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ABSTRACT

How to deliver rich multimedia content to mobile users in a resource-efficient manner is a great challenge to the communication society. The Satellite Digital Multimedia Broadcast (SDMB) system has emerged as a promising solution on the efficient delivery of the Multimedia Broadcast Multicast Service (MBMS) by implementing a satellite-based broadcast service to complement the 3G and beyond 3G terrestrial mobile cellular networks.

The SDMB covers large parts of Europe by integrating both mobile networks and satellite networks. This paper presents a picture of the SDMB system focusing on its interworking and Radio Resource Management (RRM) issues and solutions. It first presents an overview of the SDMB system; then the network architecture and interfaces for the interworking between the SDMB and the terrestrial network are specified. To support the interworking on the access layer, we define the SDMB access layer that closely follows the Wideband Code Division Multiple Access (WCDMA) air interface in order to achieve maximum commonality with the Terrestrial Universal Mobile Telecommunications System (T-UMTS). A proposed radio resource allocation algorithm on the access layer leads to the optimisation of radio resources.

INTRODUCTION

The multimedia content delivery to mobile networks can be both streaming and content downloading. The one-to-many transmission nature implies that broadcast and multicast are efficient ways to distribute these contents. A number of technologies are under development to distribute those bandwidth-consuming applications in 3G mobile networks, which include Multimedia Broadcast & Multicast Services for 3G (MBMS), Digital Video Broadcasting - Handhelds (DVB-H), as well as terrestrial and satellite Digital Multimedia Broadcast (DMB). MBMS [1, 2, 3, 5] were developed in the 3rd Generation Partnership Project (3GPP) to provide both multicast and broadcast modes for the 3G mobile networks to efficiently distribute one-to-many services. The SDMB takes advantage of the satellite-inherent
capability to provide broadcast services over global coverage, to constitute an efficient way to deliver mobile multimedia contents to a potentially unlimited audience.

Using the Universal Mobile Telecommunications System (UMTS) standard, the SDMB system will complement mobile networks with broadcast and multicast capabilities for spectrum-efficient delivery of multimedia services to mobile devices in both outdoor and indoor environments, without introducing constraints on the user terminal or the consumer. To complement other mobile Broadcast/Multicast solutions, the Mobile Applications & Services based on Satellite and Terrestrial inteRwOrking (MAESTRO) integrated project [6] is focusing on a satellite broadcast-based architecture to enhance 3G and beyond 3G systems in the delivery of mobile multimedia broadcast services. The resulting hybrid architecture makes the most use of satellite and terrestrial technologies efficiently. The output of the MAESTRO has been extended to the Digital Video Broadcasting - Handheld plus (DVB-H+). Former partners of the MAESTRO project, i.e., Alcatel Alenia Space, are planning to put the DVB-H+ satellite and terrestrial repeaters in the market in the next two years.

We present the SDMB system in terms of the network architecture and the access layer optimization. Its network architecture enables the satellite system to be seamlessly integrated with the terrestrial 3G and beyond 3G mobile infrastructures by extending and adapting the 3rd Generation Partnership Project (3GPP) standards over a GEOstationary (GEO) satellite network. Its access layer uses a new multiplexing scheme to achieve high utility of the satellite bandwidth.

The content described herein is presented in four sections. The first of these sections is the SDMB system overview that gives the coverage and the capacity of the system as well as its business role models; the section entitled SDMB Network Architecture and Interworking presents the SDMB network architectures defining new interfaces and extending Broadcast Multicast Service Centre (BM-SC) functions; the section entitled SDMB Access Layer describes the SDMB access layer, to which a 2-level multiplexing scheme is proposed. Finally, the Conclusion draws the author’s conclusions for this paper.

SYSTEM OVERVIEW

The SDMB system is illustrated in Figure 1. It can provide anytime, anywhere broadcast services to mobile end users. Multimedia contents are provided by the content providers and delivered via the high power GEO satellite broadcast capacity to 3G mobile handset equipments using the 3GPP push service. The mobile users can interact with the system using the terrestrial link provided by the mobile networks. The SDMB system is able to offer umbrella cells with a typical diameter of 700 to 1000 km to provide large area coverage. This gives the advantage to integrate a large

![SDMB Concept Overview to enhance MBMS delivery on 3G and beyond 3G Systems](image)

number of scattered audiences and significantly reduce the retail service fee.

The system is unidirectional, covering large parts of Europe with multiple geostationary satellite spot beams. The overall system is closely integrated into the architecture of 2.5G/3G mobile cellular networks, in a design that aims to maximize the reuse of technology and infrastructure, and minimize system development cost.

The SDMB service interactivity is achieved at two levels:

1. The User Equipments’ (UE) local storage enables immediate interactivity and contributes to decrease the access time resulting in an enhanced perceived Quality of Service (QoS);

2. The 3G system point-to-point capability provides service interactivity with the distant service centre, when local interactivity cannot serve the user’s requests.

The system infrastructure will typically aim at an average availability greater than 95% over the umbrella cell to address the 3G handset market. This requires that indoor satellite coverage must be ensured, which implies large radio margin, higher than 15 dB, specific reliable transport layers based on Forward Error Correction (FEC), interleaving and data carousel techniques, terrestrial repeaters, and selective retransmission using the 3G system point-to-point capability and/or the satellite direct return link.

Two role models have been identified in the SDMB system. The Aggregator Centric Model is centred on the role of a content provider / aggregator contracting a satellite operator to provide broadcast capacity for the Aggregator’s content to all suitably configured UEs, regardless of Mobile Network Operator (MNO) affiliation. The MNO Centric Model is much more closely aligned to the MNO’s business. Control remains exclusively within the MNO, who can decide whether given traffic should be sent via satellite or terrestrial means. This model is better suited to the option of broadcasting data via satellite to selected base stations and
for the future when certain mobile handsets might include a transmission-to-satellite capability, is better suited to UMTS provision in areas of poor terrestrial coverage.

SDMB NETWORK ARCHITECTURE AND INTERWORKING

Interworking Architecture

This section describes the SDMB network architecture and its interworking between SDMB satellite network and 3G mobile networks.

Figure 2 illustrates the key functional elements within the network that will be used to support the SDMB service. These elements include:

- **SDMB-capable UE**: The 3G handset has a dual-mode and activates S-DMB features as a background task in order to allow 3G default network operations without requiring additional WCDMA reception chain.

- **SDMB Satellite**: The satellite that will support the transmission of SDMB services to defined coverage areas.

- **SDMB Terrestrial Repeater**: Repeaters may be deployed to enhance the SDMB signal availability for UEs in urban areas by retransmitting the satellite signal on the ground.

- **SDMB Hub**: The Hub controls broadcast transmission over the SDMB satellite system taking media streams as input from the Broadcast Multicast Service Centre (BM-SC).

- **BM-SC**: The functional entity that controls all aspects of the delivery of SDMB services including authentication and authorisation of subscribers, the delivery of services over the SDMB network, as well as service billing.

Also in Figure 2 the Content Providers provide the multimedia contents to be delivered over the SDMB system. The SDMB Satellite Hub (S-HUB) interfaces with the 3GPP Multimedia Broadcast/Multicast Service (MBMS) BM-SC which needs to be upgraded to take into account the additional WCDMA downlink carrier capacity. Moreover, an MBMS-capable 3G network actually opens up the potential for the BM-SC to apply policy based routing between terrestrial MBMS and satellite SDMB. The policies enable contents to be broadcasted to UEs either over SDMB satellite or via the terrestrial network infrastructure using MBMS Broadcast services. Contents can also be delivered to UEs using the MBMS Multicast services. For example, a relatively large multimedia service addressing large audiences over a scattered area will be routed to the satellite broadcast network, whereas a football result addressing a stadium audience will be delivered using the terrestrial carrier.

One of the main implications of the introduction of MBMS Multicast mode over the T-UMTS network is that the BM-SC now manages Join requests at the network level (in addition to the service level):

- **Handling explicit network join and leave (at both network layer and application layer).**

- **Authentication and authorisation** of the end user (at both network layer and application layer).
Bearer management processes

**Fig. 3. Gmb** * bearer control signalling plane

* Authorisation may optionally be based upon the end user’s location.

This is required to ensure the necessary routing path is established for the delivery of multicast packets over the network. The BM-SC is now also required to control the activation of multicast bearer resources within the T-UMTS network.

**Interfaces**

In SDMB, the Hub is effectively performing the function of a MBMS-capable Gateway General Packet Radio Service (GPRS) Support Node (GGSN) toward the BM-SC and external Public Data Networks. It is noted however that only a subset of the MBMS GGSN functionality is required to support SDMB. In particular, the signalling interface Gmb and data interface Gi toward the SDMB Hub only need to be able to support the Broadcast Mode defined in the 3GPP specifications [2, 4]. Furthermore, the interfaces, particularly Gmb, may need to support functionalities/attributes which are specific to the SDMB system. For these reasons we refer to the interfaces as Gmb and Gi respectively, in SDMB. The Gmb interface is principally required to provide the signalling plane interface to control establishment of broadcast bearers over the SDMB system (Hub to UE via satellite or satellite/terrestrial repeater). This includes the means to specify bearer-level QoS requirements and the geographic service area.

The ITU-T TSG CN3 work group is currently recommending adoption of the Internet Engineering Task Force (IETF) Authentication, Authorization, and Accounting (AAA) signalling protocol, Diameter [7], as the basis for the Gmb interface although Remote Authentication Dial In User Service [8] is equally capable of meeting the requirements on this interface. This is shown in Figure 3 for the SDMB:

**Fig. 4. Gi** * User Plane

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Fig. 6. SDMB access scheme

G₁* user plane interface for Broadcast transmission was defined for SDMB. The user plane interface is required to carry IP traffic from the BM-SC to the satellite Hub for transmission over the SDMB system. It is assumed that all traffic related to an SDMB service is carried in IP packets with a distinct multicast-Internet address (i.e., Class D address). The use of multicast addressing and, where applicable, IETF multicasting procedures on the G₁* interface should not be confused with the broadcast nature of the SDMB system: it is assumed that the SDMB Hub has no information about the recipients of each SDMB service. G₁* is proposed as Figure 4.

BM-SC Functional Structure

With the support of the new defined G₁* and G₉* interface, the BM-SC can provide new functions in SDMB, such as G₁* and G₉* interface support, and path choosing function, in addition to the service provisioning and delivery functions as it does in MBMS systems [2]. It consists of a set of sub-functions as shown in Figure 5:

- **Membership Function**: the SDMB membership function provides authorization for UEs requesting to activate an SDMB service in the commercial scenarios where UE subscribed to mobile operators only or to both mobile operators and aggregators.

- **Session and Transmission Function**: The SDMB session and transmission function is able to schedule SDMB session transmissions.

- **Proxy and Transport Function**: Proxy and transport function is a SDMB bearer service function that is for signalling over G₉* interface between the S-HUBs and the other BM-SC sub-functions, e.g., the BM-SC membership function and the session and transmission functions.

- **Service Announcement Function**: The BM-SC Service Announcement function is able to provide service announcements for broadcast SDMB user services.

- **Security Function**: This function gives the BM-SC the ability to authorize and authenticate users to access the SDMB services.

- **Path Choosing Function**: Path choosing function makes the decision for the BM-SC if the content data should be forwarded to the satellite hub or the GGSN.

To perform the path choosing function, e.g., to terminate the data transferred to satellite networks and start transferring them to the mobile networks, a new indicator should be added.

- **Satellite/Mobile Indicator** is required to indicate the BM-SC Proxy and Transport function which path message should be routed.

SDMB ACCESS LAYER

Access Layer Definition

The SDMB radio access scheme follows closely the WCDMA air interface in order to achieve maximum commonality with the T-UMTS. Due to the unidirectional
nature of the SDMB system and the point-to-multipoint services, only the subset of WCDMA functionalities required for the support of common / point-to-multipoint channels is relevant to SDMB. 3GPP specifications have been a starting point for the SDMB access scheme definition, and adaptations and modifications have been made to suit the satellite environment.

The radio network layer within the SDMB access scheme is part of the control plane and is also organized into sub-layers, including the main one: the Radio Resource Control (RRC) sub-layer. The user and control-plane layers of the SDMB access scheme are summarized in Figure 6.

1) SDMB Access Scheme Channels
The functionality of the SDMB radio interface layers is organized into the concept of channels, each one grouping a specific set of functions at the user and/or control planes. The SDMB set of channels, as shown in Figure 7, is a subset of the WCDMA set of channels; only the downlink common channels are relevant given the unidirectional nature of the system and the point-to-multipoint services it provides. The WCDMA logical channels relevant to SDMB are as follows:

- **MBMS point-to-multipoint Traffic Channel (MTCH):** it is used for a point-to-multipoint downlink transmission of user plane information between networks and UEs [9].

- **MBMS point-to-multipoint Control Channel (MCCH):** it is used for a point-to-multipoint downlink transmission of control plane information between networks and UEs [9].

- **Broadcast Common Control Channel (BCCH):** it carries fundamental signalling information in the SDMB Radio Access Network and its reception is mandatory for all terminals.

The SDMB-relevant WCDMA transport channels are the Forward Access transport Channel (FACH), which is a downlink transport channel for data transmission, and the Broadcast Channel (BCH), which is used to broadcast system and cell specific information. Their use in SDMB does not introduce additional issues.

The WCDMA physical channels relevant to SDMB are as follows:

- **Primary Common Control Physical Channel (P-CCPCH),** which is used to carry the BCH transport channel.

- **Secondary Common Control Physical Channel (S-CCPCH),** which is used to carry the FACH.

- **Synchronisation Channel (SCH),** which is a downlink signal used for cell search.

- **Common Pilot Channel (CPICH),** which is the physical channel used to carry the paging indicators.

- **MBMS Notification Indicator Channel (MICH),** which is a new MBMS-specific Paging Indicator Channel (PICH) used to send the MBMS notification indicators, thus enabling the UE to be informed about imminent or on-going transfers [9].

2) SDMB Radio Link Layer Definition
The SDMB radio access layer protocols comprising the Radio Resource Control (RRC), the Packet Data
Convergence Protocol (PDCP), the Radio Link Control (RLC), and the Medium Access Control (MAC) sub-layers implement a subset of those functionalities defined in T-UMTS. The RRC is responsible for the broadcast of information related to the non-access stratum layers and access stratum layers; the establishment, reconfiguration and release of radio bearers; and the initial spot beam selection, but does not implement any of the functions related to RRC connection given that there is no direct satellite return link within the baseline architecture. For the system information broadcast, the RRC includes specific parameter configurations required for the SDMB system. The PDCP provides header compression and decompression of IP data streams. Similar to MBMS, the Unidirectional mode (U-mode) of the ROBust Header Compression (ROHC) protocol is the only operation mode supported in SDMB since the packets are sent only in one direction from the SDMB Radio Access Network (RAN) to the UE, and there is no return path from the decompressor (located at the UE) to the compressor (located at the SDMB RAN). As for the RLC, only the transparent mode (for BCCH) and unacknowledged mode (for the three newly defined MBMS logical channels – MCCH, MSCH, and MTCH) are applicable, which includes support for the added RLC unacknowledged mode functionality defined for MBMS such as out of sequence Service Data Unit (SDU) delivery. All of the newly-defined functionalities associated with MAC for MBMS such as buffering, and the addition and reading of MBMS-ID are also supported in SDMB.

Given the unique nature of the SDMB system and that only the MBMS broadcast mode is supported, only a subset of those MBMS UMTS Terrestrial Radio Access Network (UTRAN) procedures described in [9] is pertinent to SDMB. Figure 8 shows three main procedures for the delivery of the MBMS services within SDMB radio access network – notification, radio bearer establishment, and data transfer triggered by the session-start procedure of BM-SC.

**Radio Resource Management Schemes**

Radio resources in satellite networks such as bandwidth, transmit power and codes are generally limited due to the physical and regulatory restrictions as well as the interference-limited nature of CDMA networks. In order to support high user densities in CDMA networks, while maintaining high quality in the wireless links, radio resource management is essential. In order to maximize the overall SDMB system capacity, a Radio Resource Allocation (RRA) has been proposed. The performance of the proposed RRA has been evaluated via simulation studies and compared with existing schemes. The obtained results will be used as recommendations for the optimum SDMB system configuration and algorithm selection at the access layer.

The RRA is responsible for estimating the required number of logical / transport / physical channels, and mapping them together with the actual Transport Format Combination Set (TFCS) for each physical channel [10]. Previous research on the channel mapping has used a conventional single-stage bin-packing algorithm [11], which assumes that the MBMS MTCH are mapped one-to-one onto the Forward Access CHannel (FACH) transport channels, which are subsequently multiplexed onto the Secondary Common Control Physical CHannel (S-CCPCH). This type of channel mapping which considers only a single-level of multiplexing at the physical layer is shown in Figure 9A. The problem with this simple one-to-one mapping at the transport channel is that there exists residual capacity on the transport channel which is not utilized when the bit rate of the logical channel does not exactly match the corresponding bit rate of the transport channel, i.e., the MTCH rate is less than the FACH rate.
In order to resolve the resource utilisation inefficiency experienced in single-level channel multiplexing scheme, an optimised two-level channel multiplexing approach has been proposed [12]. This algorithm performs channel multiplexing at both transport and physical channels. At the first level of multiplexing, multiple logical channels are mapped onto a single transport channel (logical channel multiplexing); whereas the mapping of several transport channels onto a physical channel (transport channel multiplexing) is regarded as the second level of multiplexing as shown in Figure 9B. The introduction of MBMS-ID field and the Target Channel Type Field (TCTF) in newly standardized MAC-m header makes logical channel multiplexing become a feasible solution in designing efficient RRA multiplexing schemes.

Aiming at achieving the highest possible degree of utilising the residual capacity on transport and physical channels, a two-stage bin-packing with optimum estimation algorithm has been proposed to extend the research in [12]. It must also be noted that it is generally assumed that only services with similar characteristics and QoS requirements are multiplexed together to the same transport channel.

There are four steps for the 2-stage bin-packing channel multiplexing. The first step is to estimate the number of the required MTCHs for each stream service that is the number of servers that will guarantee the target blocking probability. The second step is to estimate the intermediate-bins (FACHs) required, which will be used in the next step of 2-level channel multiplexing. Optimum estimation algorithm is applied at this step, which compares the set of required MTCHs’ bit rates and the set of available FACHs’ bit rates to find the best fit to achieve both minimum FACH residual capacity and minimum number of required FACHs. This step finishes the first stage of channel multiplexing (logical channel multiplexing) and leads to the maximum utilisation on both FACHs and S-CCPCHs. Best-Fit bin-packing algorithm [11], where the FACH is assigned to a feasible bin (S-CCPCHs, if any) having the smallest residual capacity, is chosen as the mapping algorithm in the second stage of channel multiplexing (transport channel multiplexing) in that it achieves the best performance under certain bin-packing mapping conditions.

In order to evaluate the performance of 2-level channel multiplexing, simulation has been carried out for a wide range of different traffic mixes and physical channel capacities, as highlighted below:

- **Traffic mix of x% streaming service and (1-x)% download service:** 80% - 20%; 50% - 50%; 20% - 80%
- **S-CCPCH configurations:** 3 × 384 kbps; 2 × 384 kbps; 1 × 384 kbps; 3 × 128 kbps; 1 × 384 kbps + 3 × 128 kbps

The traffic mixes herein refer to the capacity allocated to (reserved for) each type of services (streaming, download) assuming implicitly a fixed boundary for the capacity.

Typical scenarios illustrated in this article:

- **Scenario 1:** 3 S-CCPCHs of 384 kbps each, with traffic mix of 80% for streaming and 20% for download;
- **Scenario 2:** 3 S-CCPCHs of 384 kbps each, with traffic mix of 50% for streaming and 50% for download.
The overall channel mapping configuration for Scenario 1 is illustrated in Figure 10. After the mapping for the streaming services (MTCHs) has been performed, there is no residual capacity on streaming FACHs, whilst there are residual capacities on S-CCPCHs, which are assigned to download FACHs for carrying download services. For instance, the 128 kbps residual capacity on S-CCPCH 3 is allocated to one download FACH 6, which in turn is assigned equally in capacity to 2 MTCHs of 64 kbps each, so as to accommodate two download applications.

The simulation results show that the proposed 2-level channel multiplexing achieves higher utilisation on FACHs than single-level multiplexing by assigning more MTCHs into them. As seen from Figure 11, there is a fairly large amount of residual capacity, which could not be further utilized and appears as a pure waste of capacity on FACHs/S-CCPCHs, remaining in FACHs in single-level multiplexing for both scenarios. Numerically, these residual FACH capacities for Scenario 1 and 2 are: 704 kbps and 640 kbps, respectively, which correspond to 61.1% and 55.6% of total FACH capacities. However, by applying 2-level multiplexing, these residual capacities are further fully utilised and zero residual FACHs capacities have been achieved for both Scenarios. As seen from Figure 12, the proposed 2-level multiplexing also increased the transmission capacity over limited physical channel capacity. By using single-level multiplexing, the total MTCH transmission capacity (streaming and download) is 448 kbps and 480 kbps for Scenario 1 and 2, respectively. However, when the proposed 2-level multiplexing is applied, the total MTCH transmission capacity over the same lower layer FACHs/S-CCPCHs is significantly increased to 1152 kbps and 1088 kbps, respectively, which in effect leads to better radio resource utilisation.

**CONCLUSIONS**

The innovative SDMB concept proposed in the MAESTRO project can provide wide coverage and cheap service for multimedia content broadcasting to complement 3G and beyond 3G mobile networks. It’s fully compatible with IP and designed based on the 3GPP MBMS standards, which allow us to easily integrate SDMB with the terrestrial mobile networks.

The proposed SDMB network architecture provides flexibility to enable operators to gradually adopt powerful functions to distribute media to their subscribers with full compatibility with MBMS systems. The enhanced BM-SC and new interface between the BM-SC and the satellite HUB makes it feasible to support both SDMB satellite broadcast and MBMS mobile one-to-multipoint delivery to adapt different network situations and subscriber distributions.

The access layer is defined for SDMB that follows closely the WCDMA air interface in order to achieve high commonality with the T-UMTS. To resolve the resource utilisation inefficiency experienced in single-level channel
multiplexing scheme of the RRA, an optimised two-level channel multiplexing approach has been proposed. The simulation showed that this scheme achieved the maximum utilisation on FACHs by assigning more MTCHs into them and increased the transmission capacity over limited physical channel capacity comparing to the conventional single level multiplexing.

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Fig. 12. Comparison of total MTCHs transmission capacity between single-level and 2-level channel multiplexing under different traffic mixes