GSM functions and signalling protocols. We have also proposed how call handling functions should be distributed in the satellite systems for two promising integration scenarios. In conclusion, the split MSC integration scenario can be optimized by

- Defining a fixed geographic LA associated with a SMSC;
- Using a guarantee coverage area mobility management approach;
- Locating a satellite specific paging FE and a diversity channel allocation FE in the SMSC.

The split MSC integration scenario has the following advantages compared to the single MSC scenario:

- fewer modifications concerning the GSM functions and signalling protocols;
- individual optimization of both satellite and terrestrial segments;
- better throughput and delay performance.
In addition, we have proposed two approaches to deal with tracking and location of dual mode MSs. Detailed signalling sequences have been investigated. Related problems and advantages have been addressed.

Future work, aimed at a fully integrated satellite and GSM system, could focus on:
1. Performance investigation of the two approaches proposed for dual-mode MS tracking and location, by taking the environmental changing rate and the STE size into account;
2. Functions and signalling protocols for call handover between two environments, by taking the resource management optimization and charging issues into consideration;
3. The single number plan for an integrated satellite and GSM system.
Chapter 8

Conclusion and Future Work

The world-wide acceptance of the GSM system is partly due to a standard signalling system (CCITT SS No7) and the other advanced digital transmission techniques. However, GSM as a terrestrial system, it is not financially practicable to provide global coverage to support seamless terminal and personal mobility.

As far as the coverage gaps left by the terrestrial cellular systems are concerned, satellite systems are considered a promising solution to the provision of complete global coverage. By the end of this century, at least four global satellite systems will provide services to handheld and vehicle mounted terminals. All of these systems adopt non-GEO satellite constellations due to their advantages in the link power budget and propagation delay. The link power budget is a critical factor affecting mobile and satellite power consumption whilst the propagation delay can have significant effect on service quality. The inclusion of satellite systems, especially the non-GEO satellite constellations, into personal mobile communication systems will increase their complexity. Adopting the GSM signalling architecture and protocols in the S-PCNs can simplify the interworking and integration between satellite and GSM system at both network and terminal sides. However, the satellite link features, the satellite dynamics and the satellite resource control, impose a restriction on the use of the GSM signalling protocols in S-PCNs. Modifications to the GSM signalling protocols are necessary to provide a comparative quality of service in S-PCNs.

The work presented in this thesis has focused on the design of a signalling system for use in S-PCNs, in particular, the call handling related signalling and functions. As a fundamental part of evaluation, the coverage and connectivity properties for two satellite constellations, LEO66 and ICO10, were examined. Issues of satellite channel modelling and its effect on the satellite link to permit the evaluation of the signalling performance have been discussed. A satellite network architecture has been proposed to handle satellite dynamics and to improve satellite resource management. The physical layer of satellite air-interface has been configured with the power limitations for the terminals in mind. The application of the GSM signalling protocols for RACH, PGCH and DCCH have thoroughly been examined. To achieve the desired service quality in S-PCNs, modifications to the GSM signalling protocols have been proposed. Finally, the integration of the satellite and the GSM cellular systems has been discussed.
The study of satellite constellations has shown that users in the ICO10 system have better visibility to the diversity satellites from low latitude areas than those of the LEO66. This compensates for the link power disadvantage of the ICO10.

To provide mobiles with the flexibility to access both the satellite and the GSM systems, the use of a full set of GSM signalling protocols, network architecture and functionality is desired. However, the satellite coverage, the link features, and the dynamics of the non-GEO satellites results in that the design of the S-PCNs requiring

- A distributed satellite network architecture,
- Modifications to GSM physical layer configuration, and,
- Three modified signalling protocols corresponding to the random access (RACH), paging (PGCH) and call set-up signalling transactions (DCCH).

The distributed satellite network architecture has been found to meet the requirements of both satellite dynamics and satellite resource control satisfactorily. The distribution of the resource control is based on the idea of the localisation of the satellite resource management taking into account the satellite movement. As the satellite visibility time is limited, the fixed allocation of a subset of channels to all earth stations (ES) is not realistic. The number of earth station controllers (ESC) which are responsible for both the dedicated and the common resource management needs to be optimised in order to guarantee global coverage with minimum switching times between ESCs in an orbit period. Due to global accessibility and the limited number of ESCs, the call routing nodes, known as ESs are required to shorten the terrestrial tails. The call set-up procedure in S-PCNs is bound to be more complicated than that of the GSM because of the involvement of the second ES. Consequently, the call set-up delay in S-PCNs is longer than that of the GSM.

Our study shows that the physical layer of the GSM’s radio link is not appropriate for S-PCNs due to the limited link power and excessive propagation delay of the latter. Instead, at the physical layer of the S-PCNs’ air-interface, the GSM logical channel concept is adopted, and the GSM’s TDMA channel and frame structure as well as the transmission cycles of various signalling channels are modified and tailored for the S-PCNs.

We have proposed three signalling protocols for the satellite RACH, PGCH and DCCH in order to reduce the delay of the random access packets, the paging packets, and the DCCH signalling transactions, which leads to the reduction in call set-up delay.

1. The priority based fast access scheme (PBFA) for the RACH: This approach, based on the GCT and the time capture effect concept, can provide satisfactory RACH performance in terms of low access delay and low loss rate with fairly low channel allocations. This is in contrast to the Slotted-ALOHA protocol used in the GSM-
Chapter 8 Conclusion and Future work

RACH that has unacceptable loss rate and poor access delay performance when it is adopted in S-PCNs.

2. The satellite diversity based paging scheme for the PGCH: In this approach, the satellite diversity feature is exploited by users receiving the PGCH of the best visible satellite from which the LOS signal is available. Additionally, the two-step paging scheme is particular efficient in reducing the PGCH load if the accuracy of the predicted paging area is high in the first paging step. With satellite diversity paging scheme which is a user assisted two-step paging approach, both the PGCH load and delay can be reduced for the ICO10 system. For the LEO66 satellite constellation, the satellite diversity is not available at the low latitude areas, hence the user assisted paging method is not applicable. However the reduced coverage overlap in the low latitude areas and the short propagation delay for the LEO66 satellite constellation can, to some extent, compensate the deteriorated PGCH performance caused by the shadowing.

3. The modified Go-Back-N (M-GBN) and the modified Selective Re-transmission (M-SRT) protocols for the DCCH: The simulation results show that the GSM Stop-And-Wait (SAW) protocol cannot provide satisfactory call set-up delay (around 1 minute in city environment) in the S-PCNs due to the long propagation delay and the link power limitation. The newly proposed M-GBN and M-SRT protocols can however provide satisfactory call set-up delay. Comparing the M-GBN and M-SRT schemes, we have found that the M-SRT outperforms the M-GBN when the channel condition is bad and the satellite propagation delay is long. In addition, the M-SRT protocol has a stable and lower capacity requirement as compared to the M-GBN. Both protocols require larger window-size compared to the GSM SAW protocol (WS=1). However, compared with the M-GBN protocol, the M-SRT requires more modifications to the LAPDm protocol, such as the multiple timer and the control field in the frame header. Hence this is a trade-off between performance and protocol modification.

The call set-up related control function and the associated signalling protocols which are affected by the satellite resource control and the mobility management approach have been investigated for two integration scenarios, the split MSC and the single MSC schemes. We have examined the necessary modifications to the GSM functions and signalling protocols imposed by the call control requirements in the S-PCNs. New functions and associated signalling protocols which are specific to S-PCNs have been defined. In conclusion, the split MSC integration scenario can be optimised by

- Define a fixed geographic LA associated with a SMSC;
- Using the guaranteed coverage area (GCA) mobility management approach;
Chapter 8 Conclusion and Future work

- Locating a satellite specific paging and diversity channel assignment function entities in a SMSC.

The comparisons between the two scenarios show that the split MSC integration scenario is superior to the single MSC because a) less modifications to the GSM call control functions and associated signalling protocols are required; b) the satellite and terrestrial segments can be optimised separately, and c) it has better signalling load and delay performance.

The signalling system is the core of any communication system. The call set-up related signalling research presented in this thesis is far from complete. Future work is envisaged in the following areas:

1. Performance evaluation of mobility management signalling procedures for dual-mode MSs. Two approaches dealing with the tracking and locating of dual-mode MSs were proposed. The corresponding signalling sequences have been investigated. It will be worthwhile to perform a comparative study of the two approaches taking into account the changing environment rates and the size of the segment tracking entities.

2. Call handover related signalling in the integrated satellite and GSM systems. The issues of resource management optimisation and service charging are two important factors as far as the call handover between the terrestrial and the satellite segments is concerned. The channel reallocation requires the call re-establishment and the call re-routing. To this end, study of new functionality and associated signalling procedures, as well as the complexity estimation, should be carried out in the future.

3. Mobile-to-Mobile call set-up signalling performance evaluation. The study and performance evaluation for mobile originated and terminated call set-up signalling procedures were the main goal of this research. An area concerning the call set-up signalling remaining uncovered in this study is the mobile-to-mobile call set-up procedure. If both the end users are in a S-PCN, the call can be established either through the space links (LEO66) or the ground links (ICO10) depending on the availability. Various situations need to be considered: a) one satellite is visible to both users, b) two satellites each being visible to one user are both visible to one ESC. For the former case, if on-board satellite processing is provided, the call can be directly connected via the satellite. In this case, the one-hop link can significantly reduce the call delay and provide higher quality of service. For the latter case, the satellite link (LEO66) can be used to connect the call. Therefore the ESC is only involved in the call set-up signalling procedure and performs the call control function throughout the call. For the ICO10 where the inter-satellite link is not available, the ESC has to act as the call routing point and the call set-up signalling point. Further work on the mobile-to-mobile call set-up signalling procedure and the performance evaluation should be carried out.
Chapter 8 Conclusion and Future work

4. A unified numbering plan. The numbering plans are important in integrated global system. Further work in this area should focus on the design of a numbering plan which is compatible with the current numbering systems used in different networks.

5. Coding schemes for S-PCNs. The fading statistics from the propagation experiments can be incorporated into the channel simulation model. Further work required is to select appropriate FEC and ARQ coding scheme according to the channel characteristics for the signalling channel.
APPENDICES

Appendix A  Call Set-up Signalling at Satellite Air-interface

A1 Immediate Assignment (AGCH)

This message [GSM 04.08/9.1.17] is sent on the AGCH by an ESC to an MS from which a RA packet is successfully received for changing the channel configuration (idle) to a dedicated configuration by assigning a DCCH.

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Page mode</td>
<td>MF</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>Channel description</td>
<td>MF</td>
<td>3</td>
<td>3*</td>
</tr>
<tr>
<td>Request Reference</td>
<td>MF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mobile allocation</td>
<td>MV</td>
<td>1-9</td>
<td>0*</td>
</tr>
<tr>
<td>Starting time</td>
<td>OF</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>19</td>
<td>7</td>
</tr>
</tbody>
</table>

**Channel description** In S-PCN, RF hopping channel is not used [RE95], therefore MAIO (Mobile Allocation Index Offset) field (4bits) and HSN (Hopping Sequence Number) field (7bits) are not used. The *channel description* element is coded as shown in *Figure A-1*.

<table>
<thead>
<tr>
<th>Time-slot Number (TN)</th>
<th>TDMA offset</th>
<th>Training Sequence Code</th>
<th>ARFCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octet 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octet 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octet 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure A-1 Channel description*

**Mobile allocation** This information element is used to indicate that part of RF channels belonging to the cell allocation which is used in the frequency hopping sequence. In S-PCN, no frequency hopping is used, therefore this field is empty.

**Starting time** The purpose of this information element is to provide the start TDMA frame number when using frequency hopping. In the S-PCNs, frequency hopping is not employed, the starting time information element is empty.
Appendices

**A2 Authentication Request**

GSM 04.08/9.2.2, ESC→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ciphering key sequence num.</td>
<td>MF</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>Authentication parameter RAND</td>
<td>MF</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>19</td>
<td>19</td>
</tr>
</tbody>
</table>

**A3 Authentication Response**

GSM 04.08/9.2.3, MS→ESC

<table>
<thead>
<tr>
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<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authentication parameter SRES</td>
<td>MF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**A4 CM Service Request**

This message [GSM 04.08/9.2.7] is sent by the MS to the ESC to request a service for the connection management sub-layer entities, e.g. circuit switched connection establishment, supplementary service activation, short message transfer.

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM service type</td>
<td>MF</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>Ciphering key sequence number</td>
<td>MF</td>
<td>1/2</td>
<td>0*</td>
</tr>
<tr>
<td>Mobile station classmark 2</td>
<td>MV</td>
<td>1-4</td>
<td>1-4</td>
</tr>
<tr>
<td>Mobile identity</td>
<td>MV</td>
<td>1-9</td>
<td>1-9</td>
</tr>
<tr>
<td>Called party BCD number*</td>
<td>OV</td>
<td></td>
<td>2-13</td>
</tr>
<tr>
<td>Satellite diversity*</td>
<td>OV</td>
<td></td>
<td>4-8</td>
</tr>
<tr>
<td>ES preference*</td>
<td>OF</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>MS location*</td>
<td>OF</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>17</td>
<td>5-44</td>
</tr>
</tbody>
</table>

*Ciphering key sequence number* For the call set-up process, this information element is already included in the AUTHENTICATION REQUEST message. It can be omitted from CM SERVICE REQUEST message.
**Satellite diversity*** This information element conveys IDs of two diversity satellites and four SBs in case that the practical channel availability is different from the prediction of network due to satellite fading channel effect. Satellites are coded using 7 bits, maximum 128 satellites is allowed in a satellite constellation. SBs are coded using 8 bits and a satellite can have 256 SBs. The IDs of visible SBs are reported if a MS has no capability to measure their locations. The satellite diversity information element is coded as shown in Figure A-2.

$$\begin{array}{cccccccc}
8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 \\
0 & & & & & & & \\
\text{Satellite diversity IEI} & \text{Octet 1} \\
\text{Length of satellite diversity contents} & \text{Octet 2} \\
\text{Best visible satellite} & \text{Octet 3} \\
\text{Second visible satellite} & \text{Octet 4} \\
\text{SB 1} & \text{Octet 5} \\
\text{SB 2} & \text{Octet 6} \\
\text{SB 3} & \text{Octet 7} \\
\text{SB 4} & \text{Octet 8} \\
\end{array}$$

*Figure A-2 Satellite diversity information element*

**MS location*** This information element includes the MS location parameter (latitude, longitude) measured by MS. It is coded as shown in Figure A-3.

$$\begin{array}{cccccccc}
8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 \\
0 & & & & & & & \\
\text{MS location IEI} & \text{Octet 1} \\
\text{latitude sign} & \text{Octet 2} \\
\text{latitude digit 1} & \text{Octet 3} \\
\text{latitude digit 2} & \text{Octet 4} \\
\text{longitude sign} & \text{Octet 5} \\
\text{longitude digit 1} & \text{Octet 6} \\
\text{longitude digit 2} & \text{Octet 7} \\
\text{longitude digit 3} & \text{Octet 8} \\
\end{array}$$

*Figure A-3 MS location information element*

Latitude is expressed XX.X and longitude is expressed as XXX.

**ES preference*** This information element gives the ES’ ID selected by the MS. It is coded as shown in Figure A-4.

$$\begin{array}{cccccccc}
8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 \\
0 & & & & & & & \\
\text{ES preference IEI} & \text{Octet 1} \\
\text{ES ID} & \text{Octet 2} \\
\end{array}$$

*Figure A-4 ES preference information element*
**A5 CM Service Accept**

GSM 04.08/9.2.5, ESC→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF²</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**A6 Cipher Mode Command**

GSM 04.08/9.1.9, ES→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
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<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF²</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cipher mode setting</td>
<td>MF²</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**A7 Cipher Mode Complete**

GSM 04.08/9.1.10, MS→ES

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF²</td>
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<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
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<td></td>
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<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**A8 Additional Assignment**

This message [GSM 04.08/9.1.1] is sent on the main DCCH by the BSC to the MS to allocate an additional dedicated channel while keeping the previously allocated channels. In S-PCN, this message is sent by ESC to allocate another DCCH to both ES and MS for performing call set-up transactions.

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF²</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel description</td>
<td>MF²</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Mobile allocation</td>
<td>OV</td>
<td>2-10</td>
<td>0*</td>
</tr>
<tr>
<td>Starting time</td>
<td>OF²</td>
<td>3</td>
<td>0*</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>18</td>
<td>5</td>
</tr>
</tbody>
</table>
### A9 Set-up, Mobile Originated Call

**GSM 04.08/9.3.16, MS→ES**

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
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<th>S-PCN code length</th>
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<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Repeat indicator</td>
<td>OF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mobile capabilities</td>
<td>OV</td>
<td>2-11</td>
<td>3-11</td>
</tr>
<tr>
<td>Facility</td>
<td>OV</td>
<td>2-?</td>
<td>2-?</td>
</tr>
<tr>
<td>Calling party BCD number</td>
<td>OV</td>
<td>2-13</td>
<td>2-13</td>
</tr>
<tr>
<td>Calling party sub-address</td>
<td>OV</td>
<td>2-23</td>
<td>2-23</td>
</tr>
<tr>
<td>Called party BCD number</td>
<td>OV</td>
<td>2-14</td>
<td>2-14</td>
</tr>
<tr>
<td>Called party sub-address</td>
<td>OV</td>
<td>2-13</td>
<td>2-13</td>
</tr>
<tr>
<td>Repeat indicator</td>
<td>OF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Low layer compatibility</td>
<td>OV</td>
<td>3-15</td>
<td>3-15</td>
</tr>
<tr>
<td>Repeat indicator</td>
<td>OF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>High layer compatibility</td>
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<td>4-5</td>
<td>4-5</td>
</tr>
<tr>
<td>User-User</td>
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</table>

### A10 Set-up, Mobile Terminated Call

**GSM 04.08/9.3.16, ES→MS**

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repeat indicator</td>
<td>OF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mobile capabilities</td>
<td>OV</td>
<td>2-11</td>
<td>0*</td>
</tr>
<tr>
<td>Facility</td>
<td>OV</td>
<td>2-?</td>
<td>2-?</td>
</tr>
<tr>
<td>Progress indicator</td>
<td>OV</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Signal</td>
<td>OF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Calling party BCD number</td>
<td>OV</td>
<td>2-14</td>
<td>2-14</td>
</tr>
<tr>
<td>Calling party sub-address</td>
<td>OV</td>
<td>2-23</td>
<td>2-23</td>
</tr>
<tr>
<td>Called party BCD number</td>
<td>OV</td>
<td>2-13</td>
<td>2-13</td>
</tr>
<tr>
<td>Called party sub-address</td>
<td>OV</td>
<td>2-23</td>
<td>2-23</td>
</tr>
<tr>
<td>Repeat indicator</td>
<td>OF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Low layer compatibility</td>
<td>OV</td>
<td>3-15</td>
<td>3-15</td>
</tr>
<tr>
<td>Repeat indicator</td>
<td>OF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>High layer compatibility</td>
<td>OV</td>
<td>4-5</td>
<td>4-5</td>
</tr>
<tr>
<td>User-User</td>
<td>OV</td>
<td>2-35</td>
<td>2-35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>152</td>
<td>2-141</td>
</tr>
</tbody>
</table>

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**Bearer capabilities** [GSM 09.07] Assuming one directory number is allocated to all the services in MS, the bearer capability information element can be omitted.

### A11 Call processing

GSM 04.08/9.3.3, ES→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Progress indicator</td>
<td>OV</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

### A12 Assignment Command

This message [GSM 04.08/9.1.2] is sent on the main DCCH by the ESC to the MS to change the channel configuration to another independent dedicated channel configuration (e.g., speech channel), no timing adjustment needed.

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Channel description</td>
<td>MF</td>
<td>3</td>
<td>3*</td>
</tr>
<tr>
<td>Power command</td>
<td>MF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cell channel description</td>
<td>OF</td>
<td>17</td>
<td>25*</td>
</tr>
<tr>
<td>Channel mode</td>
<td>OF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Channel description</td>
<td>OF</td>
<td>4</td>
<td>4*</td>
</tr>
<tr>
<td>Channel mode 2</td>
<td>OF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mobile allocation</td>
<td>OV</td>
<td>2-10</td>
<td>0*</td>
</tr>
<tr>
<td>Starting time</td>
<td>OF</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>44</td>
<td>39</td>
</tr>
</tbody>
</table>

**Cell channel description** The absolute RF channel numbers (ARFCN), which are belong to the cell allocation, are conveyed using this information element. Assuming maximum 200 channels are allocated to one spot beam coverage. A channel is represented by 1 bits, This element is 25 octets long.
Appendices

A13 Alerting

GSM 04.08/9.3.1
ES→MS for mobile originated call

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Facility</td>
<td>OV</td>
<td>2-?</td>
<td>0*</td>
</tr>
<tr>
<td>Progress indicator</td>
<td>OV</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>User-user</td>
<td>OV</td>
<td>2-35</td>
<td>2-35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>43</td>
<td>2-41</td>
</tr>
</tbody>
</table>

**Facility** This information element is used for functional operation of supplementary service. The facility message can be used for this purpose in all states after the SETUP message has been sent. Since SETUP message (MS→ES) already includes the facility element, the facility element in ALERTING message (ES→MS) is used to indicate the return result: Return error or Reject component message type.

MS→ES for mobile terminated call

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
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<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Facility</td>
<td>OV</td>
<td>2-?</td>
<td>0</td>
</tr>
<tr>
<td>User-user</td>
<td>OV</td>
<td>2-35</td>
<td>2-35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>39</td>
<td>2-37</td>
</tr>
</tbody>
</table>

A14 Connect

GSM 04.08/9.3.5
ES→MS for mobile originated call

<table>
<thead>
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<th>S-PCN code length</th>
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</thead>
<tbody>
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<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Facility</td>
<td>OV</td>
<td>2-?</td>
<td>0*</td>
</tr>
<tr>
<td>Progress indicator</td>
<td>OV</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>User-user</td>
<td>OV</td>
<td>2-35</td>
<td>2-35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>43</td>
<td>2-41</td>
</tr>
</tbody>
</table>
Appendices

**MS→ES for mobile terminated call**

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Facility</td>
<td>OV</td>
<td>2-7</td>
<td>0*</td>
</tr>
<tr>
<td>User-user</td>
<td>OV</td>
<td>2-35</td>
<td>2-35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>39</td>
<td>2-37</td>
</tr>
</tbody>
</table>

**A15 Connect Acknowledge**

MS→ES for mobile originated call: To allow symmetrical call control
ES→MS for mobile terminated call: To indicate the MS has been awarded the call

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**A16 Paging Request Type 1**

GSM 04.08/9.1.21, ESC→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
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<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Page mode</td>
<td>MF</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>Mobile identity</td>
<td>MV</td>
<td>1-9</td>
<td>1-9</td>
</tr>
<tr>
<td>Mobile identity</td>
<td>OV</td>
<td>2-10</td>
<td>0*</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>22</td>
<td>12</td>
</tr>
</tbody>
</table>

In S-PCN, each signalling burst can only include 15 octets information. To increase the paging efficiency, if a paged MS has no other identity other than international mobile subscriber identity (IMSI 15 digits), second mobile identity is impossible to be included in the paging request type 1 message.
A17 Paging Request Type 2

GSM 04.08/9.1.22, ESC→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Page mode</td>
<td>MF</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>TMSI</td>
<td>MV</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>TMSI</td>
<td>MF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Mobile identity*</td>
<td>OV</td>
<td>2-10</td>
<td>0*</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>21</td>
<td>11</td>
</tr>
</tbody>
</table>

Two MSs which have TMSI (Temporary Mobile Subscriber Identity) can be paged using PAGING REQUEST TYPE 2 message.

A18 Paging request type 3

GSM 04.08/9.1.23, ESC→MS

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Page mode</td>
<td>MF</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>TMSI</td>
<td>MF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>TMSI</td>
<td>MF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>TMSI</td>
<td>MF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>TMSI</td>
<td>MF</td>
<td>4</td>
<td>0*</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>19</td>
<td>15</td>
</tr>
</tbody>
</table>

Three MSs can be paged using a PAGING REQUEST TYPE 3 in which mobile identity is represented by TMSI (4 octets)

A19 Call Confirmed

GSM 04.08/9.3.2, , MS→ESC

<table>
<thead>
<tr>
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<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/Transaction Identifier/Message Type</td>
<td>MF</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Bear capabilities</td>
<td>OV</td>
<td>3-11</td>
<td>3-11</td>
</tr>
<tr>
<td>Cause</td>
<td>OV</td>
<td>4-32</td>
<td>4-32</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>45</td>
<td>2-45</td>
</tr>
</tbody>
</table>
A20 MS related information

MS→ESC: This message provides satellite diversity, mobile location and ES preference information to the network for handling the satellite resource management.

<table>
<thead>
<tr>
<th>Information format</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol Discriminator/</td>
<td>MF</td>
<td>N/A</td>
<td>2</td>
</tr>
<tr>
<td>Transaction Identifier/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satellite diversity*</td>
<td>OV</td>
<td></td>
<td>4–8</td>
</tr>
<tr>
<td>ES preference*</td>
<td>OF</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>MS location*</td>
<td>OF</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>2-17</td>
</tr>
</tbody>
</table>
Appendices

Appendix B Call Set-up Related Signalling in S-PCNs

For two integration scenarios, single MSC and split MSC, we have investigated the possibility of adopting GSM signalling to perform the call control in the S-PCNs. The GSM signalling and the control procedures have been modified to cope with the requirements of call set-up functions in satellite systems. The S-PCN specific signalling procedures which are related to the call set-up functions have been considered, which include
1. diversity channel allocation procedure,
2. call re-routing procedure due to satellite handover between ESCs,
3. paging procedure, and
4. mobile authentication procedure for mobile-terminated calls.

Above signalling procedures and associated signalling format which have been defined for two integration scenarios are different as far as two integration scenarios are concern. The BSSMAP, DTAP, MAP/B, MAP/E and MAP/G protocols are involved in the call set-up related function. The BSSMAP and DTAP are the signalling protocols above SCCP. The MAP/x protocols have to use the services provided by the TCAP in addition to the MTP3 and SCCP.

In addition to the parameter coding, the coding overhead which is listed as below is required by different layers.
1. MTP (L2) 7 octets (including SIO, Flag, Check and Correction)
2. MTP (L3) 4 octets (routing label)
3. SCCP 14 octets for UNITDATA (Figure 6-4, excluding GT)
4. Distribution data unit
   DTAP: 2 octets, BSSMAP: 1 octet
5. TCAP
   4.1 CSL (Component Sub-Layer)
   10 octets for INVOKE

<table>
<thead>
<tr>
<th>Component type tag</th>
<th>1 octet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component length</td>
<td>1 octet</td>
</tr>
<tr>
<td>Invoke ID tag</td>
<td>1 octet</td>
</tr>
<tr>
<td>Invoke ID length</td>
<td>1 octet</td>
</tr>
<tr>
<td>Invoke ID</td>
<td>1 octet</td>
</tr>
<tr>
<td>Operation Code tag</td>
<td>1 octet</td>
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<td>Operation Code length</td>
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</tr>
<tr>
<td>Sequence tag</td>
<td>1 octet</td>
</tr>
<tr>
<td>Sequence length</td>
<td>1 octet</td>
</tr>
</tbody>
</table>
13 octets for INVOKE with linked ID
12 octets for RETURN RESULT with information element
5 octets for RETURN RESULT

4.2 TSL (Transaction Sub-Layer)
10 octets for BEGIN or END

<table>
<thead>
<tr>
<th>Message type tag</th>
<th>1 octet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total message length</td>
<td>1 octet</td>
</tr>
<tr>
<td>Originating Transaction ID tag</td>
<td>1 octet</td>
</tr>
<tr>
<td>Transaction ID length</td>
<td>1 octet</td>
</tr>
<tr>
<td>Transaction ID</td>
<td>4 octets</td>
</tr>
<tr>
<td>Component portion tag</td>
<td>1 octet</td>
</tr>
<tr>
<td>Component portion length</td>
<td>1 octet</td>
</tr>
</tbody>
</table>

16 octets for CONTINUE

**B1 Diversity Channel Allocation Procedure**

**B1.1 Single MSC Integration Scenario**

*Anchor MSC1 to ESC1:*

**B1.1.1 DTAP diversity assignment command**

This message corresponds to the DTAP handover command message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L3 information</td>
<td>M</td>
<td>11-60*</td>
<td>11-60*</td>
</tr>
<tr>
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<td>O</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

**L3 information:** same as handover command [GSM04.08]

<table>
<thead>
<tr>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
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<td>Length</td>
<td>Octet 2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handover command</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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B1.1.2 BSSMAP first assignment required

This message corresponds to the BSSMAP assignment request message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
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<td>26</td>
<td>26</td>
</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>Channel Type</td>
<td>M</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>L3 header information</td>
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<td>4</td>
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<tr>
<td>Priority</td>
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<td>3</td>
</tr>
<tr>
<td>Circuit identity code</td>
<td>O</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Downlink DTX flag</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Interference band to be used</td>
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<td>2</td>
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<td>Classmark information 2</td>
<td>O</td>
<td>4-5</td>
<td>4-5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>25</td>
<td>51</td>
</tr>
</tbody>
</table>

DTX: discontinuous transmission

ESC1 to anchor MSC1

B1.1.3 BSSMAP first assignment complete

This message corresponds to the BSSMAP assignment complete message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RR cause</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cell identifier</td>
<td>O</td>
<td>3-10</td>
<td>3-10</td>
</tr>
<tr>
<td>Chosen channel</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Chosen encryption algorithm</td>
<td>O</td>
<td>2</td>
<td>0*</td>
</tr>
<tr>
<td>Circuit pool</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>45</td>
<td>43</td>
</tr>
</tbody>
</table>

Chosen encryption algorithm: For diversity channel allocation in S-PCNs, the encryption algorithm is determined by the MSC. The same encryption algorithm is used in two allocated channels. ESC1 is not allowed to make changes. This information element is omitted.

Anchor MSC1 to relay MSC2

B1.1.4 MAP/E send end signal response for diversity assignment

<table>
<thead>
<tr>
<th>Result</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL END</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CSL RETURN RESULT</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>
Appendices

B1.1.5 MAP/E perform diversity assignment request

This message corresponds to the MAP/E perform handover request message in the GSM system.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL Begin</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CSL INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>targetCellId</td>
<td>5-7</td>
<td>5-7</td>
</tr>
<tr>
<td>servingCellId</td>
<td>5-7</td>
<td>5-7</td>
</tr>
<tr>
<td>channelType</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>classmarkInformation</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td>handover(diversity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Priority</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$k_c$</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>58</td>
<td>58</td>
</tr>
</tbody>
</table>

Relay MSC2 to anchor MSC1

B1.1.6 MAP/E perform diversity assignment response

This message corresponds to the MAP/E perform handover response message in the GSM system.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - CONTINUE</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>CSL - RETURN RESULT with INFO</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Handover (diversity)</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>accesssignalInfo</td>
<td>1-200</td>
<td>1-200</td>
</tr>
<tr>
<td>protocolld for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ExternalSignalInfo</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>239</td>
<td>239</td>
</tr>
</tbody>
</table>

B1.1.7 MAP/E process access signalling for diversity assignment

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - CONTINUE</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>CSL - INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>protocolld</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BSS⇒APDU</td>
<td>1-200</td>
<td>1-200</td>
</tr>
<tr>
<td>Total</td>
<td>230</td>
<td>230</td>
</tr>
</tbody>
</table>

B1.1.8 MAP/E send end signal request for diversity assignment

Invoke operation, no parameters

<table>
<thead>
<tr>
<th>Operation</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - CONTINUE</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>CSL - INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>
Appendices

SVLR2 to relay MSC2

B1.1.9 MAP/B send diversity assignment report

This message corresponds to the BSSMAP send handover report request message in the GSM system.

<table>
<thead>
<tr>
<th>TSL - CONTINUE</th>
<th>16</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSL - INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Operation</td>
<td>GSM code length (octets)</td>
<td>S-PCN code length (octets)</td>
</tr>
<tr>
<td>handover (diversity)</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>39</td>
</tr>
</tbody>
</table>

Relay MSC2 to SVLR2

B1.1.10 MAP/B diversity assignment number request

This message corresponds to the MAP/B handover number request message in the GSM system.

| TSL - BEGIN | 10 | 10 |
| CSL - INVOKE with ID | 13 | 13 |
| Parameters | GSM code length (octets) | S-PCN code length (octets) |
| LINKED | { SendHandoverReport } | { SendDiversityReport } |
| Total | 23 | 23 |

B1.1.11 MAP/B send diversity assignment report response

This message corresponds to the MAP/B send handover report response message in the GSM system.

| TSL - END | 10 | 10 |
| CSL - RETURN RESULT with INFO | 12 | 12 |
| Parameters | GSM code length (octets) | S-PCN code length (octets) |
| handover(diversity) | 1-10 | 1-10 |
| Number | |
| Total | 32 | 32 |
Appendices

Relay MSC2 to ESC2

B1.1.12 BSSMAP diversity assignment request

This message corresponds to the BSSMAP handover request message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Channel Type</td>
<td>M</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Encryption information</td>
<td>M</td>
<td>3-5*</td>
<td>3-5*</td>
</tr>
<tr>
<td>Classmark information 1 or</td>
<td>M</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Classmark information 2</td>
<td>M</td>
<td>4-5</td>
<td>4-5</td>
</tr>
<tr>
<td>Cell identifier (serving)</td>
<td>M</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Priority</td>
<td>O</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Circuit identity code</td>
<td>O</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Downlink DTX flag</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cell identifier (target)</td>
<td>M</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Interference band to be used</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cause</td>
<td>O</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>Classmark information 3</td>
<td>O</td>
<td>3-14</td>
<td>3-14</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

Encryption information: assuming that key will use 2 octets

<table>
<thead>
<tr>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element identifier</td>
<td>Octet 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>Octet 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permitted algorithm</td>
<td>Octet 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>key</td>
<td>Octet 4-n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ESC2 to relay MSC2

B1.1.13 BSSMAP diversity assignment request ack.

This message corresponds to the BSSMAP handover request ack. message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L3 information</td>
<td>M</td>
<td>11-60</td>
<td>11-60</td>
</tr>
<tr>
<td>Chose channel</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Chosen encryption algorithm</td>
<td>O</td>
<td>2</td>
<td>0*</td>
</tr>
<tr>
<td>Circuit pool</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>93</td>
<td>91</td>
</tr>
</tbody>
</table>
Chosen encryption algorithm: Diversity channel allocation signalling procedure in S-PCNs will use same encryption algorithm in both channels. There is no necessary for ESC2 selecting an encryption algorithm. This information element is omitted.

B1.1.14 BSSMAP diversity assignment detect

This signalling message corresponds to the BSSMAP handover detect message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

B1.1.15 BSSMAP diversity assignment complete

This signalling message corresponds to the BSSMAP handover complete message in the GSM system.

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RR cause</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>

B1.2 Split MSC

Anchor MSC1 to ESC1:

B1.2.1 DTAP diversity assignment command (98 octets)
Same as B1.1.1

B1.2.2 BSSMAP first assignment required (51 octets)
Same as B1.1.2

ESC1 to anchor MSC1:

B1.2.3 BSSMAP first assignment complete (43 octets)
Same as B1.1.3

Anchor MSC1 to ESC2:

B1.2.4 BSSMAP diversity assignment request (90 octets)
Appendices

Same as B1.1.12

**ESC2 to anchor MSC1**

**B1.2.5 BSSMAP diversity assignment request ack.** (91 octets)

Same as B1.1.15

**B1.2.6 BSSMAP diversity assignment detect** (1 octet)

Same as B1.1.16

**B1.2.7 BSSMAP diversity assignment complete** (3 octets)

Same as B1.1.17

**B2 Call Re-routing Procedure**

**B2.1 Single MSC Integration Scenario**

**ESC1 to anchor MSC1:**

**B2.1.1 BSSMAP handover required**

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cause</td>
<td>M</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>Response request</td>
<td>O</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cell identifier list*</td>
<td>M</td>
<td>2i+3 to 7i+3</td>
<td>7i+3*</td>
</tr>
<tr>
<td>(preferred)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit pool list</td>
<td>O</td>
<td>V</td>
<td>0*</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>91</td>
</tr>
</tbody>
</table>

**Cell identifier list**

<table>
<thead>
<tr>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Element identifier Octet 1
Length Octet 2
Spare Cell identification discriminator Octet 3
Cell identification 1 Octet 4 to 4+m

The number of candidate cells \((i)\) is assumed 8, \(m\) is the number of octets used to describe the cell identification which depends on the cell identification discriminator. For example, when cell identification discriminator is 0000, the whole Cell Global
Identification, CGI, is used to identify the cell. One cell identification will use 7 octets as described as below:

<table>
<thead>
<tr>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCC digit 2</td>
<td>MCC digit 1</td>
<td>Octet X+1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>MCC digit 3</td>
<td>Octet X+2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MNC digit 2</td>
<td>MNC digit 1</td>
<td>Octet X+3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Location Area Code**
- **LAC continue**
- **Cell Identification (Satellite ID)**
- **CI continue (SB ID)**

**Circuit pool list:** This information element in GSM system shall be included when cause element indicates the “switch circuit pool”. For call re-routing due to satellite handover between ESCs in S-PCNs, this information element can be omitted.

### B2.1.2 BSSMAP clear complete

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

### Anchor MSC1 to ESC1:

### B2.1.3 DTAP handover command

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>L3 information</strong></td>
<td>M</td>
<td>11-60</td>
<td>11-60*</td>
</tr>
<tr>
<td>Cell identifier</td>
<td>O</td>
<td>3-10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

L3 information: handover command [GSM04.08]

### B2.1.4 BSSMAP clear command

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>L3 header information</strong></td>
<td>O</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Cause</td>
<td>M</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

### Anchor MSC1 to relay MSC2

### B2.1.5 MAP/E send end signal response

Return result, no parameters
### Appendices

<table>
<thead>
<tr>
<th>Operation</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - END</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CSL - RETURN RESULT</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

#### B2.1.6 MAP/E perform handover request

| TSL - BEGIN               | 10                       | 10                          |
| CSL - INVOKE with ID      | 13                       | 13                          |
| parameters                |                          |                             |
| targetCellId              | 5-7                      | 5-7                         |
| servingCellId             | 5-7                      | 5-7                         |
| channelType               | 1-10                     | 1-10                        |
| classmarkinformation      | 1-2                      | 1-2                         |
| handoverPriority          | 1                        | 1                           |
| kc                        | 8                        | 8                           |
| Total                     | 58                       | 58                          |

Relay MSC2 to anchor MSC1

#### B2.1.7 MAP/E perform handover response

| TSL - CONTINUE            | 16                       | 16                          |
| CSL - RETURN RESULT with INFO | 12                     | 12                          |
| Parameters                |                          |                             |
| diversityNumber           | 1-10                     | 1-10                        |
| accessSignalInfo          | 1-200                    | 1-200                        |
| protocolId for ExternalSignalInfo | 1                  | 1                           |
| Total                     | 239                      | 239                         |

#### B2.1.8 MAP/E process access signalling

| TSL - CONTINUE            | 16                       | 16                          |
| CSL - INVOKE with ID      | 13                       | 13                          |
| Parameters                |                          |                             |
| protocolId                | 1                        | 1                           |
| BSS⇒APDU                  | 1-200                    | 1-200                        |
| Total                     | 230                      | 230                         |

#### B2.1.9 MAP/E send end signal request

Invoke operation, no parameter

<table>
<thead>
<tr>
<th>Operation</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - CONTINUE</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>CSL - INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>29</td>
</tr>
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</table>
### SVLR2 to relay MSC2

**B2.1.10 MAP/B send handover report**

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>TSL - CONTINUE</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>CSL - INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Operation</td>
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<td></td>
</tr>
<tr>
<td>handoverNumber</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>39</td>
</tr>
</tbody>
</table>

### Relay MSC2 to SVLR2

**B2.1.11 MAP/B handover number request**

<table>
<thead>
<tr>
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<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - BEGIN</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CSL - INVOKE with ID</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LINKED</td>
<td>{SendHandoverReport}</td>
<td>{SendHandoverReport}</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>23</td>
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</table>

### B2.1.12 MAP/B handover report response

<table>
<thead>
<tr>
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<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSL - END</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>CSL - RETURN</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>RESULT with INFO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diversityNumber</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

### Relay MSC2 to ESC2

**B2.1.13 BSSMAP handover request**

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Channel Type</td>
<td>M</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Encryption information</td>
<td>M</td>
<td>3-n</td>
<td>3-5</td>
</tr>
<tr>
<td>Classmark information 1 or 2</td>
<td>M</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Classmark information 2</td>
<td>M</td>
<td>4-5</td>
<td>4-5</td>
</tr>
<tr>
<td>Cell identifier (serving)</td>
<td>M</td>
<td>5-10</td>
<td>10</td>
</tr>
<tr>
<td>Priority</td>
<td>O</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Circuit identity code</td>
<td>O</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Downlink DTX flag</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cell identifier (target)</td>
<td>M</td>
<td>3-10</td>
<td>10</td>
</tr>
<tr>
<td>Interference band to be used</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cause</td>
<td>O</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>Classmark information 3</td>
<td>O</td>
<td>3-14</td>
<td>3-14</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>85+n</td>
<td>90</td>
</tr>
</tbody>
</table>
Appendices

**ESC2 to relay MSC2**

**B2.1.14 BSSMAP handover request ack.**

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L3 information</td>
<td>M</td>
<td>11-n</td>
<td>11-60</td>
</tr>
<tr>
<td>Chose channel</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Chosen encryption algorithm</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Circuit pool</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>33+n</strong></td>
<td><strong>93</strong></td>
</tr>
</tbody>
</table>

**B2.1.15 BSSMAP handover detect**

<table>
<thead>
<tr>
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<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>27</strong></td>
<td><strong>27</strong></td>
</tr>
</tbody>
</table>

**B2.1.16 BSSMAP handover complete**

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
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<th>S-PCN code length (octets)</th>
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</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RR cause</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>29</strong></td>
<td><strong>29</strong></td>
</tr>
</tbody>
</table>

**B2.2 Split MSC Integration Scenario**

**ESC1 to anchor MSC1:**

**B2.2.1 BSSMAP handover required** (91 octets)

Same as B2.1.1

**B2.2.2 BSSMAP clear complete** (27 octets)

Same as B2.1.2

**Anchor MSC1 to ESC1:**

**B2.2.3 DTAP handover command** (98 octets)

Same as B2.1.3

**B2.2.4 BSSMAP clear command** (35 octet)

Same as B2.1.4
Appendices

Anchor MSC1 to ESC2

B2.2.5 BSSMAP handover request (90 octets)
Same as B2.1.13

ESC2 to anchor MSC1

B2.2.6 BSSMAP handover request ack (93 octets)
Same as B2.1.14

B2.2.7 BSSMAP handover detect (27 octets)
Same as B3.1.15

B2.2.8 BSSMAP handover complete (29 octets)
Same as B2.1.16

B3 Paging Procedure

B3.1 Single MSC Integration Scenario

Anchor MSC1 to ESC1:

B3.1.1 BSSMAP paging parameter

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>N/A</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>IMSI</td>
<td>M</td>
<td></td>
<td>3-10</td>
</tr>
<tr>
<td>TMSI</td>
<td>O</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>MS location parameter set</td>
<td>M</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Channel needed</td>
<td>O</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>47</td>
</tr>
</tbody>
</table>

MS location parameter set

<table>
<thead>
<tr>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>Element identifier</th>
<th>Length</th>
<th>Octet 1</th>
<th>Octet 2</th>
<th>Octet 3</th>
<th>Octet 4</th>
<th>Octet 5</th>
<th>Octet 6</th>
<th>Octet 7</th>
<th>Octet 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Element identifier</td>
<td>Length</td>
<td>Octet 1</td>
<td>Octet 2</td>
<td>Octet 3</td>
<td>Octet 4</td>
<td>Octet 5</td>
<td>Octet 6</td>
<td>Octet 7</td>
<td>Octet 8</td>
</tr>
</tbody>
</table>
Appendices

**ESC1 to ESC2**

**B3.1.2 BSSMAP paging**

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>IMSI</td>
<td>M</td>
<td>3-10</td>
<td>3-10</td>
</tr>
<tr>
<td>TMSI</td>
<td>O</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Cell identifier list</td>
<td>M</td>
<td>3+7i</td>
<td>3+7i</td>
</tr>
<tr>
<td>Channel needed</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>118</td>
<td>112</td>
</tr>
</tbody>
</table>

(i = 10).

**ESC2 to ESC1**

**B3.1.3 BSSMAP complete L3 information**

<table>
<thead>
<tr>
<th>Information element</th>
<th>Type</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>M</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Message type</td>
<td>M</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cell identifier</td>
<td>M</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>L3 information</td>
<td>M</td>
<td>3-n</td>
<td>14</td>
</tr>
<tr>
<td>Chosen channel</td>
<td>O</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>41+n</td>
<td>53</td>
</tr>
</tbody>
</table>

L3 information: Paging response received on DCCH in S-PCN is 14 octets, n=14

**B3.2 Split MSC Integration Scenario**

**Anchor MSC1 to ESC1 and ESC2:**

**B3.2.1 BSSMAP paging (112 octets)**

Same as B3.1.2

**ESC1 and ESC2 to anchor MSC1**

**B3.2.2 BSSMAP complete L3 information (53 octets)**

Same as B3.1.3
Appendices

**B4. Mobile Locating Procedure for Mobile Terminating Call**

**B4.1 Single MSC Integration Scenario**

*SVLR2 to SVLR1*

**B4.1.1 MAP/G send parameter** (IMSI request)

One VLR quest another VLR for one or several parameters related to a subscriber.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GSM code length (octets)</th>
<th>S-PCN code length (octets)</th>
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<tbody>
<tr>
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<td>4-4</td>
<td>4-8</td>
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<tr>
<td>requestParameters</td>
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<td>2</td>
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<tr>
<td>Total</td>
<td>33</td>
<td>33</td>
</tr>
</tbody>
</table>

*SVLR1 to SVLR2*

**B4.1.2. MAP/G send parameter** (IMSI response)

<table>
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<tr>
<th>Parameters</th>
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</thead>
<tbody>
<tr>
<td>subscriberId</td>
<td>4-4</td>
<td>4-8</td>
</tr>
<tr>
<td>requestParameters</td>
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<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>33</td>
</tr>
</tbody>
</table>
Appendices

Appendix C Simulation Modules

C1 Simulation of Bit Error Rate

C1.1 System Level Module

BER simulation module, which is a combination of the fading channel module and the satellite connectivity module, is established to evaluate the satellite link bit error rate. The satellite connectivity module which is based on the Satlab provides the satellite connectivity statistics. The packet error rate (PER) can also be evaluated for given length of packets and the coding scheme.

Simulation parameters:
ICO10 uplink with multipath fading, city environment
- Satellite channel PDF file: City_Rice_power_PDF
- Rician CDF_10 Data File: Rician_CDF_10.file
- Rician CDF_20 Data File: Rician_CDF_20.file
- Rician CDF_30 Data File: Rician_CDF_30.file
- Rician CDF_40 Data File: Rician_CDF_40.file
- Rician CDF_60 Data File: Rician_CDF_60.file
- Rician CDF_70 Data File: Rician_CDF_70.file
- Rician CDF_80 Data File: Rician_CDF_80.file
- FOMR (Figure of Merit Ratio): 5.4
- Mobile antenna gain: 0dBi
Appendices

- Uplink carrier frequency: 2.01GHz
- Minimum elevation: 10°
- Data Rate: 50kb/s
- Packet length in bits: 99 (RA packet)
- Overhead bits: 47
- Correctable bits: 3 (convolutional code: 1/2 rate, K=7) [HAY94]
- Mobile TX power (W):
  0.1,0.25,0.5,0.75,1,1.5,2,2.5,3,3.5,4,4.5,5,5.5,6,6.5,7,8,9,10
- Time: 9:00AM, 20, February, 1995
- NodePositionUpdate Time Delay: 600 second

SatLab input parameters - ICO10

- Satellite altitude: 10345km
- Inclination: 45°
- Argument of right ascending node: 0°, 180°
- Eccentricity: 0°
- Mean anomaly: (0,1,2,3,4)*MA, MA=72°
- Argument of Perigee: 0°
- Mobile location: latitude: 40°-50°; longitude: 30°-40°

C1.2 Sub-level Modules

The BER system module consists of "BER evaluation", "system initialisation" and "UPDATE MS_sat POSITION" sub-modules.

"BER evaluate" module (Figure C1-2) includes the "traffic source" module which is a packet generator, the up-link and down-link BER modules, and the "elevation BER" module which distinguishes the BER at different elevation angles.

As shown in Figure C1-3, the "BSIM2" module provides the interface between Satlab and satellite network simulation modules in BONEs package. The "System initialisation" module provides the number of satellites and mobile stations, as well as their latitude and altitude information, which are the input parameters in the Satlab simulation.

The "UPDATE MS_Sat POSITION" module (Figure C1-4) updates the memories every time interval which is given by the parameter "NodePositionUpdate Time Delay". The information stored in the memories includes the distance between mobiles and satellites, the mobiles' visible satellites and the mobiles' elevation angels to the visible satellites.
Appendices

---

### Figure C1-2 BER Evaluation - Sub-Module

- **Traffic source**
- **Insert frequency**
- **Mean BER uplink**
- **Elevation BER**
- **Downlink BER**
- **Propagation Delay**
- **Delay**

- **Overhead bits**
- **Data Rate (kbps)**
- **Correctable bits**
- **Single trip delay**
- **Minimum Elevation**
- **Inter-arrival Rate**
- **Module TX power [W]**
- **Sat. TX Power [Watts]**
- **Packet length in bits**
- **Uplink carrier frequency**
- **Downlink carrier frequency**
- **Sat channel PDF File**
- **Rician CDF_10 Data File**
- **Rician CDF_40 Data File**
- **Rician CDF_60 Data File**
- **Rician CDF_70 Data File**
- **Rician CDF_100 Data File**

### Figure C1-3 System Initialisation

- **Start**
- **BSIM 2**
- **Number of Nodes**
- **Number of Stations**
- **Latitude Table Memory**
- **Altitude Table Memory**
- **Number of Sats**
- **Year**
- **Month**
- **Day**
- **Hour**
- **Minute**
- **Second**

---
C2 RACH simulation module

In RACH performance evaluation, we consider the priority based access scheme, the good channel transmission, the time capture effect and the collision probability of random access packets.

Since we had to limit the random accesses within a spot beam coverage area to consider the collision probability in an RACH, the satellite ephemeris from the Simulation Package of Coverage (SPOC<sup>+</sup>) is used in the RACH simulation.

The RACH system module including following sub-level modules

- Random access traffic generator;
- Random access re-transmission;
- Good/Bad channel states;
- Capture detection;
- Random access packet error detection, and
- Random access delay

The simulation parameters for ICO10 system are given as following:

- Data rate: 50kb/s
- Mobile velocity: 25m/s
- Satellite channel model city file: Sat-channel-model_city.file
- Satellite channel model highway file: Sat-channel-model_Highway.file
- RA Cycle duration ($t_{RA}$ as shown in Figure 3-10): 0.04 second
- Single trip delay for an ESC: 0.04813
- RA processing time at ESC: 150ms
- RA length in bits: 99
- Correctable bits: 3
- Satellite ID: 1
- Low step: 1
Appendices

- Initial time: 100 second
- Stop time: 1000 second
- Satellite height: 10354km
- Amplification\(^1\): 1000
- Step interval: 200 second
- Inter-arrival rate:
  - 0.06, 0.08, 0.1, 0.13, 0.15, 0.17, 0.2, 0.25, 0.3, 0.32, 0.35, 0.38, 0.4, 0.45, 0.5, 0.55, 0.6, 0.7
- Latitude range: 3°
- Longitude range: 2.65°
- Number of satellites: 10
- Minimum elevation: 10°
- Maximum elevation: 18.5°
- Earth central angle of a SB coverage: 2°
- Period sub-satellite point file: ICO10_112_200sec.map
- Percentage of users in city environment: 30%
- Percentage of fast access packets: 30%
- Number of redundant re-transmission times: 2
- Latitude distance between cell centre to sub-satellite: -21.5°
- Longitude distance between cell centre to sub-satellite: 20.5°
- City BER File: ICO10_city_3W_BER
- Highway BER File: ICO10_highway_3W_BER
- Fast access packets time out: 0.4 second
- Slow access packets time out: 1.2 second
- Maximum re-transmission number: 10
- Random back-off parameter: uniform distribution (1-7)
- Time-out for dropping access: 6 seconds

---
\(^1\) Amplification is a purely simulation associated parameters, which is used to increase the number of accesses in order to obtain performance statistics.
C3 Paging Simulation Module

Paging simulation module (Figure C3-1) evaluates mainly the paging signalling load and paging delay performance. The one-step and two-step paging schemes as well as the diversity paging method (with user assistance) are distinguished using the parameters. In addition to the SatLab related modules which provide the satellite connectivity's, a sub-level module "Paging procedure" (Figure C3-2) consists of the paging traffic generator, the paging transmission module and the paging delay module.

The simulation parameters for the ICO10 satellite system using the diversity paging scheme in the city environment are given as follows. The paging delay and signalling load performance is evaluated versus the paging accuracy probability in the first step (PAP).

- Multiframe length of CCCH: 0.48 second
- Paging packet transmission delay: 0.00667 second
- Minimum elevation angle to diversity satellite: 10°
- Number of paging repetition in a multiframe: 1
- Interval between paging repetition in a multiframe: 0.04 second
- Probability of the second best satellite visible when the main satellite is shadowed depends on the elevation angle
- Data rate: 50kb/s
- Paging generating rate: 0.7 page/sec
- Number of paging spot beams: 11 (Radius of LA is 600km)
- Mobile velocity: 25m/s
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- Paging packet length in bits: 320
- Overhead bits: 32
- Correctable bits: 3
- Diversity satellite paging? 1 (Yes)
- Maximum number of paging times: 10
- One or two paging steps: 2
- Time out for paging response:
  \[2 \times \text{multiframe length} - \text{paging packet length} = 2 \times 0.48 - 0.00667 \text{ (second)}\]
- BER file: ICO10_city_3W_BER
- RA delay CDF File: City_FastRA_delay_CDF
- Satellite channel model File: Sat-channel-model_city.file
- Start time: 9:00AM, 20, February, 1995
- Simulation time: 100000 seconds
- NodePositionUpdate Time Delay: 600 seconds
- Paging accuracy probability: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1
- Accuracy of predicted second best satellite: Paging accuracy probability

![Figure C3-1 Paging system module](image-url)
Appendices

C4 Modified Selective Re-Transmission Protocol used on DCCH - Call Set-up Delay Evaluation

C4.1 System Level Module

The signalling transaction delay on the DCCH is the primary part in the call set-up delay. To cope with the transaction type of transmission on the satellite DCCH, selective re-transmission (SRT) ARQ protocol is modified. The “Call set-up SRT” simulation module implements the M-SRT protocol and evaluates the call set-up delay.

The call set-up signalling procedure begins at the network which issues the immediate assignment message. The delay of channel request signalling in the mobile originated call set-up and the delay of paging and paging response signalling in the mobile terminated call set-up procedure are taken into account through an input delay file.

The simulation parameters for mobile originated call set-up signalling delay evaluation in the ICO10 satellite system are given as follows:

- Data Rate: 50kb/s
- Data packet time-out period: 0.48 second
- Elevation angle range: 30°-40°
- Mobile velocity: 25m/s
- 1-frame length in bits: 320
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- Overhead bits: 32
- Correctable bits: 3
- S-frame length in bits: 64
- Downlink carrier frequency: 2.2 GHz
- Uplink carrier frequency: 2.01 GHz
- Number of I-frame in transactions_network: 18
- Number of I-frame in transactions_user: 18
- Mobile originated/terminated? 0 (originated)
- Window size: 1,2,3,4,5,6,7,8,9,10
- BER file: ICO10_city_3W_BER
- RA delay CDF File: City_FastRA_delay_CDF
- \( t_{RA} \), the duration between adjacent random access time slots: 0.04 second
- Satellite channel model File: Sat-channel-model_city.file
- Number I-frame in transactions_user file: Num_P_in_user_transaction_Morig
- Number I-frame in transactions_net file: Num_P_in_net_transaction_Morig
- Start time: 9:00 AM, 20, February, 1995
- Simulation time: 100000 seconds
- NodePositionUpdate Time Delay: 600 seconds

![Call setup SRT diagram](figure)

**Figure C4-1 Call set-up delay evaluation system module**

(using M-SRT protocol on DCCH)

**C4.2 Sub-layer Module**

The sub-layer module “M-SRT DCCH” consists of six modules. The “DCCH traffic source” module generates the call set-up request. The “call set-up delay” module evaluates the delay performance. The “Satellite up- and down-link” modules mainly
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perform the packet error detection and the propagation delay evaluation. The M-SRT protocol is implemented by two modules, “M-SRT user” and “M-SRT network”.

Figure C4-2 Signalling transactions on DCCH using M-SRT protocol
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List of Publications

Publications


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