Call Admission Control for High Altitude Platform Station UMTS

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Summary

The increasing demand for higher bit rate wireless mobile communications services has accelerated the need to develop more innovative communications infrastructures. Terrestrial tower-based systems and satellite systems are the existing well-established ways of providing mobile communications services. However, each concept has its specific advantages and disadvantages. Communications using high altitude platform stations (HAPS) has received much attention in the recent years because it combines advantages of both satellite and terrestrial tower-based systems, making it attractive as an alternative telecommunications infrastructure.

In this thesis, we study the problem of call admission control (CAC) in HAPS Universal Mobile Telecommunications System (UMTS) employing wideband code division multiple access (WCDMA) technique. The focus is on the development of CAC schemes for HAPS UMTS by exploiting the unique characteristics of HAPS.

We identify the HAPS unique characteristics and quantify the capacity supportable by HAPS UMTS. Based on the unique HAPS characteristics, we optimise the nth-power-of-distance power control scheme for HAPS UMTS and propose a new optimum power control scheme for HAPS UMTS based on antenna radiation pattern to ensure uniform quality of service throughout the cell. In addition, a HAPS UMTS system level simulator is developed to comprehensively model the dynamic HAPS UMTS mobile environment for the evaluation of CAC schemes.

We propose two centralised total received power based CAC schemes and also a transmit power based CAC scheme with onboard power resource sharing for HAPS UMTS. The performances of these schemes are evaluated and are found to outperform the traditional schemes proposed for terrestrial tower-based UMTS. We also extend our study to the HAPS and terrestrial tower-based hierarchical UMTS environment and propose three CAC schemes with centralised resource reservation to optimise the system performance. Results obtained show that the proposed schemes improve the system's overall grade of service.
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<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>1G</td>
<td>First Generation</td>
</tr>
<tr>
<td>2G</td>
<td>Second Generation</td>
</tr>
<tr>
<td>3G</td>
<td>Third Generation</td>
</tr>
<tr>
<td>A-CAC</td>
<td>Adaptive Call Admission Control</td>
</tr>
<tr>
<td>B-ISDN</td>
<td>Broadband Integrated Services Digital Network</td>
</tr>
<tr>
<td>BS</td>
<td>Base Station</td>
</tr>
<tr>
<td>CAC</td>
<td>Call Admission Control</td>
</tr>
<tr>
<td>CCSR</td>
<td>Centre for Communications Systems Research</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>CRP-RA</td>
<td>Centralised Received Power Based, Random Model Call Admission Control</td>
</tr>
<tr>
<td>CRP-RK</td>
<td>Centralised Received Power Based, Ranking Model Call Admission Control</td>
</tr>
<tr>
<td>CTP-BS</td>
<td>Centralised Transmit Power Based, Base Station Limited Call Admission Control</td>
</tr>
<tr>
<td>CTP-PF</td>
<td>Centralised Transmit Power Based, Platform Limited Call Admission Control</td>
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<tr>
<td>EIRP</td>
<td>Effective Isotropic Radiated Power</td>
</tr>
<tr>
<td>F-CAC</td>
<td>Fixed Call Admission Control</td>
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<tr>
<td>FDMA</td>
<td>Frequency Division Multiple Access</td>
</tr>
<tr>
<td>GEO</td>
<td>Geostationary Earth Orbit</td>
</tr>
<tr>
<td>GF-CAC</td>
<td>Global Fixed Call Admission Control</td>
</tr>
<tr>
<td>GoS</td>
<td>Grade of Service</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HALE</td>
<td>High Altitude Long Endurance</td>
</tr>
<tr>
<td>HAPS</td>
<td>High Altitude Platform Station</td>
</tr>
<tr>
<td>IMT-2000</td>
<td>International Mobile Telecommunications System 2000</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
</tr>
<tr>
<td>kbps</td>
<td>Kilo Bits per Second</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>LF-CAC</td>
<td>Local Fixed Call Admission Control</td>
</tr>
<tr>
<td>LMDS</td>
<td>Local Multipoint Distribution System</td>
</tr>
</tbody>
</table>
Mbps  Mega Bits per Second
Mcps  Mega Chips per Second
MEO  Medium Earth Orbit
MSC  Mobile Switching Centre
N-ISDN Narrowband Integrated Services Digital Network
NRT  Non Real-time
PCS  Personal Communications System
PDC  Personal Digital Cellular System
PHS  Personal Handyphone System
PSTN Public Switched Telephone Network
QoS  Quality of Service
RNC  Radio Network Controller
RR  Radio Regulations
RRM  Radio Resource Management
RR-RA Call Admission Control with Centralised Resource Reservation, Random Model
RR-SS Call Admission Control with Centralised Resource Reservation, Speed Selection
RR-TS Call Admission Control with Centralised Resource Reservation, Traffic Selection
RT  Real-time
RTT  Radio Transmission Technology
SIR  Signal-to-interference Ratio
S-UMTS Satellite Universal Mobile Telecommunications System
TDMA Time Division Multiple Access
UAV  Unmanned Aerial Vehicle
UMTS Universal Mobile Telecommunications System
WCDMA Wideband Code Division Multiple Access
WWW  Worldwide Web
Chapter 1

1 Introduction

1.1 High Altitude Platform Station Communications Systems

The increasing demand for higher bit rate wireless mobile communications services has accelerated the need to develop more innovative communications infrastructures. Terrestrial tower-based systems and satellite systems are the existing well-established ways of providing mobile communications services. While terrestrial tower-based systems have advantages such as low-cost, low-power user terminals, short propagation delays and good scalability of system capacity, they have various disadvantages as well. The radio signal is subjected to high scattering and multi-path effects that affect the quality of service (QoS) delivered. Furthermore, as the base stations are dispersed over a wide geographical area, communications resources cannot be optimally utilised. In addition, it is expected that more infrastructure is required, as smaller cells will be required to provide high quality broadband services. Although satellites can provide similar services with much less infrastructure and higher elevation angles, they have their own limitations. Geostationary satellite systems suffer large signal delays due to their large distances from the earth, while non-geostationary satellite systems are more complex in design. Furthermore, high launching costs and limited orbit space means high connection costs must be borne.

An innovative way of overcoming the shortcomings of both the terrestrial tower-based and satellite systems is to provide cellular communications via High Altitude Platform Station (HAPS) [1]. HAPS is defined in Radio Regulations (RR) No. S1.66A as “a station located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the earth” [2]. A HAPS is either a lighter-than-air balloon held geostationary in the stratosphere by a station keeping mechanism or a manned/unmanned aircraft flying in a tight circle.

A HAPS communications system has potential to exploit many of the advantages of terrestrial tower-based and satellite systems, making it attractive as an alternative telecommunications infrastructure. A single HAPS with communications payloads (bent pipe transponders and phased
array antenna) onboard can provide cellular coverage and replace a large number of terrestrial tower-based base stations and their backhaul infrastructure (microwave or optical links). Therefore, HAPS communications systems have the potential to be rapidly deployed using considerably less communications infrastructure than a terrestrial tower-based network. In addition, unlike satellites, HAPS can be brought down for servicing and upgrading easily. Also, equipment upgrading can be conveniently performed at a central location. With regard to radio propagation, the main reasons why HAPS communications systems are highly favoured are their free space like path loss characteristic and low propagation delay compared to satellite systems.

One of the first and most ambitious HAPS project was undertaken by Sky Station (U.S.A.) [3]. It aims to deploy a network of lighter-than-air platforms held geostationary at altitudes of approximately 22 km in the stratosphere. 250 platforms with inter-platform links will be required to provide worldwide coverage, although initial deployment will be over major metropolitan cities. Other projects were subsequently proposed worldwide, including HALO (U.S.A.) [4], Helinet (Europe) [5], SkyTower (U.S.A.) [6] and SkyNet (Japan) [7].

Many communications applications have been proposed for HAPS, such as broadband wireless access, broadcasting, as well as third-generation Universal Mobile Telecommunications System (UMTS) employing wideband code division multiple access (WCDMA) technique.

Recently, the International Telecommunication Union (ITU) has accepted HAPS as an alternative means of delivering the IMT-2000/UMTS (International Mobile Telecommunications System 2000/Universal Mobile Telecommunications System) services, in the frequency ranges 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz in Regions 1 and 3, and 1885-1980 MHz and 2110-2160 MHz in Region 2. Various worldwide on-going HAPS projects such as Sky Station (U.S.A.) and SkyNet (Japan) are currently looking into providing UMTS services via HAPS.

1.2 Previous Work and Motivation

In UMTS employing WCDMA technique, call admission control (CAC) is a critical issue that has attracted much research interest.

Unlike time division multiple access (TDMA) or frequency division multiple access (FDMA), all users in a WCDMA system share a common frequency allocation concurrently, so there are no
hard capacity limits in any cell. Capacity is limited only by the total level of interference generated from the transmissions of all connected users (so-called “soft capacity”). The system can accommodate more users by allowing more interference into the system and hence sacrificing the communications quality of existing users (so-called “graceful degradation”). However, the level of interference cannot increase indefinitely; the number of simultaneous users occupying a base station must be limited such that an appropriate level of communications quality can be maintained. CAC is the selective denial of service to new calls arriving in the system in order to avoid the deterioration of the link quality for on-going calls.

A survey of existing work shows that CAC schemes for terrestrial tower-based systems employing code division multiple access (CDMA) technique have been widely studied previously. The proposed techniques differ in the criteria used for CAC. Generally, two categories of criteria are used. The first category concerns information about connection traffic parameters. These parameters include the number of connected calls as well as their service type and peak rate. For example, in [8], [9], [10] and [11], the CAC criterion is the number of on-going calls. The second category concerns information about measured channel characteristics, which are available to the local base station, e.g., signal-to-interference ratio (SIR) as in [12], total interference power level, as in [13], [14] and [15] or mobile transmit power as in [13], [16] and [17]. These two categories of information can either be retrieved solely from the local cell (local scheme) or from the local as well as surrounding cells (global scheme). Various enhancements to these standard schemes have also been proposed, including handover reservation, delay of blocked calls, etc.

As with terrestrial tower-based UMTS, CAC techniques must be applied in HAPS UMTS to regulate the acceptance of incoming calls and manage the trade-off between system capacity and the level of communications quality. However, we note that existing CAC schemes proposed in literature are for terrestrial tower-based UMTS systems. As HAPS UMTS is a relatively new research topic, no CAC techniques for HAPS UMTS have yet been proposed or evaluated. Therefore, the issue of CAC design for HAPS UMTS is still outstanding and must be addressed.

1.3 Research Objective

Although HAPS UMTS will use the same Radio Transmission Technology (RTT) as terrestrial tower-based UMTS, HAPS UMTS differs from terrestrial tower-based UMTS in various aspects. The main difference is that unlike terrestrial tower-based systems, all the base stations of a HAPS
communications system are collocated, resulting in unique HAPS system and interference characteristics. Consequently, while it may be possible to apply existing CAC schemes proposed for terrestrial tower-based UMTS directly to the HAPS UMTS environment, this approach may not be the most effective or efficient, resulting in non-optimum performance.

Our objective in this work is to exploit the unique characteristics of HAPS to develop CAC techniques customised to the HAPS environment so as to optimise system performance and maximise the capacity supportable by HAPS UMTS.

1.4 Research Focus and Approach

As mentioned in Section 1.2, a number of CAC schemes with different criteria and enhancements have already been proposed for terrestrial tower-based systems by other researchers. Most of the existing schemes and their enhancements are expected to work in the HAPS UMTS environment, because HAPS UMTS and terrestrial tower-based UMTS share the same RTT.

Our intention is to concentrate on identifying unique HAPS properties not found in the terrestrial environment and making use of the unique HAPS properties for CAC design.

Our approach is to first identify and understand the unique characteristics of HAPS UMTS. Next, we will incorporate these unique HAPS characteristics in the CAC design process to develop specific CAC schemes that are customised and optimised for the HAPS environment. Finally, we evaluate the performances of the proposed schemes via simulation and compare them with the performance achievable by existing conventional CAC schemes proposed for terrestrial tower-based systems.

1.5 Significant Research Contributions

The novel work undertaken in this research are summarised as follows:

- Characterisation of the unique properties of HAPS UMTS for CAC design.
- Investigation of the reverse and forward link capacities of HAPS UMTS.
- Optimisation of distance based forward link power control scheme for HAPS UMTS.
- Development of an optimum forward link power control scheme for HAPS UMTS.
• Development of a dynamic HAPS UMTS system level simulator.

• Development of two centralised total received power based CAC schemes for HAPS UMTS (CRP-RA and CRP-RK).

• Development of a centralised transmit power based CAC scheme for HAPS UMTS with onboard power resource sharing (CTP-PF).

• Development of three CAC schemes with centralised resource reservation for HAPS and terrestrial tower-based hierarchical UMTS (RR-RA, RR-TS, RR-SS).

• Publications and contributions.
  


Chapter 1. Introduction


1.6 Structure of Thesis

The structure of this thesis is illustrated in Figure 1-1.

Chapter 2 introduces the key concepts of mobile communications via HAPS. Issues discussed include components of HAPS communications systems, comparison between HAPS, terrestrial tower-based and satellite systems and the general architecture of HAPS UMTS.
In Chapter 3, we explain the need for CAC in UMTS and discuss considerations in the design of CAC schemes for UMTS in general. The strategy adopted to address the problem of CAC for HAPS UMTS will also be highlighted.

In Chapter 4, we analyse the unique HAPS interference geometry and characterise the interference properties of HAPS UMTS. We make use of the results to investigate the capacity of HAPS UMTS and compare its capacity with that supportable by conventional terrestrial tower-based UMTS. We also explain how the unique properties of HAPS allow distance based power control schemes to perform favourably. Furthermore, we optimise the nth-power-of-distance power control scheme and propose an optimum forward link power control scheme for HAPS UMTS. We will show that the power control schemes provide significant capacity improvements to HAPS UMTS.

Based on the discussions presented in Chapters 2, 3 and 4, we describe, in Chapter 5, the factors taken into consideration in the design of the dynamic HAPS UMTS system level simulator, which is used for the evaluation of CAC schemes. The detailed functionalities of the simulator will also be explained.

In Chapter 6, we explain in detail how we make use of the unique characteristics of HAPS to develop two centralised total received power based CAC schemes and a centralised transmit power based CAC scheme with onboard power resource sharing for HAPS UMTS. We will show that the proposed schemes outperform the conventional schemes proposed for terrestrial tower-based UMTS.

In Chapter 7, we extend our study to HAPS and terrestrial tower-based hierarchical UMTS. We highlight the considerations in CAC design in such systems and further propose three CAC schemes with centralised resource reservation suitable for this scenario. We will show that the proposed schemes improve the overall grade of service of the system.

The conclusions of this research and potential future work are presented in Chapter 8.
Chapter 2

2 Overview of HAPS UMTS

2.1 Introduction

In this chapter, we explain why HAPS is viewed as a potential candidate for future mobile communications by describing its advantages over terrestrial tower-based and satellite systems. We follow by introducing the key concepts of mobile communications via HAPS and describing the general operating characteristics of HAPS UMTS.

2.2 Definition of HAPS

A HAPS is defined in Radio Regulations (RR) No. S1.66A as "a station located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the earth" [2]. It is basically either a helium-filled airship or an unmanned/manned aircraft operating in the stratosphere (20 - 50 km above the ground).

2.3 HAPS: An Innovative Solution with Air Supremacy for the Delivery of 3G and Beyond 3G Mobile Communications Services

Mobile cellular communications systems have evolved from first generation (1G) systems supporting only analogue voice services to second generation (2G) systems supporting digital voice and low bit rate circuit switched data. The envisaged third generation (3G) systems are expected to provide multimedia services with bit rates up to 2 Mbps and 144 kbps in indoor and vehicular environments respectively. However, demands for higher access speeds for multimedia communications will be unlimited.

Figure 2-1 [18] shows a prediction on the development trend of mobile communications for the next 20 years. It is anticipated that future mobile communications systems are expected to meet the requirements of high mobility, high bit rate and seamless coverage.
It is foreseen that systems beyond 3G will include not only cellular phone systems, but also new types of communications systems such as wireless local area network (LAN) and broadband wireless access. This means that the bit rate for the services supported by the beyond 3G systems will be at least two orders of magnitude higher than that provided by 3G systems. Hence, the cell radius of beyond 3G systems will decrease, resulting in even smaller cell sizes as compared to those of 3G systems.

With the trend of moving towards smaller cell sizes in order to support high bit rate services with the required quality of service, it will be difficult to provide seamless coverage with terrestrial tower-based systems due to high infrastructure costs. In addition, governments are also increasingly reluctant to grant planning permissions for additional terrestrial tower-based base stations due to concerns over radiation and environment hazards. This has created some concerns among the new operators, as they might not have enough cell sites to provide a good coverage for their new 3G services. Existing 2G cells will likely be used to bridge the island of small 3G cells,
Chapter 2. Overview of HAPS UMTS

if the satellite components of the UMTS (S-UMTS) or other more innovative ways of delivering 3G services are not available. This means that complex dual-mode terminals must be developed to operate in such a deployment scenario.

S-UMTS has always been identified as the best solution to provide coverage and capacity for areas where it is too expensive to deploy terrestrial tower-based systems. While mobile satellite communications do provide global coverage, the high altitude of satellites also results in substantial signal delay, and the speed of low earth orbit (LEO) or medium earth orbit (MEO) satellites will also cause large Doppler shifts. Furthermore, satellite communications are expensive due to limited orbit space and high launching costs. In addition, the satellites cannot be retrieved from space for servicing and technological updating. These disadvantages make mobile satellite systems less attractive and have also resulted in the push for the development of new and more innovative solutions for the delivery of 3G and beyond 3G services.

One alternative telecommunications infrastructure that is actively pursued today is HAPS. HAPS are either airships or aeroplanes located in the stratosphere, typically 22 km above the earth. Antenna arrays attached to the underside of the airship or aeroplane produce multiple beams that form radio cells on the surface of the earth. A HAPS telecommunications architecture is unique because it combines advantages of both terrestrial tower-based and satellite communications systems. For example, it enjoys terrestrial tower-based system’s low propagation delay but enjoys satellite system’s favourable path loss characteristics. It is also flexible in deployment. For example, a HAPS can be sited over cities to increase capacity, or in rural areas to provide wide area coverage. HAPS can also be linked to ground stations, satellites or other HAPS to form a network in the sky. Each HAPS can produce tens to hundreds of cells and these cells can be tens of kilometres to a few hundred metres. Compared to mobile satellite systems, the spectral efficiency achievable by HAPS is enormously higher as cell sizes are much smaller. Furthermore, the HAPS can be returned to earth for equipment upgrades and maintenance.

Considering the number and diversity of worldwide HAPS projects, e.g., Sky Station (U.S.A.), HALO (U.S.A.), Helinet (Europe), SkyTower (U.S.A.), SkyNet (Japan), and the advantages and infrastructure cost savings possible with HAPS, one is tempted to believe that the realisation of HAPS communications will be possible in the near future.
2.4 Comparison between HAPS, Terrestrial Tower-based and Satellite Communications Systems

Terrestrial tower-based and satellite systems are two well-established methods of providing wireless communications. HAPS has the potential to become the third communications infrastructure after terrestrial tower-based and satellite systems because it combines both of their advantages as summarised in Table 2-1 [1].

One of the advantages of HAPS is its free space like path loss characteristic. Also, the HAPS propagation channel is characterised by Rician distributed fading while terrestrial tower-based channel has deeper, i.e. Rayleigh distributed fading. Other main advantages of HAPS are as follows:

- Centralised architecture can be implemented, which improves efficiency in resource allocation and channel utilisation.
- Synchronisation among different cells is possible, because a single timer can be implemented. Hence, handover between cells can be faster.
- System capacity can be increased by reducing the cell size through antenna beam shaping.
- Unlike satellite systems, HAPS can be brought down for servicing and upgrading easily. Also, equipment upgrading can be conveniently performed at a central location.

Table 2-1: Comparison between HAPS, satellite and terrestrial tower-based systems [1]

<table>
<thead>
<tr>
<th>Issue</th>
<th>Terrestrial (Tower-based)</th>
<th>Satellite</th>
<th>HAPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability and cost of mobile</td>
<td>Huge cellular/PCS market drives high volumes resulting in small, low-cost, low-power units</td>
<td>Specialised, more stringent requirements lead to expensive, bulky terminals with short battery life</td>
<td>Terrestrial terminals applicable</td>
</tr>
<tr>
<td>Propagation delay</td>
<td>Not an issue</td>
<td>Causes noticeable impairment in voice communications in GEO (and MEO to some extent)</td>
<td>Not an issue</td>
</tr>
<tr>
<td>Health concerns with radio emissions from handsets</td>
<td>Low-power handsets minimise concerns</td>
<td>High-power handsets due to large path losses (possibly alleviated by careful antenna design)</td>
<td>Power levels like in terrestrial systems (except for large coverage areas)</td>
</tr>
<tr>
<td>Issue</td>
<td>Terrestrial (Tower-based)</td>
<td>Satellite</td>
<td>HAPS</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Communications technology risk</td>
<td>Mature technology and well-established industry</td>
<td>Considerable new technology for LEOs and MEOs; GEOs still lag cellular/PCS in volume, cost and performance</td>
<td>Terrestrial wireless technology, supplemented with spot-beam antennas; if widely deployed, opportunities for specialised equipment (scanning beams to follow traffic)</td>
</tr>
<tr>
<td>Deployment timing</td>
<td>Deployment can be staged; substantial initial build-out to provide sufficient coverage for commercial service</td>
<td>Service cannot start before the entire system is deployed</td>
<td>One platform and ground support typically enough for initial commercial service</td>
</tr>
<tr>
<td>System growth</td>
<td>Cell-splitting to add capacity, requiring system reengineering; easy equipment update/repair</td>
<td>System capacity increased only by adding satellites; hardware upgrade only with replacement satellites</td>
<td>Capacity increase through spot-beam resizing, and additional platforms; equipment upgrades relatively easy</td>
</tr>
<tr>
<td>System complexity due to motion of components</td>
<td>Only user terminals are mobile</td>
<td>Motion of LEOs and MEOs a major source of complexity, especially when intersatellite links are used</td>
<td>Motion low to moderate (stability characteristics to be proven)</td>
</tr>
<tr>
<td>Operational complexity and cost</td>
<td>Well-understood</td>
<td>High for GEOs, and especially LEOs due to continual launches to replace old for failed satellites</td>
<td>Some proposals require frequent landings of platforms (to refuel or to rest pilots)</td>
</tr>
<tr>
<td>Radio channel &quot;quality&quot;</td>
<td>Rayleigh fading limits distance and data rate; path loss up to 50 dB/decade; good signal quality through proper antenna placement</td>
<td>Free-space like channel with Ricean fading; path loss roughly 20 dB/decade; GEO distance limits spectrum efficiency</td>
<td>Free-space like channel at distances comparable to terrestrial</td>
</tr>
<tr>
<td>Indoor coverage</td>
<td>Substantial coverage achieved</td>
<td>Generally not available (high-power signals in Iridium to trigger ringing only for incoming calls)</td>
<td>Substantial coverage possible compared to satellite communications.</td>
</tr>
</tbody>
</table>
Chapter 2. Overview of HAPS UMTS

<table>
<thead>
<tr>
<th>Issue</th>
<th>Terrestrial (Tower-based)</th>
<th>Satellite</th>
<th>HAPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth of geographical coverage</td>
<td>A few kilometres per base station</td>
<td>Large regions in GEO; global for LEO and MEO</td>
<td>Hundreds of kilometres per platform</td>
</tr>
<tr>
<td>Shadowing from terrain</td>
<td>Causes gaps in coverage; requires additional equipment</td>
<td>Problem only at low look angles</td>
<td>Similar to satellite</td>
</tr>
<tr>
<td>Communications and power infrastructure; real estate</td>
<td>Numerous base stations to be sited, powered, and linked by cables or microwave</td>
<td>Single gateway collects traffic from a large area</td>
<td>Comparable to satellite</td>
</tr>
<tr>
<td>Aesthetic issues and health concerns with towers and antennas</td>
<td>Many sites required for coverage and capacity; “smart” antennas might make them more visible; continued public debates expected</td>
<td>Earth stations located away from populated areas</td>
<td>Similar to satellite</td>
</tr>
<tr>
<td>Public safety concern about flying objects</td>
<td>Not an issue</td>
<td>Occasional concern about space junk falling to earth</td>
<td>Large craft floating or flying overhead can raise significant objections</td>
</tr>
</tbody>
</table>

2.5 HAPS Communications Systems

2.5.1 System Components

A HAPS communications system consists of telecommunications equipment onboard the HAPS, one or more ground switching/control stations, and mobile subscriber terminals as shown in Figure 2-2. The HAPS architecture is in concept very similar to a very tall terrestrial tower that is sectorised into hundreds of cells using directional antennas.
2.5.1.1 Platform

The HAPS is either a fixed wing flying aircraft (manned or unmanned) or a lighter-than-air airship positioned in the stratosphere. An aircraft is kept relatively stationary with respect to the ground by flying in a tight circle, while an airship will employ station keeping technology to counteract movements due to wind to remain stationary with respect to the earth.

2.5.1.1.1 Airships

The ITU has recommended that the HAPS should be stationed within a location sphere with a radius of 500 m. This is more achievable with the use of lighter-than-air airships than flying aircraft. In addition, airships are today the only class of stratospheric platforms that can maintain flight duration measured in months. An airship is a helium-filled lighter than air platform with a telecommunications payload. The platform is approximately 150 m in length and 40 m in diameter and can carry mission payloads of up to 1000 kg.

The airship is environmentally neutral. It does not generate pollution or debris, and does not impact the ozone layer. Solar cells covering the majority of the surface of the airship generate all the necessary power for station-keeping, telecommunications, and fuel cell charging. Fuel cells provide power for all operations during the night and eclipses. Onboard and remote power management controls automatically adjust the power mix to meet ever changing demands from the propulsion module, the communications modules, and the control module [21].
The airship is deployed from a launch centre through cleared air space. The buoyancy of the helium carries it to an altitude of about 22 km within several hours. Propellers move the HAPS to its service location at speeds of up to 200 km/h. The airship is stationed at an altitude far above commercial aircraft but below the protective covering of the outer atmosphere.

Electric motor driven propellers and a thermal control system are used for station-keeping. The propellers maintain position against the wind. The atmosphere at 22 km altitude is about 5% the density of the atmosphere at sea level and therefore the drag from wind is greatly reduced. A HAPS employs both passive and active thermal controls to limit the temperature variation inside the platform to within a few degrees. This enables the platform to maintain a stable altitude and provides a protective environment for the structure and the payload. Multiple redundant Global Positioning System (GPS) receivers and the station-keeping technologies enable the HAPS to remain in a nominal fixed position in all three dimensions, and further enable the antenna assemblies to maintain a fixed coverage pattern on the ground. In addition, any residual pointing error due to the movement of the HAPS is compensated by appropriate station keeping mechanisms or by steering the beams electronically.

The airship is returned under a controlled descent to ground facilities for payload upgrades, routine maintenance and redeployment, or recycling.

HAPS projects that propose the use of airships are Sky Station [3] and SkyNet [7].

2.5.1.1.2 Fixed Wing Aircraft

Fixed wing aircraft may be manned or unmanned, and must fly in a tight circle above the service area. The endurance of the aircraft is shorter than that of an airship and is in the order of hours and weeks instead of months due to fuel constraints. For manned aircraft, the time aloft will be limited to about 8 hours due to human factors. Therefore, the aircraft must be operated in shifts to provide round-the-clock service. Unmanned aircraft powered by solar cells have longer flight endurance in terms of months and are currently under development with good progress [6].

HAPS projects that are based on flying aircraft include HALO [4], Helinet [5] and SkyTower [6].
2.5.1.2 Communications Payload

The HAPS telecommunications payload consists of multi-beam light weight reflector or phased array antennas, transmit/receive antennas for gateway links with ground switching stations, and a very large bank of processors that handle receiving, multiplexing, switching and transmitting functions. The payload can utilise various multiple-access techniques and standards, e.g., CDMA, TDMA.

The high gain transmit/receive antennas used onboard the HAPS project a large number of cells onto the ground in a pattern similar to that created by a traditional cellular system, as shown in Figure 2-2. The sizes of the HAPS coverage area and of the spot beams within the coverage area are determined by the antenna array that is designed to match the demand for capacity within any selected coverage area. The power allocated to each cell, and the cell's boundaries, are controlled to maximise overall system capacity. Small cells serve high-density zones in order to provide a high level of capacity whereas larger cells serve less dense zones. A HAPS system may provide mobile cellular coverage or fixed wireless services such as Local Multipoint Distribution Systems (LMDS) or broadcasting to regions ranging from high-density urban areas to low-density rural areas. HAPS will also likely use shaped beams and/or phased array antennas that will provide contour shaping of the coverage beams.

2.5.1.3 Ground Equipment

Communications between the HAPS and the ground is established via the backhaul link to a single ground installation, or perhaps into two locations for redundancy. There is considerable advantage to collocating RF units, base stations and mobile switching centres (MSC), as will be highlighted in the subsequent chapters. From the ground station, the signals are passed in the usual manner to through the MSC to the public switched telephone network (PSTN) and internet. The return signal path from the PSTN and internet towards the HAPS is also established through the ground station in the reverse direction.

2.5.2 General Architecture of HAPS UMTS

2.5.2.1 Frequency Allocation for HAPS UMTS

The frequency bands used for HAPS UMTS will be within the frequency range 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz in Regions 1 and 3 and 1885-1980 and 2110-2160 MHz in Region 2 [20]. Backhaul links to and from gateway stations or between HAPS will not be in
bands designated for UMTS and will utilise non-UMTS frequencies, e.g., millimetre-wave frequencies.

2.5.2.2 Radio Interface

HAPS UMTS provides terrestrial UMTS services using a base station network located in the stratosphere instead of traditional tower/rooftop deployed base stations. Although the delivery platform for HAPS (base stations consolidated on a geostationary platform in the stratosphere) is very different from traditional ground based systems (base stations distributed on towers and rooftops), HAPS UMTS will use radio transmission technologies that satisfy terrestrial tower-based UMTS requirements and therefore provide the same functionality and meet the same service and operational requirements as terrestrial tower-based UMTS [21]. Consequently, the HAPS UMTS network operates in the same fundamental manner as terrestrial tower-based UMTS, transparent to the user.

Each platform provides instant telecommunications infrastructure for an entire region and does not require the deployment of additional, or a constellation of, stations to provide service. The platforms can be linked directly to one another by hop stations located midway between the platforms or by inter-platform links, and can also be linked indirectly via satellite or the PSTN. The HAPS user terminals will be designed to share the same radio interface as traditional terrestrial tower-based systems and, therefore, a single handset will work with both a HAPS and traditional terrestrial towers. This will enable regional and worldwide roaming with a single handset.

2.5.2.3 Reference Phased Array Antenna Radiation Pattern

One of the key components of a HAPS communications system is the multi-beam phased array antenna, which projects cells from the HAPS onto the ground in a cellular pattern. For interference-limited HAPS UMTS based on WCDMA technique, high performance antennas are required to support high capacity. In addition, as HAPS UMTS will be interoperating with existing terrestrial tower-based and satellite systems, it can potentially introduce interference to these components operating in the same frequency band. Therefore, high performance antennas are required to also limit unwanted out-of-band emissions.

To ensure the HAPS can co-exist with other communications infrastructures with minimum interference, ITU has defined the reference antenna radiation pattern for HAPS UMTS. It is based
on high performance, multi-beam phased array using digital beam forming technology and a cosine square illumination profile. The antenna roll off is 60 dB/decade, which is much better than the 25 dB/decade performance of a parabolic antenna. As will be shown in subsequent chapters, the improved roll off significantly reduces adjacent cell interference and enables a significant capacity improvement for interference-limited HAPS UMTS.

The ITU reference antenna radiation pattern is given by [19]:

\[
G(\psi) = \begin{cases} 
G_m - 3 \left( \frac{\psi}{\psi_h} \right)^2 \text{ (dBi) for } 0 \leq \psi \leq \psi_1, \\
G_m + L_N \text{ (dBi) for } \psi_1 < \psi \leq \psi_2, \\
X - 60 \log(\psi) \text{ (dBi) for } \psi_2 < \psi \leq \psi_3, \\
L_F \text{ (dBi) for } \psi_3 < \psi \leq 90^\circ, 
\end{cases}
\]  

(2.1)

where

- \(G(\psi)\): Gain at the angle \(\psi\) from the main beam direction (dBi),
- \(G_m\): Maximum gain in the main lobe (dBi),
- \(\psi_h\): One-half the 3 dB beamwidth in the plane of interest (3 dB below \(G_m\)) (degrees),
- \(L_N\): Near-in-side-lobe level in dB relative to the peak gain required by the system design

and

\[L_F = G_m - 73 \text{ (dBi)},\]  

(2.2)

\[\psi_1 = \psi_h \sqrt{\frac{L_N}{3}} \text{ (degrees)},\]  

(2.3)

\[\psi_2 = 3.745 \psi_h \text{ (degrees)},\]  

(2.4)

\[X = G_m + L_N + 60 \log(\psi_2) \text{ (dB)},\]  

(2.5)

\[\psi_3 = 10^{- \frac{X-L_F}{60}} \text{ (degrees)}.\]  

(2.6)
Chapter 2. Overview of HAPS UMTS

The 3 dB beamwidth \( (2\psi_h) \) is estimated by

\[
(\psi_h)^2 = \frac{7442}{10^{0.1G_m}} \text{ (degrees}^2) .
\]  \hspace{1cm} (2.7)

Figure 2-3 shows the masks of phased array antenna radiation patterns with different values of \( G_m \) that conform to the above ITU specifications.

![Figure 2-3: Mask of the antenna radiation pattern recommended by ITU for HAPS UMTS](image)

2.5.2.4 Service Coverage

The HAPS UMTS coverage will likely include three regions: (i) high-density (urban); (ii) moderate-density (suburban); and (iii) low-density. The high-density region is characterised by many users concentrated in a limited geographical area. This service region needs to support both vehicular (typically low-speed) and pedestrian traffic. The moderate-density region is characterised by a mix of mostly high and moderate-speed vehicular users but with some pedestrian users. The low-density region typically includes fixed wireless users and mobile users (voice only). These users will be spread over a wide geographical area [21].
2.5.3 Characteristics of HAPS UMTS

HAPS UMTS supports most of the same environments as terrestrial tower-based UMTS networks. In addition, both the HAPS and terrestrial tower-based systems have many of the same features as outlined in Table 2-2 [21]. Only very small pico-cells (< 100 m) and indoor high-speed operations are not supported by HAPS.

Table 2-2: Comparison between HAPS and terrestrial tower-based UMTS [21]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Terrestrial Tower-based Systems</th>
<th>HAPS Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Coverage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell size ($r =$ radius)</td>
<td>Different sizes supported:</td>
<td>Different sizes supported:</td>
</tr>
<tr>
<td></td>
<td>micro: $100, m &lt; r &lt; 1, km$</td>
<td>micro: $150, m &lt; r &lt; 1, km$</td>
</tr>
<tr>
<td></td>
<td>macro: $r &gt; 1, km$</td>
<td>macro: $1, km &lt; r &lt; 20, km$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>regional: $r &gt; 20, km$</td>
</tr>
<tr>
<td><strong>Environments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business indoor environment</td>
<td>Supported (specialised indoor systems)</td>
<td>Not supported</td>
</tr>
<tr>
<td>Neighbourhood indoor/outdoor environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Home environment</td>
<td>Supported (specialised systems)</td>
<td>Not supported</td>
</tr>
<tr>
<td>Urban vehicular outdoor environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Urban pedestrian outdoor environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Rural outdoor environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Terrestrial aeronautical environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Fixed outdoor environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Local high bit rate environment</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td><strong>Mobile Station</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power (EIRP)</td>
<td>$&lt; 1, W$</td>
<td>$&lt; 1, W$</td>
</tr>
<tr>
<td>Antenna</td>
<td>Omni (0 dBi gain)</td>
<td>Omni (0 dBi gain)</td>
</tr>
<tr>
<td><strong>Base Station</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Tower or rooftop</td>
<td>Geostationary platform in stratosphere</td>
</tr>
<tr>
<td>Power (EIRP)</td>
<td>$30, dBW$</td>
<td>$30, dBW$</td>
</tr>
</tbody>
</table>
Chapter 2. Overview of HAPS UMTS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Terrestrial Tower-based Systems</th>
<th>HAPS Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna gain</td>
<td>13 dBi (vehicular)</td>
<td>30-50 dBi (peak)</td>
</tr>
<tr>
<td></td>
<td>10 dBi (pedestrian)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 dBi (indoor)</td>
<td></td>
</tr>
</tbody>
</table>

Although comparable in many ways to terrestrial tower-based UMTS, HAPS UMTS have the following additional features.

- **Infrastructure savings**: A single HAPS, when deployed, can serve a footprint that extends over an entire 200 km radius footprint. On the other hand, for traditional tower-based systems, substantial build-out is required to provide sufficient coverage for commercial service.

- **Centralised resources**: For HAPS UMTS, as the base stations are collocated at the same facility, delay in information exchange between them is minimum, thereby enabling more optimum resource management.

- **Soft infrastructure**: HAPS UMTS can make use of dynamic beam assignment to dynamically reassign capacity among the cells in order to focus the capacity where it is most needed at any given time. For instance, the HAPS can direct additional capacity towards automobile traffic during rush hour and then shift it to a stadium during an evening sports event or performance. This gives HAPS UMTS greater flexibility than terrestrial tower-based UMTS.

- **Softer handover**: As all base station antennas are collocated on the platform, a single timer can be implemented to synchronise the cells, enabling handover to be faster and softer. Therefore service to extremely fast moving vehicles is possible.

- **Better interference rejection**: HAPS UMTS provides an improved antenna radiation pattern as compared to the R^4 law used by terrestrial tower-based base station antennas. This enables higher bandwidth utilisation across the entire coverage area since other cell interference is greatly reduced.

2.5.4 HAPS UMTS Deployment Scenarios

HAPS UMTS can be deployed alone or be jointly deployed with terrestrial tower-based base stations, satellites and other HAPS. For the latter case, inter-HAPS links or HAPS-satellite links will be needed to interconnect HAPS traffic to other HAPS and/or satellite systems.
One important deployment scenario is the use of HAPS UMTS to bridge islands of terrestrial tower-based cells. The cell sizes of the 3G systems are expected to be much smaller than those of the existing 2G Global System for Mobile Communications (GSM) systems due to the need to support high bit rate multimedia services. During the initial implementation phase of WCDMA, it is expected that the 2G systems will be required to provide continuous coverage, i.e., to bridge the islands of 3G cells, if the satellite component of the UMTS (S-UMTS) is not available [22]. This means that complex dual-mode terminals will be necessary. In this case, HAPS UMTS can offer an effective and attractive solution because it can be quickly deployed to fulfil the function of providing continuous macrocell coverage and bridging the islands of terrestrial tower-based UMTS cells. Figure 2-4 shows an envisaged integrated UMTS network consisting of HAPS and terrestrial tower-based UMTS. With such a deployment scenario, it is then possible to realise an overlay cellular communications system with a common air interface for both macrocell and microcellular coverage, leading to faster mobile service deployment.

Figure 2-4: Deployment scenario for HAPS UMTS macrocells overlaying with terrestrial tower-based UMTS microcells
2.6 Conclusion

With specific advantages over terrestrial tower-based and satellite systems, HAPS will play an increasingly important role in the provision of wireless services. ITU has recently endorsed the use of HAPS as an alternative means of delivering UMTS. HAPS UMTS will use the same radio transmission technologies as terrestrial tower-based UMTS and share the same mobile terminals. Therefore, the operation of HAPS UMTS as compared to terrestrial tower-based UMTS will be transparent to the user. Although comparable in many ways to traditional terrestrial tower-based systems, HAPS systems offers key unique features that can improve overall system performance and provide increased design flexibility. In cooperation with both terrestrial and satellite elements, HAPS can provide another degree of flexibility for system deployment that can be easily adjusted to the needs of the network operators and users’ traffic demands.
Chapter 3

3 Call Admission Control for UMTS

3.1 Introduction

In this chapter, we discuss the importance and role of CAC in UMTS. We will also present an overview of the various classes of CAC schemes and discuss their relative advantages and disadvantages. Finally, we will highlight the approach adopted in this research in addressing the problem of CAC for HAPS UMTS.

3.2 The Need for CAC for UMTS

For systems using FDMA and TDMA techniques, traffic channels are allocated to users as long as there are channels available, after which all incoming traffic is blocked until a channel becomes free at the end of a call. However, in UMTS employing WCDMA technique, users all share a common frequency allocation over the time that they are active. Hence, new users can be accepted as long as there are receiver processors to service them, independent of time and frequency allocations [23].

We will assume henceforth that there is a sufficient number of receiver processors in the base stations such that the probability that a new arrival finding no processors is negligible. With this assumption, CDMA networks do not have hard capacity limits in any cell, but manifest excessive outage in case the cell is overloaded with calls, i.e., capacity is limited only by the total level of interference generated from the transmissions of all connected users (so-called “soft capacity”). The system can accommodate more users by allowing more interference into the system and hence sacrificing the communications quality of existing users (so-called “graceful degradation”) [8].

Although a WCDMA based system is not characterised by a hard limit on the number of users, the level of interference in the system cannot increase indefinitely; the number of simultaneous users occupying a cell must be limited such that an appropriate level of communications quality
can be maintained. When the system is congested, admitting a new call can only make link quality worse for ongoing calls and may lead to loss of communications quality (call dropping). However, when the interference level is still "bearable", the system should not block a new call if the network can support it in order to provide a good grade of service (i.e., a low call blocking rate). In order to manage this trade-off between system capacity and communications quality, UMTS needs a CAC policy to regulate the admission of new call requests.

3.3 Objective of CAC

The role of CAC in UMTS is to regulate and manage incoming calls so as to guarantee both a grade of service (GoS), i.e., blocking rate, and a quality of service (QoS), i.e., the probability of loss of communications quality [8]. The CAC procedure decides whether to accept or reject a new connection and CAC should always be performed when a new or handover call requests service from a base station.

3.4 Location of CAC Functionality in UMTS Network

As shown in Figure 3-1, CAC is part of radio resource management (RRM) in Layer 3 of the radio interface protocol responsible for utilisation of air interface resources.

RRM is needed to guarantee the QoS, maintain the planned coverage and offer high capacity. The full scope of RRM is very large thus several algorithms are needed to perform the task. These algorithms are:

- Call admission control
- Power control
3. Call Admission Control for UMTS

- Handover control
- Load control
- Packet scheduler

CAC is carried out by the Radio Network Controller (RNC) in the UMTS network, as shown in Figure 3-2.

![Figure 3-2: Location of CAC functionality in the radio network](image)

To be able to decide whether a new call can be accepted, the current load situation of the access cell and the surrounding cells in the network has to be known and the additional load contributed by the call request has to be estimated. Therefore, the CAC functionality is located in the RNC where all these information is available [24].

3.5 Principles of CAC

CAC needs to use both the system and user characteristics to manage the available resources, i.e., to monitor the system’s available capacity, accommodate the new call requests and at the same time ensuring the QoS of existing calls.

As shown in Figure 3-3, a typical CAC procedure requires a number of inputs in order to make an admission decision. The inputs may be the call’s service type, QoS requirements (e.g., energy-per-bit to interference density ratio \(E_b/I_0\), delay tolerance, bit error rate, etc.) and the current
system load. The output of the call admission control process is a decision on whether to admit or block a call and the allocation of resources to all mobiles if a new call is admitted.

The call admission control procedure can be divided into three phases: computation/measurement, decision and execution, as shown in Figure 3-4.
When the base station receives a new call request, the admission controller measures/computes/estimates the CAC metric, which, for example, may be the uplink interference level at the base station or the downlink transmission power of the base station. Next, the CAC metric is compared against predefined thresholds or criteria obtained through radio network planning. Separate metrics are obtained for the uplink and downlink. Only if both uplink and downlink admission criteria are fulfilled can the call be admitted.

Because of the different nature of different services, CAC will have to treat each service type differently. For real time traffic (the delay-sensitive conversational and streaming classes), it must be decided based on the measured/computed metric whether the mobile station is allowed to enter the network. If the new call will cause excessive interference to the system, i.e., the CAC criterion is not met, access is denied. For non-real-time (NRT) traffic (less delay-sensitive interactive and background classes) the optimum scheduling of the packets (time and bit rate) must be determined after the call has been admitted. This is done in close cooperation with the packet scheduler [24].

### 3.6 Considerations in CAC Design for UMTS

#### 3.6.1 Variation in System’s Soft Capacity

One of the difficulties in CAC is that the interference level and consequently the soft capacity of a particular cell is variable and is not known explicitly because it depend on various random, time-varying user properties. This uncertain capacity and its variation make CAC in UMTS networks not a trivial issue. The major factors affecting the UMTS soft capacity are summarised in Figure 3-5 and are described as follows.

- **User position:** The total level of interference in UMTS is affected by the positions of the mobile users. For example, in the reverse link, mobiles located at the cell boundaries of interfering cells transmit higher power (in order to be properly received at their respective base stations), causing increased interference experienced by the desired base station. As mobile positions are random, the interference generated by the mobiles is also random, making prediction of capacity difficult.
- **User mobility**: In addition to supporting different traffic types, UMTS is also envisioned to support a mixture of platform types having different mobility characteristics, e.g., pedestrians and low and high-speed vehicles. Two aspects of user mobility affect the CDMA soft capacity:

  (1) User speed: The speeds of the users affect the propagation characteristics of their connection and hence cause variations in the power received at the base station. This in turn causes dynamic variations in link quality and interference levels.

  (2) Handover: User mobility also causes handovers to occur between adjacent cells. Handover increases the complexity of CAC algorithms. From the point of view of subscribers, forced termination in the middle of a call is more disturbing than the blocking of a new call. Hence, the CAC scheme should, if possible, give priority to the admission of handover calls in order to keep handover dropping probability low. This requires coordination between both base stations to allow the user to make a seamless transition between the two cells and to ensure that the connection will remain unaffected [15].
• **Traffic activity:** The traffic generated by a mobile user is discontinuous, marked by periods of activity (ON) and inactivity (OFF). Different service types may have different fractions of activity periods versus inactivity periods, i.e., transmission activity factors. For example, a WWW call has a longer silent period (during reading time) as compared to a voice call. During silent periods, the mobile is not transmitting and is thus not causing interference. Therefore, periods of inactivity reduce the level of interference generated and increase capacity. The randomness of traffic activity adds to the unpredictability of interference level and system capacity.

• **Propagation channel:** In the mobile propagation environment, obstructions and the movement of mobiles with respect to the base stations cause the amplitude of the received signals to fluctuate. This fluctuation results from the combined effect of random multipath signals and shadowing. The QoS parameters such as BER and delay will be affected in such an environment. In addition, when the received signal level fluctuates, the capacity fluctuates as well, adding to the difficulty of making CAC decisions.

• **Power control:** In UMTS, power control is employed to regulate the mobiles’ transmit powers so as to provide each user an acceptable connection quality. However, in practice, power control cannot be completely accurate. The power control error depends on several factors, e.g., the power control algorithm, power control command rate, power control step size, power control loop delay, channel response, etc. The result of imperfect power control is that mobile users may perform power adjustments that make them achieve a QoS better or worse than the target QoS. In the first case, a user achieves a better QoS, but at the same time generates excessive interference that degrades the QoS of the other users. In the second case, the user achieves a QoS lower than required, which may lead to the call being dropped. Hence, power control error and its fluctuation add to the unpredictability of link conditions and contribute to the complexity of making CAC decisions.

A good CAC scheme should be able to adapt to the dynamic soft capacity so that QoS and capacity can be optimised.

### 3.6.2 Variable Quality of Service Requirements

HAPS UMTS networks will support a variety of traffic types and transmission rates. Hence, at any time, the system will need to serve a combination of voice, data and video users that have different requirements in terms of bandwidth, BER, delay tolerance, etc. For example, a voice service is sensitive to delay but can tolerate higher bit error rates. However, a data service can
tolerate relatively large delays (can be queued) but requires lower bit error rates than the voice service [25]. The CAC policy should be service dependent and should take into account the specific QoS requirements of each service, calculate the required resources for the connection, and estimate the impact of the allocation on existing connections. Priorities may need to be allocated to delay-insensitive services.

3.6.3 Variable Power Requirements

To maintain the same QoS, the higher the bit rate, the higher the transmit power and hence the larger the interference caused to other users. Generally, users with high bit rates and high QoS requirements limit the capacity of a mixed traffic CDMA system [26]. When system resources are limited, the admission of a high-rate data user will degrade the whole system's performance. It is thus essential that a base station identifies each user's data rate and transmit power as part of its call admission policy, in order to avoid degrading the QoS of other users. Arrivals of high-powered, high bit-rate users that require large amounts of resources may demand global information in order to make an accurate admission decision [27].

3.6.4 Cellular Structure

Different cellular layouts impose different requirements on CAC and require different CAC parameters and strategies to obtain optimum system performance. For example, in hierarchical cellular structures, there are many different types of overlaying cells whose cell radii and shapes are determined by the geographical coverage area and density of mobiles users. The addition of smaller cells to give high capacity for smaller coverage area (i.e., microcells) and can provide increased capacity and coverage for the network. In such an integrated cellular system, the main goal of CAC is to provide a balance between maximising the number of users per unit area (favours small cells) and minimising the network control and handover rate (which favours larger cells). One of the critical issues is an optimum distribution of resources between macrocell and microcell layers so as to avoid a particular layer from being overloaded. CAC in hierarchical cell architectures have to be carefully optimised so that the upper layer and lower layer can act complementarily to achieve optimum system performance.

3.7 Desirable Features of CAC

A good CAC scheme can achieve many desirable features by trading different operating characteristics. Some of the desirable features of CAC algorithms are summarised as follows [15]:
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- Accuracy: To make an accurate decision, the CAC scheme should take into account as many factors as possible (i.e., multi-criteria decision) that impact the capacity of the system (described in Section 3.6.1). Also, the CAC scheme should ensure that the mobiles meet their respective QoS both in the uplink and downlink.

- Adaptability to user characteristics: The CAC scheme should have a fast response and adapt automatically to the time varying user characteristics (described in Section 3.6.1) to define and manage the resources.

- Adaptability to different environments: The HAPS service area has different environments with different propagation statistics e.g., urban, suburban or rural. The CAC scheme should be adaptable in order to (i) maximise capacity utilisation and (ii) provide an acceptable and stable QoS in the various environments.

- Admission speed: The decision to admit or block a call should be fast in order to minimise call set up time.

- Stability of QoS: The network target performance should be maintained continuously to ensure user satisfaction.

- Easy implementation: The implementation of the CAC scheme should not incur too much additional overheads or complicated architecture. For example, a CAC scheme requiring only software implementation is simpler than one requiring additional hardware.

- Ease of reconfiguration: The CAC scheme should be easily configurable to accommodate the introduction of additional services with different QoS requirements.

The design of CAC algorithms may require a trade-off between the above properties.

3.8 Types of CAC Schemes and Their Classification

There are many features that can be used to classify CAC schemes. The most common basis is to compare the CAC schemes in terms of the way they are implemented. They can be classified as fixed, adaptive, local or global. The second method is to categorise the schemes in terms of the CAC metric used for admission decision. For example, number based CAC, interference based CAC, SIR based CAC and transmit power based CAC. Figure 3-6 summarises the most common CAC schemes proposed in literature.
3.8.1 Fixed CAC

Fixed CAC (F-CAC) schemes make admission decisions by comparing the resources required by an incoming call with a fixed, pre-determined threshold of resources available in the network. The threshold is service dependent and is computed off-line. It is normally computed by designing the system to meet certain performance criteria, while assuming average propagation conditions and traffic distributions [28]. For example, for the number based scheme in [8] and [29], the system determines off-line the maximum number of calls $N_{\text{max}}$ that can be accommodated in the system while meeting performance objectives, assuming average propagation conditions. The CAC policy is then specified as: accept an incoming call if the number of ongoing calls is less than $N_{\text{max}}$. In a multi-service environment, voice and data traffic will have different thresholds, which depend on the profile of the mixed service traffic (i.e., percentage of voice and data users). This requires the identification of an admission region which can be used to decide which number combinations of different services can coexist in the system in order to ensure that all services meet their QoS requirements [30].

3.8.1.1 Local and Global Fixed Strategies

Fixed CAC schemes can be further classified as local fixed CAC (LF-CAC) and global fixed CAC (GF-CAC). For LF-CAC, decision is made on a cell-by-cell basis, independent of the resource utilisation in other cells, e.g., in [8] and [29]. GF-CAC is an extension of LF-CAC where decision is made not only considering the resource utilisation in the access cell but also
considering the resource utilisation in adjacent cells to take the intercell interference effect into account. By doing so, it is hoped that a more accurate decision can be made at the expense of the overheads associated with the exchange of the information between the base stations [31]. For example, GF-CAC is adopted in [32].

3.8.1.2 Enhancements to Fixed Strategies

Some CAC schemes are based on fixed strategies but have additional features that allow them to perform better. Enhancements to the basic fixed CAC schemes include the use of priorities, handover reservation and queuing of blocked calls. For example, it is usually preferable to block a new incoming call than to lose an existing one, as it is irritating to a customer to lose his call when moving from one cell to another. Several CAC techniques give priority/reserve resources for handover calls. For example, it is suggested in [28] that a number based CAC scheme can be combined with handover reservation. This means that the CAC criterion will be to accept an incoming call if the number of ongoing calls is less than $N_{\text{max}} - N_h$, where $N_h$ is a reservation margin allocated to accommodate handover calls. Also, in [33] employing number based CAC, voice calls are given higher priority over data calls. An additional level of admission threshold is set so that beyond a certain threshold, the bit rate and transmit powers of data calls are reduced to accommodate more voice calls.

3.8.1.3 Advantages and Disadvantages of Fixed CAC

The main advantage of F-CAC is its simplicity. It can be easily implemented by base station control software. On the other hand, F-CAC schemes implicitly assume that the network's capacity remains constant over time. However, in reality, the system's capacity varies due to environmental factors and/or user characteristics as mentioned in Section 3.6.1. Hence, F-CAC schemes are inflexible and do not utilise the system's capacity optimally. In addition, F-CAC schemes require advanced knowledge of user distributions and propagation conditions [29], which in some cases are difficult to predict. There is also difficulty in setting the F-CAC threshold. Setting the threshold based on a worst-case scenario will guarantee that users in the system can enjoy their specified QoS. However, in this case, bandwidth utilisation can be far from optimum. On the other hand, setting the threshold based on an average scenario may risk some users being outaged. Another disadvantage is that the F-CAC thresholds must be specifically redesigned due to changes in propagation parameters and traffic distributions, or when new services are added [8].
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3.8.2 Adaptive CAC

In adaptive CAC (A-CAC), the base station performs periodic quality measurements to gauge prevailing transmission conditions. The base station then makes an admission decision by comparing the measured value with a threshold value. A-CAC schemes take into account the traffic and interference dynamics of the system because the decision on whether to admit or block a call is dependent on the current interference conditions in the cell, rather than pre-computed thresholds. Commonly used quality measurement metrics include SIR [12], interference level [14] and transmit power [13].

3.8.2.1 Local and Global Adaptive Strategies

In local adaptive CAC (LA-CAC), the local base station performs periodic quality measurements and makes an admission decision independent from other base stations, e.g., [14], [15] and [16]. Global adaptive CAC (GA-CAC) is an extension of the local adaptive strategy where the decision made by the local base station is also based on periodic information obtained from neighboring base stations, i.e., decision is made by considering a cluster of cells rather than just the local cell. This ensures that the admission of a new call will not degrade the quality of service of the calls in the surrounding cells as well. The global adaptive approach is proposed in [12] and [15]. Figure 3-7 illustrates the operation of the local vs. global CAC schemes. The global adaptive strategy is performed at the expense of high signalling load between base stations. Also, for terrestrial tower-based systems where base stations are geographically dispersed, besides the additional complexity caused by the exchange of large amounts of information between the base stations, there is also a delay in the information exchange protocol so the global information obtained at the base stations are not the most updated and generally reflects the state of the network some time in the past [31].

![Figure 3-7: Local and global CAC](image-url)
3.8.2.2 Enhancements to Adaptive Strategies

Similar to fixed CAC schemes, enhancements are also possible for adaptive CAC schemes to further improve the system performance. For example, in [34], blocked data calls are delayed and queued to retry their call request in the next time step. In [35] and [36], priorities are given to different QoS classes and QoS renegotiation is employed based on the assumption that if the users cannot acquire the necessary resources in order to obtain their highest QoS level, they are willing to accept an admission at a lower level service, rather than being blocked. Also, incoming calls will be simply queued for later contention if the interference level is too high. The authors showed that the enhanced algorithm outperforms the conventional scheme having no priority classification.

3.8.2.3 Advantages and Disadvantages of Adaptive CAC

Unlike fixed schemes, adaptive schemes adjust automatically to the changing environment. Hence, better capacity utilisation is expected. In addition, adaptive schemes are flexible and design-free because it does not require any advanced evaluation of the propagation and traffic environment. However, monitoring of the transmission conditions increases the complexity of the algorithm and may complicate base station or mobile hardware and architecture. Adaptive schemes may also suffer performance degradation due to measurement error.

3.9 Unique Characteristics of HAPS for CAC Design

The CAC schemes proposed for terrestrial tower-based UMTS can be applied directly to the HAPS environment, with appropriate CAC thresholds obtained via radio network planning. However, this may not be the most optimum approach. HAPS UMTS have the following additional unique characteristics not found in terrestrial tower-based systems that can be exploited for the design of CAC algorithms which will allow more optimum performance to be achieved.

- **Onboard power resource sharing**: Unlike terrestrial tower-based systems, all the HAPS base station antennas are collocated, so the platform power available for traffic channels can be shared among all base stations, resulting in more efficient utilisation of resources. This is especially important because of the limited power available onboard the platform due to constraints on payload, fuel cell efficiency and platform size.

- **Collocation of base station equipment**: In terrestrial tower-based systems, base stations are geographically dispersed. However, in HAPS systems, resources are centralised in a common facility. This centralised architecture will facilitate the implementation of global CAC schemes because the delay in the information exchange protocol between the base stations will be minimal. This means that global information obtained by the base stations
is likely to reflect the current state of the network rather than the status a few instances in
the past. In fact, the collocation of base station equipment allow a more integrated, i.e.,
centralised CAC schemes to be implemented.

3.10 CAC Design Strategy for HAPS UMTS

Existing terrestrial tower-based CAC schemes and their various enhancements (e.g., queuing,
handover reservation, etc.) are expected to work in the HAPS UMTS environment. But due to the
unique properties possessed by HAPS, more optimum performance can be obtained. Therefore,
in designing CAC schemes for HAPS UMTS, our approach is to exploit the unique characteristics
of HAPS to develop specific CAC schemes tailored to the HAPS environment that can provide
improved system performance over traditional terrestrial tower-based CAC schemes.

3.11 Conclusion

CAC is carried out at the RNC of the UMTS network and is responsible for managing the
resources in the service area by regulating the number of calls to ensure that mobiles meet their
QoS requirements. Variations in the mobile environment and different QoS requirements of users
contribute to the complexity of CAC design. Various CAC schemes and enhancements to the
schemes have been proposed in literature for terrestrial tower-based systems. When directly
applied to HAPS UMTS, these schemes may not yield optimum performance. The approach
adopted in this work is therefore to exploit the unique characteristics of HAPS for CAC design so
that better system performance can be obtained.
Chapter 4

4 Interference, Power Control and Capacity for HAPS UMTS

4.1 Introduction

In HAPS UMTS employing WCDMA access technique, the total interference in the system directly influences the supportable capacity. In this chapter, we analyse the unique HAPS geometry and characterise the interference properties of HAPS UMTS. Based on the unique interference characteristics of HAPS, we present a theoretical capacity estimation of the reverse and forward link capacities of HAPS UMTS. When deriving the HAPS UMTS forward link capacity, we also investigate a class of forward link power control schemes based on distance and show that these power control schemes perform favourably in the HAPS environment. In particular, a power control scheme based on nth-power-of-distance is optimised for the HAPS environment and an optimum distance based power control scheme is proposed which allows uniform service to be provided throughout the cell.

4.2 HAPS System Model

In our capacity analysis, we assume that a HAPS carrying a WCDMA communications payload and a multi-beam phased array antenna with beam/gain shaping capability is positioned at an altitude of 22 km above the service area. With the WCDMA communications payload and phased array antenna onboard the HAPS, contour shaped spot beams can be projected on the ground within the service area in a pattern similar to that created by a traditional cellular system to provide mobile communications services. To simplify the analysis, we neglect the effect of the earth's curvature and assume that the cells are approximately circular and equally sized with radius $R$. Any residual pointing error due to the movement of the HAPS is assumed to be compensated by appropriate station keeping mechanisms or by steering the beams electronically.

The antenna radiation pattern used for cell projection has a sharp roll off of 60 dB/decade and conforms to the specifications in Section 2.5.2.3. The mask of the phased array antenna radiation
pattern normalised to the maximum main lobe gain \((G_m)\) of 36.7 dB is shown in Figure 4-1. The gain at cell boundaries is taken to be \(-13\text{dB}\) with respect to \(G_m\).

![Normalized antenna gain vs. angle off boresight](image)

Figure 4-1: Mask of the HAPS UMTS antenna radiation pattern for \(G_m = 36.7\text{ dB}\)

### 4.3 Reverse Link Capacity Analysis

In the reverse link of a WCDMA cellular system, the same spectrum is shared by all users. Thus, the power transmitted by each user becomes interference to the other users, which is one of the most limiting factors on the system capacity.

#### 4.3.1 Sources of Interference in the HAPS UMTS Reverse Link

The interference on the reverse link consists of the superposition of signals from mobiles at the base station receiver. As shown in Figure 4-2, the sources of interference on the HAPS UMTS reverse link (as received at a particular base station) are:

- **Same-cell interference:** The powers transmitted by mobiles located in the cell served by the base station.

- **Other-cell interference:** The powers transmitted by mobiles located in surrounding cells served by other base stations.
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4.3.2 The Need for Reverse Link Power Control

In the reverse link of HAPS UMTS, all users transmit at the same frequency at the same time and therefore interfere with one another. Due to the propagation mechanism, the signal received by the base station from a mobile close to the cell centre will mask the weak signal received from another mobile at the cell boundary, causing the so-called near-far effect.

In order to combat the near-far effect, a power control scheme should be applied on the reverse link, so that all mobiles, irrespective of their locations in the cell, will have their transmitted signals arrive at the base station with equal power.
4.3.3 Same-cell Interference Analysis

We assume that $M$ mobile users are uniformly distributed in each cell, giving a user density of

$$\rho = \frac{M}{\pi R^2} \quad (4.1)$$

users/cell.

In the reverse link, in order to combat the near-far effect, dynamic power control of the mobile transmitter powers is required. The capacity per cell is maximised by ensuring that each signal's power is the same at the base station. Therefore, in our analysis, we assume that the reference base station receives the same power, $S$, from all mobiles within its cell coverage. For $M$ users per cell and a voice activity factor $\alpha$, the total same-cell interference power ($I_{sc}$) can be written as

$$I_{sc} = \alpha(M - 1)S. \quad (4.2)$$

4.3.4 Other-cell Interference Analysis

Figure 4-3 shows the HAPS UMTS reverse link interference geometry.

![Figure 4-3: HAPS UMTS reverse link interference geometry](image)
The reference cell is located at the platform's nadir, served by a reference base station \((B_S_0)\). Let \((i, j)\) denote the \(i\)th mobile located in the \(j\)th interfering cell, and \(B_S_j\) denote the base station serving the \(j\)th interfering cell.

Mobile \((i, j)\) is located at a distance \(r_j\) away from the centre of its serving cell and \(r_{0,j}\) from the centre of the reference cell. As mobile \((i, j)\) is power controlled by \(B_S_j\), it transmits a power of

\[
S_{T_{ij}} = S \cdot l_j^\nu 10^{-10} 10^{10}. \tag{4.3}
\]

This mobile, at the same time, will produce an interference power at \(B_S_0\) equal to:

\[
I_{B_{S_0},ij} = S \left( \frac{l_j}{l_{0,j}} \right)^\nu \frac{(r_{0,j} - \zeta_j)}{10^{-10} 10^{10}} 10^{10} G(\psi_{0,j}) G(\psi_j), \tag{4.4}
\]

where \(l_j\) and \(l_{0,j}\) are the distances from the mobile to \(B_S_j\) and \(B_S_0\) respectively. \(\zeta_j\) and \(\zeta_{0,j}\) denote the shadowing in dB corresponding to these two paths. \(\nu\) is the path loss exponent. \(G(\psi_{0,j})\) and \(G(\psi_{0,j})\) are the normalised receiving antenna gains in dB evaluated at the angles under which the mobile is seen from the antenna boresights of \(B_S_j\) and \(B_S_0\) respectively.

A typical phased array antenna deployed on a HAPS has an aperture of approximately 13 m [19]. As the dimensions of the phased array antenna is negligible compared to the height of the HAPS platform, the angle \(\beta\) between \(l_j\) and \(l_{0,j}\) is very small, implying that the signal propagating from the mobile to both base stations \((B_S_j\) and \(B_S_0\) traverses almost the same path and distance and is thus subjected to approximately the same shadowing. We hence approximate

\[
\begin{cases}
    l_j = l_{0,j} \\
    \zeta_j = \zeta_{0,j}.
\end{cases} \tag{4.5}
\]

Substituting (4.5) in (4.4), we obtain the following expression for the other-cell interference received at \(B_S_0\):

\[
I_{B_{S_0},ij} = S \cdot 10^{-10} 10^{10}. \tag{4.6}
\]

Note that with power control, the interference received by the reference base station is dependent only on the antenna radiation pattern rather than the terrain characteristics of the coverage area (i.e., path loss and shadowing).
The total interference power received by the reference base station from $N$ adjacent cells each having user density $\rho$ can then be approximated by:

$$I_{OC} = \alpha S \sum_{j=1}^{N} \int \int \frac{g(\nu_{u,v}) - g(\nu_j)}{10} \rho \, dA \tag{4.7}$$

Substituting (4.1) in (4.7),

$$I_{OC} = \alpha M S \sum_{j=1}^{N} \int_{\theta_j}^{2\pi} \int_{r_j}^{R} \frac{g(\nu_{u,v}) - g(\nu_j)}{10} \frac{l}{\pi R^2} r_j \, dr_j \, d\theta_j \tag{4.8}$$

If we let

$$f = \sum_{j=1}^{N} \int_{\theta_j}^{2\pi} \int_{r_j}^{R} \frac{g(\nu_{u,v}) - g(\nu_j)}{10} \frac{l}{\pi R^2} r_j \, dr_j \, d\theta_j \tag{4.9}$$

(4.8) can be expressed as

$$I_{OC} = (\alpha M S) f \tag{4.10}$$

$$= I_{SC} \cdot f \tag{4.11}$$

$f$ is defined as the other-cell interference factor, which is the other-cell interference expressed as a fraction of the total power from mobiles in the same cell.

### 4.3.5 Numerical Results for Other-cell Interference Factor

The value of $f$ is computed numerically for the 3 typical values of $G_m$ recommended by the ITU in [19]. For 100 tiers of interfering cells, $f$ is found to be 0.1620, 0.1628 and 0.1644 for $G_m = 45.7$ dB, 36.7 dB and 32.3 dB respectively. The results for the first 20 tiers of cells are plotted in Figure 4-4. Note that the other-cell interference is largely contributed by the first four tiers of surrounding cells.
For terrestrial tower-based CDMA systems without shadowing, the other-cell interference factor, $f$, was found in [37] to be 0.33 for $\mu = 4$. For terrestrial tower-based CDMA systems with shadowing, $f$ was found in [38] to be 0.55 for $\mu = 4$ and lognormal shadowing standard deviation $= 8$ dB.

### 4.3.6 Reverse Link Capacity

The received $\frac{E_b}{I_0}$ on the reverse link is given by

$$\frac{E_b}{I_0} = \frac{S}{R_b} \frac{1}{I_{sc} + I_{oc} + \sigma^2_n},$$

(4.12)

where $E_b$ is the signal energy per information bit, $I_0$ is the total noise plus interference power spectral density, $R_b$ is information bit rate, $W$ is the spread spectrum bandwidth and $\sigma^2_n$ is the thermal noise power. Substituting (4.2) and (4.11) into (4.12), the reverse link capacity per cell can be expressed as
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\[ M = \frac{1}{\alpha(1+f)} \left( \frac{G_p}{\frac{E_h}{I_0}} - \frac{\sigma_n^2}{S} \right) + 1, \tag{4.13} \]

where \( G_p = \frac{W}{R_h} \) is the processing gain. Note that the smaller the other-cell interference factor, the larger the capacity supportable by the system.

4.3.7 Reverse Link Capacity Comparison between HAPS UMTS and Terrestrial Tower-based UMTS

Using (4.13), we compute the reverse link capacities for \( f = 0.1628 \) (HAPS system), \( f = 0.33 \) (terrestrial tower-based system without shadowing) and \( f = 0.55 \) (terrestrial tower-based system with shadowing). Figure 4-5 shows the graphs of the reverse link capacities against \( \frac{E_h}{I_0} \) for \( G_p = 256, \alpha = 0.5 \) and \( \frac{S}{\sigma_n^2} = -1 \) dB.

![Figure 4-5: Reverse link capacity of HAPS UMTS](image-url)
From the graph, we observe that compared to a terrestrial tower-based system without shadowing, the HAPS system has approximately 14.4% higher capacity. Its capacity gain is approximately 33.3% when compared to a shadowed terrestrial tower-based system having a lognormal shadowing standard deviation of 8 dB.

4.3.8 Discussion

From the reverse link analysis we can draw the following conclusions:

- For HAPS UMTS, interference and hence capacity is dependent on the antenna radiation pattern rather than the terrain characteristics of the HAPS coverage area (i.e., path loss and shadowing).
- To achieve high capacity in HAPS UMTS, a good-performance antenna with low side lobe levels i.e., high interference rejection is required.
- Assuming that the reference antenna radiation mask recommended by the ITU is used, HAPS UMTS can support at least 14.4% higher capacity as compared to terrestrial tower-based UMTS.

4.4 Forward Link Capacity Analysis

In the forward link, the power transmitted by a base station to its serving mobile is received as interference by all the other users in the service area. Similar to the reverse link, the same forward link frequency band is used in every cell, so the forward link interference directly affects the supportable forward link capacity.

4.4.1 Sources of Interference in the Forward Link

In the forward link, each mobile, along with the desired signal, picks up interfering signals. As shown in Figure 4-6, the sources of interference on the HAPS forward link (as received at a particular mobile) are:

- **Same-cell interference**: The powers transmitted by the base station serving other mobiles in the same cell.
- **Other-cell interference**: The powers transmitted by the base stations of the neighbouring cells.
4.4.2 The Need for Forward Link Power Control

In contrast to the reverse link, all signals propagate through the same channel in the forward link and are thus received by a mobile with equal power. Therefore, no power control is required to eliminate the near-far problem. Power control, however, is required to minimise the interference to other cells and to compensate against interference from other cells. With proper design of the power control scheme, the forward link capacity can be maximised.

4.4.3 Complexities in Forward Link Power Control Design

Forward link power control is vastly different from that of the reverse link. This is primarily due to three factors [39], [40]. In the forward link compared to the reverse link,

- access is one-to-many instead of many-to-one.
the interference is received from a few concentrated large sources (base stations) rather than many distributed small ones (mobiles).

the sum of power allocated to the different users in a given cell is limited, rather than each power level allocated to users. Therefore, forward link power control is more of an allocation of available downlink power according to the needs of the mobile.

The worst-case situation for a mobile will generally occur when the mobile is at the cell edge, where it receives the most interference from neighbouring cells. Therefore, more forward link power must then be provided to users at the cell boundaries. The power control scheme should be designed to satisfy the needs of mobiles at different locations within the cell.

4.4.4 Distance Based Forward Link Power Control

Downlink power control for terrestrial tower-based systems in existing works is proposed as a procedure to allocate individual power levels to the different users of a given cell according to their relative needs. One of the earliest proposed forward link power control scheme is the distance based power control scheme suggested in [41]. It is proposed that with knowledge of mobile positions, distance based power control schemes can be used to minimise the total power transmitted by the base station. For such schemes, the base station allocates a higher power level to users located near the cell boundary and a lower power level to users close to the cell centre.

The performance of a distance based power control scheme based on an nth power of a mobile’s distance from the centre of its serving cell was analysed in [41], [42], [43] and [44] in the absence of shadowing. In [42], an optimum power control scheme based on a function of the mobile’s distance from the centre of its serving cell and its distances to the centres of adjacent cells was also proposed to ensure that a uniform level of service is provided to users in all locations in a cell. This scheme was further developed to include a mobile’s direction from the centre of its serving cell in [44].

While distance based power control schemes perform well in non-shadowed environments, they may not be appropriate in shadowed environments because the power received by the mobile depends not only on distance but also on the shadowing spread [43]. Therefore, distance alone is not a good indication of the amount of base station transmit power required by the mobile.
In the following sections, we will show that while distance based power control schemes are not appropriate for shadowed terrestrial tower-based systems, they perform favourably for HAPS UMTS due to the unique HAPS geometry.

4.4.5 HAPS Forward Link Interference Geometry

We consider the first few tiers of cells near the nadir that are approximately circular and equally sized with radius $R$. A user in a HAPS service area will experience interference from its serving beam and adjacent beams.

Let $(r, \theta)$ be the coordinates of a mobile with respect to the centre of the cell projected by its serving beam. With power control, the power transmitted by a base station onboard the HAPS to its serving mobile located at $(r, \theta)$ is given by

$$P_t(r, \theta) = P_{req} f(r, \theta), \quad (4.14)$$

where $f$ is the power control law and $P_{req}$ is the power required to reach a user at the cell corner $(R, 30^\circ)$.

We focus on the service area near the nadir and assume that the beams project approximately circular cells, each serving a uniform distribution of $N$ mobiles per cell (user density, $\rho = \frac{N}{\pi R^2}$).

To simplify the analysis, we consider two tiers of neighbouring cells and assume that the interference from tiers further away is negligible. We further assume that the total power $P_T$ transmitted by the HAPS in each beam is the same. With these assumptions,

$$P_T = \int_0^{2\pi} \int_0^R P_t(r, \theta) \rho r dr d\theta \quad (4.15)$$

$$= \frac{N}{\pi R^2} \int_0^{2\pi} \int_0^R P_t(r, \theta) r dr d\theta. \quad (4.16)$$

Figure 4-7 shows the HAPS UMTS forward link interference geometry.
As shown in the figure, we let $BS_j (j = 0, \ldots, J)$ denote the base station serving the $j$th cell. The carrier-to-interference ratio, $\frac{C}{I}$, of a mobile located at $(r, \theta)$ in the reference cell served by $BS_0$ is given by

$$\frac{C}{I} = \frac{P_T G(\psi_0) l_0^{-\alpha} \xi_0}{\sum_{j=0}^{J} P_T G(\psi_j) l_j^{-\alpha} \xi_j - P_T G(\psi_0) l_0^{-\alpha} \xi_0},$$

(4.17)

where $l_j$ and $l_0$ are the distances from the mobile to $BS_j$ and $BS_0$ respectively. $\xi_j$ and $\xi_0$ denote the shadowing corresponding to these two paths. $\alpha$ is the path loss exponent. $G(\psi_j)$ and $G(\psi_0)$ are the normalised antenna gains evaluated at the angles under which the mobile is seen from the antenna boresights of $BS_j$ and $BS_0$ respectively. Due to the unique HAPS geometry, transmit antenna beams of all base stations essentially originate from the same point [45], so we approximate $l_j = l_0$ and $\xi_j = \xi_0$. Furthermore, by neglecting the signal power in the denominator of (4.17), we obtain

$$\frac{C}{I} = \frac{P_T}{P_T \gamma_T (r, \theta)},$$

(4.18)

where
is the HAPS forward link interference factor. Note that the interference factor is dependent on the antenna radiation pattern rather than path loss and shadowing. Substituting (4.14) and (4.16) in (4.18), and assuming a minimum required carrier-to-interference ratio of \( \frac{C}{I_{\text{req}}} \), the capacity per cell is

\[
N = \frac{f(r, \theta)}{\left( \frac{C}{I_{\text{req}}} \right) \int_0^{2\pi} \int_0^{r_0} f(r, \theta) r dr d\theta .}
\]  

### 4.4.6 Nth-power-of-distance Power Control

The dependence of the interference factor of HAPS UMTS on antenna radiation pattern rather than the terrain of the coverage area (i.e., shadowing) suggests that distance based power control schemes could be more applicable in a HAPS system than in a terrestrial tower-based system.

To quantify the performance of distance based power control schemes in HAPS UMTS, we first consider a power control scheme based on the nth power of a mobile's distance away from the centre of its serving cell, as proposed in [41]. The power control law \( f \) of such a power control scheme can be written as:

\[
f(r) = \begin{cases} 
\left( \frac{r_0}{R} \right)^n & \text{for } 0 \leq \frac{r}{R} \leq \frac{r_0}{R} \\
\left( \frac{r}{R} \right)^n & \text{for } \frac{r_0}{R} < \frac{r}{R} \leq 1
\end{cases}
\]  

where \( n \) is the power control exponent and \( \frac{r_0}{R} \) is the normalised threshold distance. Below the normalised threshold distance, the user is guaranteed a minimum amount of transmitted power. Beyond the normalised threshold distance, the power allocated to a mobile is increased proportionally to the nth power of its distance from the centre of its serving cell. Note that \( n = 0 \) represents the case without power control.

Substituting (4.21) in (4.20) and evaluating the integral analytically [44], we obtain the following expression for the number of users per cell:
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\[ N = \frac{f(r)}{\left( \frac{C}{I} \right)_{req} \gamma_I(r, \theta) \left[ \frac{2}{n+2} + \frac{n}{n+2} \left( \frac{r_0}{R} \right)^{n+2} \right]} \]  \hspace{1cm} (4.22)

There are two design parameters for this type of power control law, the power control exponent \( n \) and the normalised threshold distance, \( \frac{r_0}{R} \). Both parameters must be chosen correctly for HAPS UMTS in order to maximise the supportable capacity. As capacity depends on mobile location, to ensure that the \( \left( \frac{C}{I} \right)_{req} \) condition is satisfied at all locations within the cell, the minimum value of \( N(r, \theta) \), is taken to be the system capacity. Because of the symmetry of the cellular layout, we only need to evaluate \( \frac{C}{I} \) at locations within the triangle ABC (see Figure 4-7).

Assuming that processing gain = 256 and \( \frac{E_h}{I_0} = 4.3 \) dB, \( n \) and \( \frac{r_0}{R} \) are varied and the corresponding system capacities are plotted in Figure 4-8.

Figure 4-8: HAPS UMTS forward link system capacity against power control exponent (\( n \)) and normalised threshold distance (\( r_0/R \))
From Figure 4-8, we see that for HAPS UMTS, the maximum system capacity of 56.6 users per cell is obtained with the choice of $n = 2.7$ and $\frac{r_0}{R} = 0.71$. The choice of any other combinations of $n$ and $\frac{r_0}{R}$ will give a lower value for the system capacity. We also note that without power control ($n = 0$), the system capacity is 30.5 users/cell. Hence, with the optimum values of $n$ and $\frac{r_0}{R}$, the $n$th-power-of-distance power control scheme increases the system capacity of HAPS UMTS by 86% as compared to the case without power control. Hence, $n$th-power-of-distance power control is expected to perform reasonably well in HAPS UMTS.

With $n = 2.7$ and $\frac{r_0}{R} = 0.71$, the forward link capacity is plotted against normalised distance from the cell centre in Figure 4-9. Also shown is the capacity without power control.

![Figure 4-9: HAPS UMTS forward link capacity against normalised distance from cell centre](image-url)
4.4.7 Optimum Power Control

We see from Figure 4-9 that with the nth-power-of-distance power control scheme, there is a service "hole" within the interior of the cell. It would be desirable to have the curve as flat as possible, while at the same time, maintaining a high capacity.

In order to achieve a uniform service throughout the cell, the optimum power control law for HAPS UMTS should follow the shape of the interference factor, which is dependent on the antenna radiation pattern. Thus, if we set \( f(r, \theta) \) equal to \( \gamma_i(r, \theta) \) and normalised by \( \gamma_i(r, 30^\circ) \) to ensure that \( f(r, 30^\circ) = 1 \) [42], we obtain the following optimum power control law:

\[
 f(r, \theta) = \frac{\gamma_i(r, \theta)}{\gamma_i(R, 30^\circ)}. \tag{4.23}
\]

Figure 4-10 shows the optimum power control law for HAPS UMTS against normalised distance from the cell centre, for two tiers of neighbouring cells and \( \theta = 30^\circ \).

Substituting (4.23) in (4.20), we obtain the capacity per cell as

54
\[ N = \left( \frac{C}{I_{\text{req}}} \right) \frac{1}{\pi R^2} \int_0^{2\pi} \int_0^R \gamma_1(r, \theta) r dr d\theta. \]  

(4.24)

We evaluate the double integral in (4.24) numerically and obtained \( N = 59.9 \) users/cell. Thus, the proposed optimum power control scheme for HAPS provides a significant system capacity improvement of 96%.

4.4.8 Practical Performance

In the preceding analysis, we have assumed that the power control schemes are perfect, i.e., they can be applied continuously in infinitely small step sizes. However, in practical implementation, power control is applied in discrete step sizes. To quantify the practical performance of the power control schemes, we use Monte Carlo simulation to obtain the outage statistics when the nth-power-of-distance and optimum power control schemes are applied continuously and in discrete step sizes of 0.5 dB, 1 dB and 1.5 dB. Figure 4-11 and Figure 4-12 show the outage probability vs. system capacity with different power control step sizes for nth-power-of-distance and optimum power control schemes respectively.

![Figure 4-11: Simulation results of outage probability against system capacity with different power control step sizes for nth-power-of-distance power control](attachment:image.png)
Figure 4-12: Simulation results of outage probability against system capacity with different power control step sizes for optimum power control

The simulation results show that for both power control schemes, the system capacities decrease with increasing power control step sizes. For an outage probability of 0.01, and with power control step sizes of 0.5 dB – 1.5 dB, the $n$th-power-of-distance power control scheme can maintain at least 81.5% of the system capacity obtainable with perfect power control. While for the optimum power control scheme, at least 85.3% of the system capacity can be maintained. Note that the capacities obtained via simulation for perfect power control are larger than those computed analytically because hexagonal instead of circular cellular layout was used in the simulation.

4.4.9 Discussion

From the forward link analysis, we can draw the following conclusions:

- Distance based power control schemes, which are known to be inappropriate for shadowed terrestrial tower-based systems, can perform favourably in HAPS UMTS, due to HAPS’s unique geometry and interference characteristics.
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- For the nth-power-of-distance power control scheme, the optimum parameters, i.e., power control exponent \( n \) and normalised threshold distance \( \frac{r_0}{R} \) for HAPS UMTS are found to be 2.7 and 0.71 respectively.

- The optimum power control law for HAPS is independent of the terrain characteristics of the HAPS coverage area. It follows the shape of the HAPS forward link interference factor, which dependent on the antenna radiation pattern. This optimum power control scheme outperforms the nth-power-of-distance power control scheme in capacity improvement.

- With power control step sizes of 0.5 dB – 1.5 dB, the optimum power control scheme can still maintain more than 85% of the system capacity obtainable with power control.

4.5 Conclusion

In this chapter, we have discussed how HAPS UMTS based on WCDMA technique must contend with not only other-cell interference from neighbouring cells but also same-cell interference from within the cell. As system capacity is limited by this interference, power control is needed to eliminate the near-far effect and manage this interference to achieve maximum capacity. We have shown that due to the unique geometry of HAPS UMTS, interference is dependent on the antenna radiation pattern rather than the terrain characteristics of the coverage area. As the ITU recommended antenna specification for HAPS UMTS has a sharp roll-off of 60 dB/decade, other-cell interference rejection is high leading to improved system capacity as compared to terrestrial tower-based systems. The unique geometry and interference characteristics of HAPS also enables distance based power control schemes, which are known to be inappropriate for shadowed terrestrial tower-based systems, to perform favourably in the HAPS UMTS environment.
Chapter 5

5 HAPS UMTS System Level Simulator

5.1 Introduction

As explained in Chapter 3, the interference conditions in HAPS UMTS vary dynamically according to the propagation channel, user position, user mobility and traffic activity. A HAPS UMTS system level simulator has been developed in MATLAB to incorporate these factors into the evaluation of CAC schemes. The simulator enables realistic system-level modelling of the dynamic HAPS UMTS environment to allow the investigation CAC schemes under different HAPS cellular structures with different propagation, traffic and mobility characteristics. In this chapter, we explain the factors taken into consideration in the design of the various components of the simulator and also highlight the simulator's features and functionalities.

5.2 Main Components of HAPS UMTS System Level Simulator

The HAPS UMTS system level simulator is designed to model realistically the dynamic HAPS mobile environment. The simulation parameters are entered via a Graphical User Interface (GUI) as shown in Figure 5-1.

Figure 5-2 shows the four major components of the HAPS UMTS system level simulator – the cell model, the traffic model, propagation channel model and the mobility model. The cell model defines the cell layout and specifies the simulation area within which statistics such as interference levels and power utilisation are obtained. The traffic model simulates the arrival and departure of the mobiles as well as their transmission activity characteristics. The propagation channel introduces path loss and shadowing variations into the mobile's radio link while the mobility model defines the movement of the mobiles in the service area.

These cell, traffic, channel and mobility components form the basic framework of the HAPS system level simulator. Specific CAC algorithms can be added on top of this basic framework and statistics obtained to evaluate the performance of the CAC schemes. In addition, the cell, traffic,
channel and mobility parameters can also be varied to determine their effect on the performance of the CAC algorithms.

Figure 5-1: Graphical user interface of the HAPS UMTS system level simulator

Figure 5-2: Components of the HAPS UMTS system level simulator
5.3 Cell Model

The first step in HAPS UMTS system level modelling is to establish the cell structure. The cell model defines the simulation area and specifies the shape of the cells, number of cells, cell radius, antenna radiation pattern and for the case of HAPS UMTS and terrestrial tower-based hierarchical UMTS, the overlaying area.

5.3.1 HAPS UMTS Cell Projection

The platform is assumed to be stationary at a height of \( h \) above the ground. Due to the HAPS geometry with respect to the earth's surface, the cells projected become more ovoid as we move towards the edge of the coverage area. In addition, the overlap areas will be more pronounced, causing excessive interference.

One method of compensating the distortion of the cells is to perform antenna beam/gain shaping, so that circular cells can be projected in the HAPS area, similar to that projected by a terrestrial-tower based system [19]. Beam shaping is recommended by ITU [21] and has been shown in [46] to be viable. This approach is adopted in the HAPS system level simulator.

The antenna radiation pattern used for cell projection conforms to specifications recommended by the ITU for HAPS UMTS and is defined in Section 2.5.2.3. The 3 maximum antenna main lobe gains recommended by the ITU are modelled: \( G_m = 45.7 \text{ dB}, 36.7 \text{ dB} \text{ and } 32.3 \text{ dB} \). The cell boundaries are defined by the intersection of the antenna gains at \(-13 \text{ dB} \) with respect to \( G_m \), as shown in Figure 5-3.

Table 5-1 shows the radii of the cells \( (R) \) projected by these 3 values of \( G_m \) assuming that cell boundaries are \(-13 \text{ dB} \) with respect to \( G_m \).
Figure 5-3: Cell boundaries defined by the -13 dB intersection points between two adjacent antenna radiation patterns

Table 5-1: Radii of projected HAPS UMTS cells for different peak antenna main lobe gains

<table>
<thead>
<tr>
<th>Peak main lobe gain ($G_m$)</th>
<th>Radius of projected cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>45.7 dB</td>
<td>0.3578 km</td>
</tr>
<tr>
<td>36.7 dB</td>
<td>1.0089 km</td>
</tr>
<tr>
<td>32.3 dB</td>
<td>1.6765 km</td>
</tr>
</tbody>
</table>

5.3.2 Cell Structure for HAPS UMTS

UMTS must be able to support a wide range of services in different operating environments. Different types of cells are needed for different requirements. Macrocells are used to provide continuous coverage and microcells are necessary to achieve good spectrum efficiency and high capacity. In addition, microcells will be more suitable for low mobility and high bit rate users, while macrocells will be used to serve high mobility and low bit rate users. These different types of cells are likely to coexist in UMTS and hence must be able to operate one upon another [47], i.e., in a hierarchical cell structure.
Chapter 5. HAPS UMTS System Level Simulator

Figure 5-4 [24] shows some of the possible cell structures for UMTS. Out of the possible cell configurations highlighted in the figure, two types of cell structures are modelled in the HAPS UMTS system level simulator. The first is a single-layer continuous HAPS coverage. The second cell structure is a continuous HAPS macrocell layer overlaying with selected terrestrial tower-based microcells, with the macrocells and microcells operating at different frequencies.

5.3.2.1 Single Layer Continuous HAPS Coverage

Single layer continuous HAPS cells are formed by a standalone HAPS carrying a phased array antenna located onboard with gain/beam shaping capability. Figure 5-5 shows a possible continuous coverage cell configuration consisting of 19 beam/gain shaped circular HAPS cells. Each cell is interfered by 2 tiers of surrounding cells. In order to eliminate the edge effects, during the calculation of interference that one cell incurs, the other 18 cells are reallocated so that each cell in turn becomes the centre cell surrounded by the 18 other cells. This will ensure that each cell is being interfered by 2 complete tiers of neighbouring cells. Using this reallocation, we can simulate an infinite area [8].

![Diagram of possible UMTS cell structures](image-url)

Figure 5-4: Possible UMTS cell structures [24]
Figure 5-5: Cell structure for single layer HAPS UMTS

Figure 5-6 shows the 3-dimensional antenna gain profile of the service area for the 19-cell single layer HAPS cell structure. The antenna gains are normalised to the peak main lobe gain of 36.7 dB.

Figure 5-6: HAPS 3D gain projection with $G_m = 36.7$ dB
5.3.2.2 HAPS and Terrestrial Tower-based Hierarchical Cell Structure

When considering the cell structure for HAPS UMTS and terrestrial tower-based hierarchical UMTS, it is envisaged that HAPS will likely be providing continuous macrocell coverage with terrestrial tower based UMTS providing the microcell coverage in hotspot areas [48]. This approach will be more economically viable than having the terrestrial tower-based UMTS to provide both continuous macrocell coverage and microcell hotspot coverage as less infrastructure cost is involved. Hence, the hierarchical cell structure that is modelled in the HAPS UMTS simulator is a layer of homogenous HAPS macrocells overlaying with terrestrial tower-based microcell hotspots. Figure 5-7 shows an example of a possible deployment scenario for HAPS and terrestrial tower-based hierarchical cell structure, where 6 terrestrial tower-based UMTS microcells operating at frequency $f_1$ are overlaid by 3 HAPS UMTS macrocells operating at frequency $f_2$.

![Figure 5-7: Overlaying HAPS and terrestrial tower-based cells](image)

5.4 Channel Model

In the mobile environment, the radio propagation channel affects the amplitude of the signal and interference levels received by a mobile. As it is difficult to predict the variation of radio
channels, they are modelled statistically using real propagation measurement data for different environments, e.g., urban and rural. In system level simulation, radio propagation is typically characterised by two phenomena: distance attenuation (path loss) and lognormal shadowing. In the HAPS system level simulator, these phenomena are modelled for both the single layer HAPS UMTS environment and the HAPS/terrestrial tower-based hierarchical UMTS environment.

5.4.1 HAPS Channel Model

The main difference between HAPS and terrestrial tower-based propagation channels is that mobiles have a higher elevation angle to the HAPS than to the terrestrial tower-based base station. A higher elevation angle means less chances of encountering blockages due to terrain.

5.4.1.1 Path Loss

Figure 5-8 shows the geometry of a mobile in the HAPS service area.

Neglecting the earth’s curvature, the free space path loss experienced by a mobile in the HAPS service area can be written as:

\[ L_{\text{FSL}} (\text{dB}) = 32.44 + 20 \log(l) + 20 \log(f_c), \]  

(5.1)

where

\[ L_{\text{HAPS}} \] is the free space path loss in dB, \( f_c \) is the carrier frequency in MHz and \( l \) is the path length between the mobile and the HAPS in km. \( l \) is given by

\[ l = \frac{h}{\sin \theta}, \]  

(5.2)
where $\theta$ is the elevation angle in degrees.

### 5.4.1.2 Slow Fading

The slow fading experienced by a mobile in a HAPS channel is simulated based on the satellite channel model proposed by Lutz [49], where the mobile experiences periods of clear line-of-sight and non-line-of-sight states as it moves in the service area, as shown in Figure 5-9.

![Figure 5-9: Characteristics of HAPS channel](image)

In this model, the statistics of line-of-sight and non-line-of-sight states are modelled by two distinct states, "good" and "bad". The good channel state corresponds to areas with unobstructed "view" of the HAPS (line-of-sight areas), whereas the bad channel state represents areas where the direct HAPS signal is shadowed by obstacles such as trees and buildings.

The characteristics between the switching process between shadowed and unshadowed states are described by a first-order Markov chain, in which transition from one state to another depends only on the current state. These transitions are represented by the state transition diagram in Figure 5-10.
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The transition probabilities are:

- \( P_{gg} \): Probability of transition from good state to good state.
- \( P_{gb} \): Probability of transition from good state to bad state.
- \( P_{bh} \): Probability of transition from bad state to bad state.
- \( P_{bg} \): Probability of transition from bad state to good state.

The state of the channel for a given sampling interval depends on the state of the channel in the previous sampling interval and the transition probabilities, given by:

\[
P_{bg} = \frac{v}{RD_h}
\]  
(5.3)

and

\[
P_{gb} = \frac{v}{RD_h}
\]  
(5.4)

where \( v \) is the velocity of mobile in m/s, \( D_h \) is the average duration in bad state (m), \( D_g \) is the average duration in good state (m) and \( R \) is the sampling rate (s\(^{-1}\)). Note that

\[
\begin{align*}
P_{gb} &= 1 - P_{gg} \\
P_{bg} &= 1 - P_{bh}
\end{align*}
\]  
(5.5)

Within the bad state, the shadowing variation follows a lognormal distribution with mean \( \mu_h \) and standard deviation \( \sigma_h \). Linear interpolation is used to eliminate abrupt state transitions and model more realistically the variation in the signal levels in-between states.
The values of $D_b$, $D_g$, $\mu_h$ and $\sigma_h$ used in the simulator are elevation angle dependent and are based on values obtained via the measurement campaign carried out at the Centre of Communication Systems Research (CCSR) for mobile satellite systems operating at S-band [50]. Statistics for 5 different mobile environments are available: urban, suburban, open, lightly wooded and heavily wooded, as shown in Figure 5-11.

**Figure 5-11: Environments modelled in the HAPS UMTS system level simulator**

The urban environment is characterised by high-rise buildings (e.g., 2–9 storeys) that are closely spaced. The buildings are typically constructed with brick or concrete, with typical office and shop type fronting windows. The suburban environment is characterised by residential houses typically 2-storey high and spaced apart in a reasonably uniform fashion. The distances between trees and buildings average between 10-15 m. The wooded categories have a variety of trees, ranging in height from 4-10 m. The heavily and lightly wooded environments are distinguished by different tree densities. The open environment may be open fields or highways with thinly populated trees [52].

Typically, each good/bad state will last a few metres. Appendix A gives some examples of the good and bad durations for various elevation angles under different environments.

An important parameter in the modelling of slow fading is the auto-correlation or correlation distance. This parameter describes how fast the lognormal distributed variations are. This is an important piece of information in the generation of the shadowing samples. If the generated slow
lognormal variations are faster than those in the real world, the generated amplitude series will be unrealistic. For slow fading, correlation distances in the order of 1-2 m have been observed for mobile satellite systems [51]. In our HAPS UMTS system level simulator, a variable correlation distance $L_{corr}^h$ can be set for the different environments.

5.4.1.3 Fast Fading

WCDMA is able to combat the effect of fast fading if there are more than two multiple paths that can be resolved by the receiver. By using a RAKE receiver incorporated with closed-loop power control, bit interleaving and channel coding, the effect of the fast fading can be reduced to a minimum [53]. Therefore, in our HAPS channel model, we simplify the simulations by considering only path loss and shadowing on the presumption that the receiver would effectively combat any fast fading.

Figure 5-12 summarises the procedure used by the HAPS UMTS system level simulator in generating the slow fading samples.

Figure 5-13 shows an example of the time-varying slow fading experienced by a mobile in the HAPS environment, generated by the HAPS UMTS system level simulator.
5.4.2 Terrestrial Tower-based UMTS Channel Model

5.4.2.1 Path Loss Model

The path loss model used is the non line-of-sight model based on the vehicular test environment defined in [55], and is given by

\[ L_{\text{terr}}(\text{dB}) = 40(1 - 4 \times 10^{-3} \Delta h_b) \log(r) - 18 \log(\Delta h_b) + 21 \log(f_c) + 80, \]  

(5.6)

where

\( L_{\text{terr}} \) (dB) is the path loss, \( r \) (km) is the base station to mobile station separation, \( f_c \) (MHz) is the carrier frequency and \( \Delta h_b \) (m) is the base station antenna height measured from the average rooftop level, between 0 m and 50 m.

5.4.2.2 Slow Fading

The shadowing experienced by a mobile in the terrestrial coverage is modelled as a lognormal distribution with mean \( \mu_n \), standard deviation \( \sigma_l \) and correlation distance \( L_{\text{corr}} \).

5.4.2.3 Fast Fading

Fast fading for terrestrial tower-based UMTS is also not modelled for reasons explained in Section 5.4.1.3.

5.5 Traffic Model

UMTS is expected to support multimedia services. Multimedia means the transmission of several types of information (e.g., speech, video and data) simultaneously. The bit rate and quality requirements of these services can also be highly variable. Different applications generate different traffic characteristics and thus have a different impact on the system design and on the
network capacity. For example, a video or speech call requires guaranteed QoS while non real-time packet data can be offered on a best effort basis. Therefore, it is important to model the characteristics of multimedia traffic to ensure that an accurate evaluation of CAC schemes can be made.

5.5.1 Call Generation

Call arrivals to a cell are generated by independent Poisson processes. For real-time speech and video, calls arrive with mean arrival rates of $\lambda_s$ and $\lambda_v$ for speech and video respectively. The duration of a call and is assumed to be exponentially distributed with means of $T_s$ and $T_v$ for the speech and video services respectively. The transmission bit rates for speech and video are $R_u^s$ and $R_u^v$ respectively for the uplink, and $R_d^s$ and $R_d^v$ respectively for the downlink.

For non real-time data services such as worldwide web (WWW), the session arrivals are generated by a Poisson distribution with a mean arrival rate of $\lambda_w$. The uplink and downlink bit rates for the WWW service are assumed to be $R_u^w$ and $R_d^w$ respectively.

For the HAPS UMTS and terrestrial tower-based hierarchical UMTS, different call/session arrival rates for each service can be selected for each layer.

5.5.2 Traffic Activity

Traffic activity characterises the transmission profile of a particular service in terms of bursts of active periods and silent periods. Traffic activity is important in UMTS because in systems employing WCDMA technique, a mobile's transmission is received as interference by other mobiles. Therefore, periods of silence means reduced interference (i.e., increased capacity). An average traffic activity factor of $\alpha$ provides an improvement in capacity by a factor of $\frac{1}{\alpha}$.

5.5.2.1 Speech

Human speech is known to consist of alternating talk spurts and silent periods [56]. A voice call tends to last in the order of minutes. For real-time speech, the traffic model is an on-off model, with activity and silent periods generated by an exponential distribution. The mean values for active and silent periods are equal to $\tau$ s. The uplink and downlink transmissions are independently generated. Figure 5-14 shows a sample of the speech traffic generated by the HAPS UMTS system level simulator.
5.5.2.2 Video

Real-time circuit-switched video is modelled with a constant bit rate with 100% of activity.

5.5.2.3 WWW

For non real-time WWW, the traffic model described in [55] is used. A typical WWW browsing session consists of a sequence of packet calls. The user initiates a packet call when requesting information. During a packet call, several packets may be generated. The number of packet calls corresponding to a WWW session depends on the application. For example, in a WWW browsing session, a packet call corresponds to the downloading of a WWW page. After the document has been downloaded to the user's terminal, the user will spend some time reading the downloaded information. This time interval is called the reading time. In our model, we do not take into consideration the inter-arrival time between packet bursts within a packet call because this duration is too short for system level evaluation.

Figure 5-15 shows the typical characteristics of a WWW session. The statistical distributions used to model these characteristics are summarised in Table 5-2.
Chapter 5. HAPS UMTS System Level Simulator

No. of packet calls per session \( (N_{pc}) \)

Packet size \( (S_d) \)

Reading time \( (D_{pc}) \)

A packet call

First packet arrival

A WWW session

Last packet arrival

No. of packet bursts in a packet call \( (N_d) \)

Figure 5-15: Typical characteristics of a WWW session

Table 5-2: Parameters used in WWW traffic modelling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Statistical Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{pc} )</td>
<td>Number of packet calls per session</td>
<td>Geometric distribution with mean ( \mu_{N_{pc}} )</td>
</tr>
<tr>
<td>( D_{pc} )</td>
<td>Reading time between packet calls</td>
<td>Geometric distribution with mean ( \mu_{D_{pc}} )</td>
</tr>
<tr>
<td>( N_d )</td>
<td>Number of packet bursts within a packet call</td>
<td>Geometric distribution with mean ( \mu_{N_d} )</td>
</tr>
<tr>
<td>( S_d )</td>
<td>Packet size</td>
<td>Packet size = ( \min(P, m) ), where ( P ) is normal Pareto distribution with ( \alpha = 1.1, k = 81.5 ) and ( m ) is the maximum allowable packet size, ( m = 66666 ) bytes.</td>
</tr>
</tbody>
</table>
5.6 Mobility Model

The mobility model traces a user's motion in the service area during a call and simulates various details regarding the user's mobility behaviour, as shown in Figure 5-17.
5.6.1 Initial Position

At call initiation, mobile users are first assigned a random initial position from a uniform distribution over the cell area.

5.6.2 Initial Speed Distribution

Two mobility classes are modelled, fast-speed and slow-speed. The proportion of slow-speed mobiles in the terrestrial tower-based UMTS layer and HAPS UMTS layers are $P_{slow}$ and $P_{slow}$ respectively. Mobiles of each service type can be allocated an initial speed that is fixed, uniformly distributed or Gaussian distributed with a specified mean and standard deviation. We assume that the speeds of the mobiles remain constant throughout the call duration. This could easily be modified to a random speed from a given distribution.

5.6.3 Initial Direction of Travel

All mobiles are assigned a uniformly distributed direction in the interval $[0, 2\pi]$. The uniform distribution of mobile directions is chosen both for its simplicity and because it provides a rather general and realistic representation of real-life systems. Throughout the service area, the relative orientation of streets might vary somewhat randomly, giving on the average an approximately uniform distribution of possible directions. The model can, however, be easily modified to fit a particular scenario (e.g., only right-angle streets) [57].

5.6.4 Time to Direction Change

We assume that the time between a mobile changing its direction of travel is exponentially distributed, similar to the model recommended in [55]. The reason is that the time of the last change of direction may hardly provide any information on the time to the next change of direction (memoryless). The statistics of this exponential distribution varies with the environment. The average distance travelled by a mobile before changing its direction is assumed to be $d_{urban}$, $d_{suburban}$, $d_{open}$, $d_{lightly}$ or $d_{heavily}$ in the urban, suburban, open, lightly wooded and heavily wooded environments respectively.

5.6.5 Angle of Turn

When a mobile changes direction, the new direction is generated by a uniform distribution over $[-\phi, \phi]$ with reference to the previous direction. Different values of $\phi$ can be used to cater for different environments.
5.6.6 Wrap Around

To eliminate edge effects, when mobiles exceed the service area boundary, they are “wrapped around” to re-emerge from a symmetrical location in the service area. Wrapping around ensures that calls will only terminate when the call duration has ended rather than when the mobiles exit the service area. It also ensures that the density of users is fixed and allows us to simulate an infinite coverage area.

5.7 Animation

Animation is implemented to verify the correct operation of individual modules of the HAPS UMTS system level simulator and to confirm the expected behaviour of the mobiles’ mobility, traffic and channel characteristics. A few examples of the animation output from the HAPS system level simulator are presented as follows.

Figure 5-18 shows a 3-D animation snapshot of speech, WWW and video mobiles in the HAPS service area.
Blue, red and magenta markers represent speech, WWW and video mobiles. Mobiles in the transmitting mode have filled markers and have links connecting them to the HAPS, e.g., mobile 1 is transmitting while mobile 2 is silent.

Figure 5-19 shows a snapshot of the dynamic HAPS and terrestrial tower-based hierarchical UMTS environment. Mobiles with filled markers represent high speed mobiles while unfilled markers represent slower speed mobiles. High speed mobiles are handled by the larger HAPS cells, while slower speed mobiles are served by terrestrial tower-based cells, unless the mobiles are in areas served exclusively by HAPS cells.

The channel variations can also be viewed via animation. Figure 5-20 shows a snapshot of the channel variations of the first 5 mobiles in the HAPS service area. A dip in the shadowing levels means that a mobile's view to the HAPS is blocked by obstacles.

Figure 5-19: 2-D animation of mobiles in HAPS and terrestrial tower-based hierarchical cell structure
5.8 Conclusion

In this chapter, we have described the features and functionalities of the cell, traffic, channel and mobility modules of the HAPS UMTS system level simulator. The simulator is a tool developed to evaluate CAC algorithms for HAPS and it dynamically simulates the HAPS UMTS mobile environment, including HAPS and terrestrial tower-based hierarchical UMTS. The simulator is flexible as the parameters modelled in the simulator can be varied via the GUI according to the user’s requirements. We conclude by summarising in Table 5-3 the main characteristics of the HAPS mobile environment that are modelled in the simulator.

Figure 5-20: Snapshot of channel variations for the first 5 mobiles in the HAPS service area
Table 5-3: Summary of parameters modelled in the HAPS UMTS system level simulator

<table>
<thead>
<tr>
<th>Cell Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAPS antenna radiation pattern and cell projection</td>
</tr>
<tr>
<td>Cell layout (hierarchical and single layer)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating environment (urban, suburban, open, lightly wooded and heavily wooded)</td>
</tr>
<tr>
<td>HAPS free space path loss</td>
</tr>
<tr>
<td>Terrestrial path loss</td>
</tr>
<tr>
<td>HAPS correlated slow fading</td>
</tr>
<tr>
<td>Terrestrial correlated slow fading</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call/session arrival for speech, WWW and video</td>
</tr>
<tr>
<td>Call holding times for speech, WWW and video</td>
</tr>
<tr>
<td>Bit rate for speech, WWW and video (uplink and downlink)</td>
</tr>
<tr>
<td>Traffic activity for speech, WWW and video</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobility model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position of mobile</td>
</tr>
<tr>
<td>Direction of travel</td>
</tr>
<tr>
<td>Speed of mobile</td>
</tr>
<tr>
<td>Time to direction change</td>
</tr>
<tr>
<td>Angle of turn</td>
</tr>
<tr>
<td>Wrap around</td>
</tr>
</tbody>
</table>
Chapter 6

6 Call Admission Control Schemes for HAPS UMTS

6.1 Introduction

In systems employing WCDMA technique, capacity is limited by the total interference from all connected mobiles in the service area. Therefore, CAC is required to regulate the total number of mobiles in the service area in order to guarantee that all mobiles in all service classes meet their respective qualities of service QoS.

In this chapter, we make use of the unique characteristics of HAPS to propose three CAC schemes for HAPS UMTS. Using the dynamic HAPS UMTS system level simulator, we evaluate the proposed schemes and compare their performances with those achievable by the conventional CAC schemes that do not take advantage of the unique properties of HAPS. We will show that the proposed schemes outperform the conventional schemes in overall system performance.

6.2 Centralised Total Received Power Based CAC for HAPS UMTS

As highlighted in Chapter 2, one of the unique characteristics of HAPS UMTS is that all base stations are collocated at the ground station. This enables the HAPS to centrally manage the amount of interference in all cells within the service area and allocate resources efficiently and optimally.

In this section, we propose and analyse two centralised total received power based CAC schemes for HAPS UMTS supporting mixed services. Simulation results are presented to compare the performances of the two centralised schemes with the conventional distributed global CAC scheme proposed for terrestrial tower-based UMTS.
6.2.1 Comparison to Existing Total Received Power Based CAC Schemes

Previous studies on CAC for terrestrial tower-based CDMA systems have suggested the use of the total received power at the base station as a suitable criterion for CAC [13], [14] and [15]. These studies deal with distributed schemes that can be further categorised into local and global schemes. For the distributed local scheme, CAC is based only on the total received power measured at the local base station. For the distributed global scheme, CAC is performed independently for each base station but the CAC decision also takes into account the additional interference contributed by an admitted call to neighbouring cells. Although the distributed global scheme allows a better CAC decision to be made as compared to the local scheme, it incurs higher overheads because base stations are geographically separated, hence frequent exchange of large amounts of information is required between them. Also, there may be delays in the information exchange, so the information received by the base stations may not reflect the current state of the network.

However, when considering CAC schemes for HAPS, we note that one of the unique characteristics of HAPS is that all base stations are collocated. This means that information on the current interference conditions within the cells can be exchanged between base stations with minimal signalling overheads and delay. Hence, distributed global CAC schemes can be implemented more efficiently for HAPS UMTS. In fact, the unique characteristic of HAPS allows a more integrated, i.e., centralised CAC scheme to be implemented so that interference is managed centrally rather than at individual base stations.

6.2.2 Approach

We propose two centralised CAC schemes for HAPS UMTS based on the total received power at the base stations. The proposed schemes process calls centrally so resources can be allocated more effectively resulting in better system performance. Such centralised schemes are impractical and too complex to implement in a terrestrial tower-based system but can be implemented effectively for HAPS UMTS. The performances of the proposed centralised schemes are evaluated via simulation and compared to the performance of the conventional distributed global scheme.

6.2.3 HAPS System Model

We assume that a HAPS carrying a WCDMA communications payload and a multi-beam phased array antenna with beam/gain shaping capability is positioned at an altitude of 22 km in the stratosphere. Hundreds of spot beams are projected on the ground within the service area in a pattern similar to that created by a traditional cellular system to provide mobile communications
services [19]. Any residual pointing error due to the movement of the HAPS is assumed to be compensated by appropriate station keeping mechanisms or by steering the beams electronically [19]. We consider the cells near the nadir that are approximately equally sized and circular in shape. In a mixed traffic environment, mobiles of different service types have different QoS and hence different SIR requirements. The phased array antenna radiation pattern defined in Section 2.5.2.3 which has a steep roll-off of 60 dB/decade, is used in our evaluation. The peak main lobe gain used is $G_m = 36.7$ dB. The gain at cell boundaries is taken to be $-13$ dB with respect to $G_m$.

6.2.4 HAPS Reverse Link Interference Model

In a mixed traffic environment, mobiles of different service types have different quality of service requirements.

Let the subscripts $(k, m, j)$, where $k = \{1, \ldots, K\}$, $m = \{1, \ldots, M_k\}$ and $j = \{0, \ldots, J\}$ denote the $m$th mobile of the $k$th service class served by the $j$th base station $(BS_j)$. Let $\lambda_k$ be the activity factor for the $k$th service class.

In the reverse link, each mobile station is power controlled by its serving base station so that the base station receives the same power, $S_k$, from all mobiles of the $k$th service class. Consider a reference cell served by $BS_0$ located at nadir as shown in Figure 6-1.

The power received by $BS_0$ from mobiles within its serving cell can be written as:

$$ P_{SC,0} = \sum_{k=1}^{K} \lambda_k M_k S_k. $$  \hspace{1cm} (6.1)

The power received by $BS_0$ from its $J$ adjacent cells is

$$ P_{OC,0} = \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{m=1}^{M_k} \lambda_k S_k \left( \frac{1_{0,k,m} - \sigma_{0,k,m} G(\psi_{0,k,m})}{1_{j,k,m} - \sigma_{j,k,m} G(\psi_{j,k,m})} \right). $$  \hspace{1cm} (6.2)
where \( l_{j,km} \) and \( l_{0,km} \) are the distances from mobile \((k,m,j)\) to the antennas of \( BS_j \) and \( BS_0 \) respectively. \( \xi_{j,km} \) and \( \xi_{0,km} \) denote the shadowing levels corresponding to these two paths. \( \alpha \) is the path loss exponent. \( G(\psi_{j,km}) \) and \( G(\psi_{0,km}) \) are the normalised receiving antenna gains evaluated at the angles under which mobile \((k,m,j)\) is seen from the antenna boresights of \( BS_j \) and \( BS_0 \) respectively.

As the dimensions of the phased array antenna are negligible compared to the height of the HAPS platform, the angle \( \phi \) between \( l_{j,km} \) and \( l_{0,km} \) is very small, implying that the signal propagating from the mobile to both base station antennas traverse almost the same path and distance and is thus subjected to approximately the same shadowing [45]. Therefore, we approximate \( l_{j,km} \approx l_{0,km} \), \( \xi_{j,km} \approx \xi_{0,km} \). Hence, the total other cell interference power received by the reference base station can be simplified and expressed as

\[
P_{OC,0} = \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{m=1}^{M_k} \lambda_k S_k \left( \frac{G(\psi_{0,km})}{G(\psi_{j,km})} \right). \tag{6.3}
\]

From (6.1) and (6.3), the total power received by the \( BS_0 \) is

\[
P_{T,0} = P_{SC,0} + P_{OC,0} \tag{6.4}
\]
Ignoring background noise, we can express the received SIR of an active mobile (in transmitting mode) of the \( k \)th service in the reference cell as

\[
\gamma_k = \frac{S_k}{P_{T,0} - S_k}
\]

\[\ldots\]

\[
\sum_{k=1}^{K} \lambda_k M_k S_k + \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{m=1}^{M_k} \lambda_k S_k \left( \frac{G(\psi_{0,km})}{G(\psi_{j,km})} \right) = S_k
\]

Note that the SIR is dependent on the antenna radiation pattern rather than the terrain characteristics (i.e., shadowing).

In order to meet the QoS for different service classes, the required received powers at the base station for mobiles of different service classes are expected to be different. The ratio of the base station received power for a mobile of the \( k \)th service to that for a mobile of the lowest bit rate service (\( k = 1 \)) can be expressed as

\[
\frac{S_k}{S_1} = \frac{1 + 1}{\gamma_k}
\]

\[\ldots\]

\section*{6.2.5 Outage Condition}

To ensure that all mobiles of different service classes maintain their respective QoS, we require

\[
\gamma_k \leq \gamma_k^{th}
\]

where \( \gamma_k^{th} \) is the required SIR for the \( k \)th service.

Substituting (6.9) into (6.6), the constraint on the total received power for an arbitrary BS

\[\ldots\]
where $P_T^{th}$ is the outage threshold. Hence, in order to ensure that all mobiles in the service area meet their respective service qualities, the total received power at all base stations ($P_{T,j}$) must not exceed $P_T^{th}$.

The new call blocking threshold, $P_{T,\text{block}}$, selected for this study is set to $P_T^{th}$. This means that a new call can only be established if the total received powers of all base stations after the admission of the call do not exceed $P_T^{th}$.

### 6.2.6 Power Increase Prediction

To predict the increase in received power levels at the base stations contributed by the incoming mobile, we assume that the effect of fast fading can be averaged out due to its short correlation length, so that the path loss on the forward link and the path loss on the reverse link can be assumed to be the same. Prediction can then be performed based on the received pilot strength information reported by the newly arrived mobile to its serving base station.

Let $(k, n, h)$ denote the newly arrived mobile $n$ of service $k$ wishing to connect to $BS_h$, where $n = \{1, \ldots, N\}$ and $h \in \{0, \ldots, J\}$. Let $Z_j$ be the power of the pilot signal transmitted by $BS_j$ and $z_{j,knh}$ be the $j$th pilot signal received by the newly arrived mobile. The path gain between the newly arrived mobile and $BS_j$ is

$$L_{j,knh} = \frac{z_{j,knh}}{Z_j} = l_{j,knh} G(\psi_{j,knh}). \quad (6.11)$$

The ratio of the path gain between the newly arrived mobile and $BS_j$ to the path gain between the newly arrived mobile and $BS_h$ is

$$\frac{L_{j,knh}}{L_{h,knh}} = \frac{z_{j,knh} Z_h}{z_{h,knh} Z_j}. \quad (6.12)$$

Hence, by admitting the newly arrived mobile, the increase in total received power at $BS_j$ can be estimated by
\[ \Delta \hat{P}_{j,knh} = \frac{z_{j,knh}Z_{h}}{z_{h,knh}Z_{j}} S_{k}. \]  

(6.13)

Note that $\Delta \hat{P}_{h,knh} = S_{k}$. No rise in total received power is considered for base stations whose pilot signals are too weak to be received by the newly arrived mobile.

### 6.2.7 Distributed Global Total Received Power Based CAC Scheme

For the distributed global total received power based CAC scheme, calls requesting service from different base stations will be processed in parallel independently, i.e., for every time step, every $BS_{h}$ does the following in parallel:

(i) $BS_{h}$ requests the pilot transmit powers, $Z_{j}$, from the other $J$ base stations. It also measures its current total received power and requests the current total received powers from the other base stations, $P_{T,j}^{\text{current}}$.

(ii) $BS_{h}$ obtains $z_{j,knh}$ from the newly arrived mobile $(k,n,h)$ and estimates the increment in base station total received powers, $\Delta \hat{P}_{j,knh}$, contributed by the mobile.

(iii) $BS_{h}$ computes the new total received powers of all base stations if the mobile is admitted, given by $\hat{P}_{T,j} = P_{T,j}^{\text{current}} + \Delta \hat{P}_{j,knh}$. If $\hat{P}_{T,j} \leq P_{T,\text{block}} \ \forall j$, the mobile is admitted and $BS_{h}$ updates $P_{T,j}^{\text{current}}$ to reflect the new base station total received power levels after the admission (i.e., set $P_{T,j}^{\text{current}} = \hat{P}_{T,j}$). Otherwise, the mobile is blocked and $P_{T,j}^{\text{current}}$ is left unchanged.

(iv) Repeat steps (ii) and (iii) until all new calls requesting service from $BS_{h}$ are processed.

Note that as the CAC process is not coordinated across all base stations, a base station will not know the outcome of the admission decisions made by other base stations. This means that the information on other cells' total received powers used by a base station for admission decision will not be the most updated.

### 6.2.8 Proposed Centralised Total Received Power Based CAC Schemes

For our proposed centralised total received power based CAC schemes, calls arriving to the entire service area will be grouped together and processed sequentially by a central admission controller.
For every time step, the central admission controller does the following:

(i) The central admission controller requests the pilot transmit powers, $Z_j$, and the current total received power levels, $P_{T,j}^{\text{current}}$, from all base stations in the service area.

(ii) The central admission controller obtains $z_{j,k,n,h}$ from the newly arrived mobile $(k,n,h)$ and estimates the increment in base station total received powers, $\Delta \hat{P}_{j,k,n,h}$, contributed by the mobile.

(iii) The central admission controller computes the new total received powers of all base stations if the mobile is admitted, given by $\hat{P}_{T,j} = P_{T,j}^{\text{current}} + \Delta \hat{P}_{j,k,n,h}$. If $\hat{P}_{T,j} \leq P_{T,j}^{\text{block}} \forall j$, the mobile is admitted and the central admission controller updates $P_{T,j}^{\text{current}}$ to reflect the new base station total received power levels after the admission (i.e., set $P_{T,j}^{\text{current}} = \hat{P}_{T,j}$). Otherwise, the mobile is blocked and $P_{T,j}^{\text{current}}$ is left unchanged.

(iv) Repeat steps (ii) and (iii) until all $N$ new calls requesting service from the network are processed.

Note that as all calls are centrally and sequentially processed, the central admission controller can update the base station total received power levels on a call-by-call basis so that the admission decision for each new call can be made more accurately. Such coordination is difficult to implement in traditional terrestrial tower-based systems because of the large signalling overheads and delay. However, for HAPS UMTS, base stations are collocated, so there is minimal delay and signalling. There are some design options that can be considered for centralised CAC. Various schemes may be used to decide the order that calls are processed. We investigate two centralised CAC schemes as described below.

**6.2.8.1 Centralised Received Power Based, Random Model (CRP-RA) CAC**

This scheme processes calls in random order. However, as calls are processed sequentially, the admission of a mobile to a cell that already has high total received power may cause the blocking of other subsequent calls that request service from its neighbouring cells. Hence, this scheme is expected to create some unnecessary blocking.
6.2.8.2 Centralised Received Power Based, Ranking Model (CRP-RK) CAC

A more optimal approach is for the central admission controller to give the highest priority to a call request in a cell with the lowest total received power. The central admission controller ranks the cells according to their current total received powers in ascending order. The call whose entry cell tops the ranking list will be processed first. After the call is processed, the central admission controller will re-rank the cells according to their updated total received powers and process the subsequent call accordingly, until all the calls are processed. This ranking scheme minimises the probability for the admission controller to accept a call whose entry cell has near maximum total received power and hence has to block other subsequent calls in other cells from entering the network. Furthermore, this ranking scheme also ensures that cells that have low total received powers, i.e., minimum loading, will be filled up first. By doing so, this scheme balances the loading in the service area and is expected to reduce outage and hence the dropping probabilities as compared to the CRP-RA scheme.

6.2.9 Congestion Control

The global and centralised CAC schemes are performed based on the information available at the time of decision. As conditions may deteriorate during the course of a call due to traffic distribution, mobility or traffic activity variations, call removal is applied to guarantee the QoS of the mobiles. In our evaluation, when the total received power of a cell exceeds $P_{th}$ continuously for 1 s, calls in that cell will be removed in the order of call initiation time until all links have recovered from outage.

6.2.10 Simulation Environment

We conduct simulation to evaluate the performance of HAPS UMTS with the distributed global CAC scheme and the proposed centralised CAC schemes. The simulation conditions are described as follows.

6.2.10.1 Cell Model

The simulation area consists of 19 cells below the nadir, which are approximated to be equally sized and circular in shape. Wrap around technique is used to avoid the boundary effects. The phased array antenna radiation pattern described in Section 2.5.2.3 is used in our evaluation. The maximum main lobe gain ($G_m$) of the phased array antenna is taken to be 36.7 dB. Assuming that the gain at cell boundaries is $-13$ dB with respect to $G_m$, the radius of the cells projected by the HAPS at an altitude of 22 km is 1 km.
6.2.10.2 Traffic Model

Two classes of real time services are considered, 15 kbps speech (\(k = 1\)) and 60 kbps circuit switched data (\(k = 2\)). Call arrivals are generated according to an independent Poisson process. Once calls are admitted, the call holding times are independent and exponentially distributed with a mean call duration of 120 s for speech and data calls. The speech service has an on-off model, with an activity factor of 0.5. Circuit switched data calls are assumed to have an activity factor of 1.

6.2.10.3 Mobility Model

At the start of a call, a mobile chooses a random starting location (uniformly distributed over the simulation area) and direction of motion (uniformly distributed over \([0°, 360°]\)). Each mobile monitors the pilot channels, which are transmitted at a constant power level from the base stations, and selects the base station whose pilot channel is the strongest as the serving base station. The speeds of the mobiles are 60 km/h for speech mobiles and 30 km/h for data mobiles. A mobile's speed remains constant throughout the duration of a call. The time taken before a mobile changes its traveling direction is exponentially distributed with a mean of 120 s for a speech mobile and a mean of 240 s for a data mobile. The new direction is generated by a uniform distribution over \([-45°, 45°]\) with reference to the previous direction. Hard handovers between adjacent cells are assumed.

6.2.10.4 Pilot Measurement Errors

Pilot measurement errors are modelled and are assumed to be Gaussian distributed in dB with a mean of 0 dB and a standard deviation of 2 dB.

6.2.11 Other Simulation Parameters

The remaining simulation parameters are summarised in Table 6-1.

Table 6-1: Simulation parameters used for the evaluation of centralised received power based CAC schemes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio access</td>
<td>WCDMA</td>
</tr>
<tr>
<td>Chip rate</td>
<td>3.84 Mcps</td>
</tr>
<tr>
<td>Speech service bit rate</td>
<td>15 kbps</td>
</tr>
</tbody>
</table>
### 6.2.12 Performance Measures

The performance indicators that are used to evaluate the proposed CAC schemes are as follows:

- **Call blocking probability** \( (P_b) \): The probability that a newly arrived mobile is denied access to the network as a result of the total received power level at any base station exceeding the blocking threshold, \( P_T^{\text{block}} \).

- **Call dropping probability** \( (P_d) \): The probability that a call is dropped from the network due to the congestion control mechanism.

- **Grade of service** \( (\text{GoS}) \): The GoS is defined by the cost function \( \text{GoS} = P_b + 10P_d \). A larger weighting factor is given to the dropping probability as it is much more annoying for a mobile to lose an ongoing call than to be denied access to the network.

### 6.2.13 Simulation Results

With the simulation parameters listed in Table 6-1, \( \gamma_1^{th} \) and \( \gamma_2^{th} \) are found to be 0.01628 and 0.05174 respectively. The power ratio between data and speech mobiles can be found using (6.8) to be

\[
\frac{S_2}{S_1} = \frac{1}{\gamma_1^{th}} + 1 = 3.0702. \tag{6.14}
\]

Normalising \( S_1 \) to 1, the outage threshold, obtained using (6.10), is

\[
P_T^{\text{th}} = S_k \left( \frac{1}{\gamma_k^{th}} + 1 \right) = 62.43, \tag{6.15}
\]

where \( k = 1 \) or \( 2 \). This means that outage for either service will occur if the total received power at the base station exceeds 62.43.
Throughout the simulation, the traffic load for the speech service is kept at 10 Erlangs/cell. With the traffic load for the data service varying from 6-10 Erlangs/cell, the blocking probabilities, dropping probabilities and GoS for both services are obtained and presented in Figure 6-2 to Figure 6-4 respectively.

![Blocking probability comparison between distributed global, CRP-RA and CRP-RK CAC schemes](image)

Figure 6-2: Blocking probability comparison between distributed global, CRP-RA and CRP-RK CAC schemes
Figure 6-3: Dropping probability comparison between distributed global, CRP-RA and CRP-RK CAC schemes

Figure 6-4: Grade of service comparison between distributed global, CRP-RA and CRP-RK CAC schemes
6.2.14 Performance Comparison between the Proposed Centralised CAC Schemes and the Distributed Global CAC Scheme

The distributed global scheme usually underestimates the other cells' total received powers. This inaccurate information will result in fewer mobiles being blocked by the network but the increase in interference levels contributed by the wrongly admitted mobiles will increase outage and dropping probabilities. In contrast, the centralised schemes process calls based on more accurate and updated knowledge of the interference levels of all cells. Hence, compared to the distributed global scheme, both the CRP-RA and CRP-RK schemes are able to achieve lower dropping probabilities with only slight increases in blocking probabilities. With significantly lower dropping probabilities, the centralised schemes can achieve better GoS for the system as compared to the distributed global scheme.

6.2.15 Performance Comparison between CRP-RA and CRP-RK Schemes

Comparing the two centralised schemes, we note that the CRP-RK scheme is able to achieve better blocking and dropping probabilities than the CRP-RA scheme. The main reasons for this are as follows. The CRP-RK scheme is able to minimise the blocking probabilities by giving the highest priority to a call that requests service from a cell with the lowest total received power. Otherwise, a call accepted by a cell already having a high total received power is likely to result in the blocking of subsequent calls in other cells from entering the network. Furthermore, the CRP-RK scheme also minimises the probability of overloading a particular cell and achieves better load balancing among all cells. This results in lower outage and dropping probabilities as compared to the CRP-RA scheme. With lower blocking and dropping probabilities, the overall GoS for the system is better with the CRP-RK scheme.

6.2.16 Discussion

From this study on centralised total received power based CAC for HAPS UMTS, we can draw the following conclusions.

- The proposed centralised CAC schemes can be effectively implemented for HAPS UMTS because unlike traditional terrestrial tower-based cellular systems, HAPS can centrally manage the base stations.
- The proposed centralised CAC schemes provide better GoS than the conventional distributed global scheme because the central admission controller has more updated information on the interference conditions in the service area. Therefore, more accurate CAC can be performed leading to better system performance.
• By prioritising the incoming calls according to the current interference status of their target base stations, the GoS achievable by centralised schemes can be further improved.

6.3 Centralised Transmit Power Based CAC for HAPS UMTS with Onboard Power Resource Sharing

6.3.1 Comparison to Existing Transmit Power Based CAC Schemes

For terrestrial tower-based systems, each base station has a fixed, maximum allowable downlink output power. This power is a limited resource shared by the signalling channels and traffic channels. Signalling channels are normally transmitted with a fixed power whereas the power transmitted by the forward link traffic channels varies according to the forward link power control scheme, which ensures that the SIR requirements of all traffic channels can be met under variations of traffic density, traffic distribution, propagation channel, user mobility and traffic activity.

An incoming call will increase the interference levels of its target cell as well as adjacent cells. Hence, with the admission of the new call, the forward link powers transmitted to all mobiles must be increased to satisfy all mobiles’ SIR requirements. A call will be blocked if admitting the call causes the call’s target base station as well as other neighbouring base stations to exceed their individual maximum allowable output powers [59].

For HAPS UMTS, the limited power resource available for traffic channels onboard the platform is likely to make the forward link the limiting link, as new asymmetric services will be introduced in UMTS. Hence, it is important to identify an efficient method of managing this limited power resource so as to maximise the capacity that can be supported by the system. When considering forward link CAC for HAPS UMTS, we note that all base stations’ transmit antenna beams originate from the same phased array antenna onboard the platform, so it is possible for the base stations to share the limited power resource available onboard the HAPS. In this case, the conventional method of allocating fixed amounts of power to individual base stations may not be the most optimum approach.

6.3.2 Approach

We make use of the unique HAPS property that all base station antennas are collocated onboard the platform to propose and analyse a CAC scheme for HAPS UMTS that considers the available
platform output power onboard the HAPS as a single resource to be allocated to base stations depending on their demand. Using the dynamic HAPS UMTS system level simulator, the performance of the proposed scheme is evaluated and compared to the performance of the conventional scheme where fixed amounts of power are allocated to individual base stations and managed at base station level.

![Diagram of HAPS forward link path gains](image)

Figure 6-5: HAPS forward link path gains

### 6.3.3 HAPS Forward Link Power Control Model

We assume that there are $Q$ active mobiles in the HAPS service area indexed by $i$ where $1 \leq i \leq Q$. We define $p_i$ as the downlink transmit power allocated to mobile $i$ so that

$$ p_i = [p_1, ..., p_Q]^T $$

(6.16)

represents the powers dedicated to the $Q$ mobiles.

As shown in Figure 6-5, we let $k$ and $l$ denote the cells to which mobiles $i$ and $j$ belong respectively, and let $BS_k$ and $BS_l$ represent the base stations serving cells $k$ and $l$ respectively. We
further assume that the signal transmitted to mobile $i$ is received correctly so that the SIR received by mobile $i$, $\gamma_i$, is greater than or equal to a given target value, $\gamma'_i$.

With these assumptions, the constraint on the received SIR of mobile $i$ is given by

$$\gamma_i = \frac{g_{ik}P_i}{\sum_{j=1 \atop j \neq i}^Q g_{il}P_j + n_i} \geq \gamma'_i,$$  \hspace{1cm} (6.17)$$

where $g_{il}$ is the link gain to mobile $i$ from BS$\ell$ and $g_{ik}$ is the link gain on the desired path of mobile $i$ [60]. $n_i$ denotes the interference received at mobile $i$ from background noise and control signals including pilots. The instantaneous link gain to mobile $i$ from BS$\ell$ can be written as

$$g_{il} = G(\psi_{il})L_{il} z_{il},$$  \hspace{1cm} (6.18)$$

where $G(\psi_{il})$ is the antenna gain evaluated at the angle under which mobile $i$ is seen from the antenna boresight of BS$\ell$. $L_{il}$ is the path loss between mobile $i$ and BS$\ell$. $z_{il}$ denotes the shadowing level corresponding to this path.

Rearranging (6.17), we obtain

$$p_i \geq \gamma'_i \left( \sum_{j=1 \atop j \neq i}^Q \frac{g_{il}P_j}{g_{ik}} + \frac{n_i}{g_{ik}} \right),$$  \hspace{1cm} (6.19)$$

If we define the $Q \times Q$ normalised downlink gain matrix $H = [h_{ij}]$ with elements

$$h_{ij} = \begin{cases} \frac{\gamma'_i g_{il}}{g_{ik}}, & i \neq j \\ 0, & i = j \end{cases},$$  \hspace{1cm} (6.20)$$

and the $Q \times 1$ normalised noise vector $\eta = [\eta_i]$ with $\eta_i = \gamma'_i \frac{n_i}{g_{ik}}$, we can express the linear inequality given in (6.19) as

$$(I - H)p \geq \eta,$$  \hspace{1cm} (6.21)$$

where $I$ denotes the $Q \times Q$ identity matrix [61]. Note that $k$ and $l$ are not independent variables, but are dependent on $i$ and $j$ respectively [60].
6.3.4 Centralised Transmit Power Based CAC Schemes

A centralised call admission controller is assumed to have perfect knowledge of all link gains. The objective of power control is to obtain a feasible power vector \( p \) that is non-negative and satisfies the transmission quality requirement that \( \gamma_i \geq \gamma'_i \) for all \( i \) \[61\]. The component-wise smallest power vector that satisfies this condition can be found by solving (6.21) with equality \[62\].

Due to constraints on payload, fuel cell efficiency and platform size, the available platform output power for traffic channels is limited. Hence, any feasible power assignment that satisfies the mobiles' SIR requirements must also fulfil the platform power limitation condition, i.e., the total power required to support all the mobiles in the service area should not exceed the maximum allowable platform downlink output power. We describe two centralised downlink transmit power based CAC schemes with different methods of managing the available platform power resource as follows.

6.3.4.1 Centralised Transmit Power Based, Base Station Power Limited (CTP-BS) CAC

The conventional method of managing the platform power resource is for the HAPS to allocate a fixed amount of power to each base station. In the Centralised Transmit Power Based, Base Station Power Limited (CTP-BS) CAC scheme, calls are only allowed to enter the network provided that in meeting the SIR requirements of the new and existing calls, a feasible power vector that accommodates the new and existing calls can be found, and that the output powers of all base stations in the service area do not exceed their respective limits. We let \( I_k \) be the index set of mobiles served by \( BS_k \) and \( P_k \) be the total output power of \( BS_k \) where

\[
P_k = \sum_{i \in I_k} p_i .
\]

Therefore, if \( BS_k \) has an output power limit \( P'_{k_i} \), a user can be admitted to the system if

\[
\begin{align*}
\exists \ p \geq 0 & \text{ such that } \gamma_i \geq \gamma'_i \ \forall \ i, \\
0 \leq P_k & \leq P'_{k_j} \ \forall k.
\end{align*}
\]

When a newly arrived mobile requests service, the network will exercise admission control. If (6.23) is satisfied for the new and existing calls, the new call will be accepted and the base station transmit powers will be readjusted according to the new feasible power vector. Otherwise, the call will be rejected and the powers remain as they were.
6.3.4.2 Centralised Transmit Power Based, Platform Power Limited (CTP-PF) CAC

A unique property of HAPS is that all base station transmit antennas are collocated onboard the platform, so power allocation can be more flexible. We propose the Centralised Transmit Power Based, Platform Power Limited (CTP-PF) CAC scheme, which considers the total platform output power available for traffic channels as a single resource to be shared among all base stations according to their demand. In this scheme, a call is allowed to enter the network provided that in meeting the SIR requirements of the new and existing calls, a feasible power vector that accommodates the new and existing calls can be found, and that total output power required to support all the calls in the service area does not exceed the total platform output power limit, i.e.,

\[ \exists \mathbf{p} \geq 0 \quad \text{such that} \quad \gamma_i \geq \gamma_i' \quad \forall i, \]

\[ 0 \leq \sum_{i=1}^{c} p_i \leq P_{PF}' \quad \text{(6.24)} \]

where \( P_{PF}' \) is the maximum platform output power available for traffic channels. If (6.24) is satisfied for the new and existing calls, the new call will be accepted and the platform transmit powers will be readjusted according to the new feasible power vector. Otherwise, the call will be rejected and the powers remain as they were.

In our study, individual downlink channel power limits are not taken into consideration for both CAC schemes.

6.3.5 Simulation Model

Using the dynamic HAPS UMTS system level simulator, we evaluate and compare the performances of the CTP-BS and CTP-PF CAC schemes in a mixed traffic environment. The simulation conditions are described as follows.

6.3.5.1 Cell Model

The cell model used is similar to that described in Section 7.10.1.

6.3.5.2 Traffic Model

Two real time circuit switched services are considered, d1 (30 kbps) and d2 (120 kbps). Call arrivals are generated according to an independent Poisson process. Once calls are admitted, the call holding times are independently and exponentially distributed with a mean call duration of 120 s for both services. The data activity factors of d1 and d2 are 0.5 and 1 respectively.
6.3.5.3 Mobility Model
At the start of a call, a mobile chooses a random starting location (uniformly distributed over the simulation area) and direction of motion (uniformly distributed over \([0, 360^\circ]\)). Each mobile arriving to the system chooses the base station providing the best link as its serving base station. The speeds of the mobiles are 60 km/h for d1 mobiles and 30 km/h for d2 mobiles. The speed of a mobile remains constant throughout the duration of a call. The time taken before a mobile changes its travelling direction is exponentially distributed with a mean of 120 s for a d1 mobile and a mean of 240 s for a d2 mobile. These values are obtained based on the assumption that a mobile will travel an average distance of 2 km before changing its travelling direction. The new direction is generated by a uniform distribution over \([-45^\circ, 45^\circ]\) with reference to the previous direction. Hard handovers between adjacent cells are assumed.

6.3.5.4 Other Simulation Parameters
The remaining simulation parameters are summarised in Table 6-2.

Table 6-2: Simulation parameters used for the evaluation of centralised transmit power based CAC schemes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio access</td>
<td>WCDMA</td>
</tr>
<tr>
<td>Chip rate</td>
<td>3.84 Mcps</td>
</tr>
<tr>
<td>d1 service bit rate</td>
<td>30 kbps</td>
</tr>
<tr>
<td>Required (\frac{E_b}{I_0}) for d1</td>
<td>6.2 dB</td>
</tr>
<tr>
<td>d2 service bit rate</td>
<td>120 kbps</td>
</tr>
<tr>
<td>Required (\frac{E_b}{I_0}) for d2</td>
<td>5.2 dB</td>
</tr>
</tbody>
</table>

6.3.6 Congestion Control
Due to link gain variations caused by the mobility of the mobiles and/or varying channel and traffic conditions, even if no new mobiles are admitted, a feasible power vector might not be found at a particular instant. In this case, call removal is required to recover the link, where the criterion for call removal is another issue. In our evaluation, no priorities are given to any data.
Chapter 6. Call Admission Control Schemes for HAPS UMTS

types and a simple stepwise call removal algorithm is implemented where the mobile which has the worst link gain condition is outaged (i.e., have its downlink traffic channel switched off) until the required SIR levels are achieved in the remaining links. A mobile that is in outage continuously for 1 s will be dropped from the network.

6.3.7 Comparison between CTP-BS and CTP-PF CAC Schemes

The individual base station output power limit used for the CTP-BS scheme is assumed to be 15 W while the HAPS output power limit used for the CTP-PF scheme is assumed to be 285 W. The platform output power limit of the CTP-PF scheme is taken to be the sum of the individual base stations’ output power limits of the CTP-BS scheme, so that relative comparison can be made between the two schemes. Throughout the simulation, the traffic load for the d2 service is kept at 4 Erlangs/cell. With the traffic load for the d1 service varying from 3-8 Erlangs/cell, the blocking and dropping probabilities of both services were obtained and presented in Figure 6-6 and Figure 6-7 respectively.

![Figure 6-6: Blocking probability comparison between CTP-BS and CTP-PF schemes](image-url)
Figure 6-7: Dropping probability comparison between CTP-BS and CTP-PF schemes

From Figure 6-6 and Figure 6-7, we see that the CTP-PF scheme outperforms the CTP-BS scheme in terms of blocking and dropping probabilities. This is mainly because the CTP-PF scheme is more flexible in the allocation of downlink output power as compared to the CTP-BS scheme. Therefore, depending on their demands, base stations requiring more output power than the amount allocated by the CTP-BS scheme can now be allocated their required power by the CTP-PF scheme. With reduced blocking and dropping probabilities, better grades of service for the system are achieved by the CTP-PF scheme as shown in Figure 6-8. Hence, centralising and sharing the power resources among all base stations can improve system performance.
6.3.8 Power Savings with Onboard Platform Sharing

The CTP-PF CAC scheme offers significant power savings as compared to the CTP-BS scheme, for the same required GoS. This is because not all base stations will utilise their peak power allocations (of 15 W) at the same instant. This effect is illustrated in Figure 6-9, which shows the variation of the base station power utilisation for 3 separate base stations against time.

As shown in the figure, the power consumptions of the 3 base stations peak at different times. Therefore, considering the system power utilisation as a whole, the average base station power utilisation is much lower than the individual base stations’ peak power allocations. However, because each base station manages its own power, maximum power still has to be sized for each base station. By centralising the platform power instead of allocating it in a distributed manner to individual base stations, power savings can be made since the central pool of platform power can be allocated to each base station on a time-sharing basis, i.e., “power-on-demand” allocation.
Chapter 6. Call Admission Control Schemes for HAPS UMTS

To establish the benefit of centralising the platform power in terms of power savings, we determine the total platform power required to support the CTP-BS scheme by summing the individual base stations’ output power limits. Next, we fix d1 and d2 loads at 4 Erlangs/cell and vary the platform output power limit of the CTP-PF scheme from 10% to 100% of the total platform power required by the CTP-BS scheme.

The GoS achieved by the CTP-PF scheme vs. the percentage of the total platform power required by the CTP-BS scheme is shown in Figure 6-10.

From Figure 6-8, we know that with a d1 load of 4 Erlangs/cell, we are able to achieve GoS levels of 0.25 and 0.54 for d1 and d2 respectively using the CTP-BS scheme. It is observed from Figure 6-10 that the CTP-PF scheme requires only approximately 24% of the total platform power required by the CTP-BS scheme to meet these GoS levels.
6.3.9 Discussion

From this study on centralised total received transmit power based CAC for HAPS UMTS, we can draw the following conclusions:

- Centralised transmit power CAC schemes can be implemented for HAPS UMTS due to the HAPS's centrally managed base stations.
- As compared to the conventional CTP-BS scheme, the CTP-PF scheme utilising "power-on-demand" allocation can achieve better system performance.
Chapter 6. Call Admission Control Schemes for HAPS UMTS

- To achieve the same levels of GoS, the platform power required by the CTP-PF scheme is significantly lower than the total platform power required by the CTP-BS scheme.

6.4 Conclusion

In this chapter, we have studied the problem of CAC for HAPS UMTS and have explained how we made use of the centralised base station property of HAPS to propose three CAC schemes for HAPS UMTS — the CRP-RA, CRP-RK and CTP-PF schemes.

All three CAC schemes outperform conventional terrestrial-tower based schemes applied directly to the HAPS environment. For the CRP-RA and CRP-RK schemes, the performance improvement comes from more updated awareness of the interference conditions due to the centralised nature of the base stations. For the CTP-PF scheme, the performance improvement comes from the extra power made available by sharing the onboard platform power among all base stations on a “power-on-demand” basis.
Chapter 7

7 Call Admission Control Schemes for HAPS and Terrestrial Tower-based Hierarchical UMTS

7.1 Introduction

One possible operating scenario for HAPS communications systems is for HAPS UMTS to be jointly deployed with terrestrial tower-based UMTS in a hierarchical cellular structure. In such a scenario, it is envisaged that HAPS will likely provide the contiguous macrocell coverage with terrestrial tower-based UMTS providing the microcell coverage in hotspot areas [48]. In this chapter, we investigate the CAC problem for HAPS UMTS in this scenario and propose CAC schemes to efficiently manage the resources (i.e., power) on the HAPS in order to improve the overall system's grade of service.

7.2 Design of Hierarchical Systems in UMTS

UMTS will most likely employ a variety of cell types consisting of macrocells and microcells in order to support a wide range of services in different operating environments. A macrocell’s service radius is usually larger than 1 km. A microcell’s service radius is around several hundred metres. The size of the cells is closely related to the expected speed of the mobiles that the system is to support (i.e., the faster the mobiles move, the larger the cells should be), to keep the complexity of handovers at manageable level. Furthermore, the cell size is also dependent on the expected system load (Erlangs per unit area); that is, the larger the system load, the smaller the cell should be [65].

These different types of cells are likely to co-exist in UMTS and operate one upon another, forming a hierarchical multi-layer system. In such an architecture, a lower layer of microcells is covered by an upper layer of umbrella macrocells. Microcells are used to achieve higher capacity, while macrocells provide a larger coverage area and reduce overheads due to handovers. Such
Hierarchical architectures are of great interest since they can boost system capacity and improve handover signalling load if properly engineered.

However, due to their effective frequency reuse factor of one, hierarchical UMTS based on WCDMA must deal with cross-interference between the hierarchical layers. A preferable option is to assign different spectrums to different tiers to avoid power control problems and excessive cross-layer interference [66]. This option is considered in our study.

7.3 Deployment Scenario for HAPS and Terrestrial Tower-based Hierarchical UMTS

We note one possible deployment scenario for HAPS communications systems is for HAPS UMTS and terrestrial tower-based UMTS to be jointly deployed in a hierarchical system. In this case, it is envisaged that HAPS UMTS will likely provide the contiguous macrocell coverage with terrestrial tower-based UMTS providing the microcell coverage in isolated and concentrated high traffic areas called "hotspots" [48]. This approach whereby a cluster of microcell hotspots are embedded in a continuous layer of HAPS macrocells will be more economically viable due to reduced infrastructure costs as compared to the case where terrestrial tower-based UMTS is used to provide both continuous macrocell coverage and hotspot microcells. The cell structure considered in this study is therefore contiguous HAPS macrocells overlaying with a cluster of isolated terrestrial tower-based microcells.

7.4 CAC for Hierarchical UMTS

The CAC problem in a hierarchical system is more complex than in a single layer system because in the overlaying areas, CAC provides a mechanism to obtain better performance if mobiles are allowed to flow between the layers. System performance can also be improved if a mechanism whereby various mobility and traffic types (such as speech and data) in the overlaying areas can be differentiated and assigned to different layers.

Some of the important CAC design considerations for a hierarchical system are:

- **Different service types**: High bit rate services should ideally be served by the microcells since microcells can support higher capacity.
User mobility: High-speed mobiles should be directed to the macrocells in order to reduce call dropping due to frequent handovers between cells and to minimise the network's signalling load.

Overflow/underflow traffic: To reduce blocking probability, mobiles that are being blocked at one layer during the admission phase should be allowed to overflow/underflow to the other layer.

Load balancing between layers: Resource utilisation should be optimally distributed between layers to avoid a particular layer from being overloaded. This will ensure that better overall system performance can be achieved.

Several hierarchical CAC schemes have been proposed in literature. These are summarised as follows.

a) An overflow sensitive CAC strategy can be applied to improve overall system performance. For example, when a microcell has no more resources available, mobiles arriving to the microcell can “overflow”, i.e., be redirected to the overlaying macrocell in order to minimise the blocking and dropping probability. Overflowing in the reverse direction, i.e., from macrocell to microcell is also possible [67].

b) A speed sensitive CAC strategy can also be applied whereby fast-speed mobiles are allocated to the macrocell layer and slow-speed mobiles are allocated to the microcell layer. This strategy aims at reducing handover rate and handover dropping probability for fast users traversing successive microcells [68], [69].

c) A combination of the overflow and speed sensitive CAC strategy is possible. The speed sensitive CAC can be applied first followed by the overflow sensitive strategy [67].

d) If mobiles are not admitted to their target layer, they can attempt to handup/handdown to their target layer (as long as they are within the target layer’s coverage area) when resources in their target layer is available. For example, a fast-speed mobile that is served by the microcell layer due to (i) lack of resources in the macrocell layer or (ii) being out of macrocell layer coverage will be handed up to the macrocell layer as soon as resources are available in the macrocell layer and the mobile is within macrocell layer coverage [68].

e) A mechanism can be implemented whereby each user has the possibility of having a layer reselection after a speed change. If users have changing speeds, the system must monitor the users constantly so as to place the users in the “correct” layer to minimise handover rate [68].
These CAC schemes have been extensively studied in the appropriate references, mainly for non-CDMA systems and for the case where both macrocell and microcell layers provide continuous radio coverage. However, none of the work has considered a cell structure having continuous macrocell coverage scattered with selected areas of microcell hotspots, which can exist in a practical scenario, since it is too costly to deploy continuous microcell coverage. These CAC schemes and their performances can generally be applied to the cell structure we are concerned with, i.e., contiguous HAPS macrocells overlaying isolated terrestrial tower-based microcell hotspots. However, direct application of these schemes may not yield optimum performance in this unique operating environment.

### 7.5 Approach

For the cellular structure where HAPS UMTS macrocells are overlaying isolated terrestrial tower-based UMTS microcell hotspots, mobiles arriving to coverage areas served exclusively by HAPS do not have an alternate layer to overflow if they are being denied entry. Therefore, some power resource could be reserved for them in order to ensure that overall system's grade of service is not degraded.

The benefit of using onboard power sharing for HAPS UMTS has already been shown in Chapter 6. We extend our work in Chapter 6 and make use of the centralised onboard resource management concept to propose three CAC schemes with centralised resource reservation for HAPS and terrestrial tower-based hierarchical UMTS. These centralised resource reservation CAC schemes exploit the unique characteristics of HAPS UMTS to efficiently and effectively complement the upper and lower layers to achieve a more optimum system performance.

Using the HAPS UMTS system level simulator, we evaluate the proposed CAC schemes and compare their performances with the performance of a reference CAC scheme without resource reservation.

### 7.6 System Model and Terminology

We assume that a HAPS carrying a WCDMA communications payload and a multi-beam phased array antenna with beam/gain shaping capability is positioned at an altitude of 22 km in the stratosphere. With the WCDMA communications payload and phased array antenna onboard the HAPS, a homogenous network of circular macrocells can be projected on the ground. We further assume that a cluster of omnidirectional terrestrial tower-based microcells is embedded within the
macrocells as shown in Figure 7-1 to cover hotspot areas. The macrocell and microcell layers are assumed to operate with different frequency bands. Therefore no cross-layer interference is considered.

The power resource onboard the HAPS is centrally managed and shared among all macrocells. However, for the terrestrial tower-based cells, each base station is allocated a fixed amount of power and each base station manages this allocated power independently.

For the remainder of this chapter, the following terminologies are used:

- **HAPS macrocell layer**: The coverage area served by HAPS UMTS.
- **Microcell layer**: The coverage area served by terrestrial tower-based UMTS.
- **Overlaying area**: The overlapping coverage areas of the macrocell and microcell layers.
- **HAPS exclusive area**: The non-overlapping coverage area served exclusively by HAPS UMTS.

![Diagram](image)

**Figure 7-1: Homogenous HAPS macrocells overlaying terrestrial tower-based hotspot microcells**
7.7 Forward Link Power Control Model

Figure 7-2 shows the interference geometry of the HAPS and terrestrial tower-based hierarchical system. As the HAPS and terrestrial tower-based layers operate in separate frequencies, we assume that interference to a particular mobile is only caused by the transmit powers of base stations within the same layer as the mobile.

7.7.1 HAPS (Macrocell) Layer

For the HAPS (macrocell) layer, the power control model adopted is similar to that described in Section 0. This means that the power is centralised onboard the platform and centralised power control is used to obtain a feasible power vector \( p \) that is non-negative and satisfies the transmission quality requirement that \( \gamma_i \geq \gamma'_i \) for all \( i \). As described in Section 0, the component-wise smallest power vector that satisfies this condition can be found by solving the equation

\[
(I - H)p = \eta
\]  

(7.1)

7.7.2 Terrestrial Tower-based (Microcell) Layer

As all terrestrial tower-based microcells are closely located in a cluster, we assume that the centralised downlink power control model can also be applied in the microcell layer. However, each base station manages its power independently since all base stations are physically separated.

We assume that there are \( W \) active mobiles served by the terrestrial tower-based layer indexed by \( m \) where \( 1 \leq m \leq W \). We define \( s_m \) as the downlink transmit power allocated to mobile \( m \) so that

\[
s = [s_1, ..., s_W]^T
\]  

(7.2)

denotes the powers dedicated to the \( W \) mobiles.
As shown in Figure 7-2, we let $u$ and $v$ denote the cells to which mobiles $m$ and $n$ belong respectively, and let $BS_u$ and $BS_v$ represent the base stations serving cells $u$ and $v$ respectively. We further assume that the signal transmitted to mobile $m$ is received correctly so that the SIR received by mobile $m$, $\Gamma_m$, is greater than or equal to a given target value, $\Gamma'_m$.

With these assumptions, the constraint on the received SIR of mobile $m$ is given by...
\[ \Gamma_m = \frac{a_{mv} s_m}{\sum_{n=1}^{W} a_{nv} s_n + v_m} \geq \Gamma'_m, \]  

(7.3)

where \( a_{mv} \) is the link gain to mobile \( m \) from BS, and \( a_{nu} \) is the link gain on the desired path of mobile \( m \) [60]. \( v_m \) denotes the interference received at mobile \( m \) from background noise and control signals including pilots. The instantaneous link gain to mobile \( m \) from BS, can be written as

\[ a_{nv} = L_{nv}, \]  

(7.4)

where \( L_{nv} \) is the path loss between mobile \( m \) and BS. \( \zeta_{nv} \) denotes the shadowing level corresponding to this path.

If we define the \( W \times W \) normalised downlink gain matrix \( B = [b_{mn}] \) with elements

\[ b_{mn} = \begin{cases} \Gamma'_m \frac{a_{mv}}{a_{nu}} & , m \neq n \\ 0 & , m = n \end{cases} \]  

(7.5)

and the \( W \times 1 \) normalised noise vector \( \lambda = [\lambda_m] \) with \( \lambda_m = \Gamma'_m \frac{\gamma_m}{\sigma_{nu}} \), we can express the linear inequality given in (7.3) as

\[ (I - B)s \geq \lambda, \]  

(7.6)

where \( I \) denotes the \( W \times W \) identity matrix [61]. Note that \( \gamma \) and \( v \) are not independent variables, but are dependent on \( m \) and \( n \) respectively [60].

With knowledge of all link gains, the power control process obtains a feasible power vector \( s \) that satisfies the transmission quality requirement that \( \Gamma_m \geq \Gamma'_m \) for all \( m \). The component-wise smallest power vector \( s \) that satisfies this condition is found by solving

\[ (I - B)s = \lambda. \]  

(7.7)

## 7.8 Reference CAC Scheme

A reference CAC scheme is used against which the proposed CAC schemes with centralised resource reservation are compared. The reference CAC scheme uses a combination of overflow
and speed sensitive CAC strategies as described in Section 7.4.

7.8.1 Layer Selection

Calls arriving to service areas served by both macrocell and microcell layers will be directed to the appropriate layer based on a simple speed sensitive strategy. As pointed out earlier, it is beneficial for high-speed mobiles to be serviced in the HAPS macrocell layer and slow-speed mobiles to be serviced in the terrestrial tower-based microcell layer in order to minimise the number of handovers. Therefore, it is important to estimate the speed of the mobiles precisely for the purpose of selecting the target layer. In our study, we assume that the speeds of the mobiles are known prior to call connection so that layer selection can be made prior to CAC.

The layer selection strategy is as follows. We distinguish two classes of fast and slow mobiles. A design parameter called the speed threshold, $z_{th}$, is set so that mobiles with speeds $\geq z_{th}$ will be directed to the macrocell layer, while mobiles with speeds $< z_{th}$ will be directed to the microcell layer for admission.

Note that the layer selection strategy will not be applied to mobiles arriving to the service areas served exclusively by HAPS.

7.8.2 Call Admission

Once arriving calls are directed to the appropriate layer, CAC is performed to ensure that the admission of the calls will not deteriorate link qualities of the existing calls in that layer. CAC is performed separately for the two layers, but with the possibility of overflow to the alternate layer for calls arriving to the overlaying areas.

7.8.2.1 Mobiles Arriving to the HAPS (Macrocell) Layer

Three groups of mobiles may request connection to the macrocell layer at the start of their call. They are:

(i) mobiles arriving to the HAPS exclusive area.

(ii) mobiles with speeds $\geq z_{th}$ arriving to the overlaying area and directed to the macrocell layer by the speed sensitive layer selection strategy.

(iii) overflowing mobiles from the microcell layer, i.e., mobiles arriving to the overlaying area with speeds $< z_{th}$ but are refused admission by the microcell layer.
For these mobiles, the CTP-PF CAC scheme proposed in Chapter 6 is used to decide whether the mobile can be admitted to the macrocell layer. In this scheme, a call is allowed to enter the macrocell layer provided that in meeting the SIR requirements of the new and existing calls in the macrocell layer, a feasible power vector $p$ that accommodates the new and existing calls can be found, and that the total output power required to support all the calls in the macrocell layer does not exceed the total platform output power limit. Using the notation defined in Chapter 6, the admission criteria for the macrocell layer can be written as

\[
\exists \ p \geq 0 \text{ such that } \gamma_i \geq \gamma_i' \ \forall i, \\
0 \leq \sum_{i=1}^{Q} p_i \leq P_{PF}, \tag{7.8}
\]

If (7.8) is satisfied for the new and existing calls, the new call will be accepted by the macrocell layer and the platform transmit powers will be readjusted according to the new feasible power vector. Otherwise, the call will be rejected by the macrocell layer and the powers remain as they were.

Rejected call requests from mobiles in categories (i) and (iii) are blocked. Rejected call requests from mobiles in category (ii) are allowed to seek admission to the neighbouring microcell (i.e., overflow to the microcell). These calls will be served by the microcell provided that resources are available in that cell (see Section 7.8.2.2). Otherwise, the admission request will fail and the calls will be blocked.

### 7.8.2.2 Mobiles Arriving to the Terrestrial Tower-based (Microcell) Layer

Two groups of mobiles may request connection to the microcell layer at the start of their call. They are:

(i) mobiles with speeds $< z_{th}$ arriving to the overlaying area and directed to the microcell layer by the speed sensitive layer selection strategy.

(ii) overflowing mobiles from the macrocell layer. i.e., mobiles with speeds $\geq z_{th}$ arriving to the overlaying area but are refused admission by the macrocell layer.

For these mobiles, the following CAC scheme which is similar to the CTP-BS scheme described in Chapter 6 is used to decide whether the mobile can be admitted to the microcell layer.
Calls are only allowed to enter the microcell layer provided that in meeting the SIR requirements of the new and existing calls, a feasible power vector $s$ that accommodates the new and existing calls can be found, and that the output powers of all base stations in the microcell layer do not exceed their respective limits. We let $J_u$ be the index set of mobiles served by $BS_u$ and $S_u$ be the total output power of $BS_u$ where

$$S_u = \sum_{m \in J_u} s_m.$$  \hfill (7.9)

Therefore, if $BS_u$ has an output power limit $S_u^t$, a user can be admitted to the microcell layer if

$$\exists s \geq 0 \text{ such that } \Gamma_m \geq \Gamma_m^t \ \forall \ m, \ 0 \leq S_u \leq S_u^t \ \forall u.$$  \hfill (7.10)

If (7.10) is satisfied for the new and existing calls, the new call will be accepted by the microcell layer and the microcell base station transmit powers will be readjusted according to the new feasible power vector. Otherwise, the call will be rejected by the microcell layer and the powers remain as they were.

Rejected call requests from mobiles in category (ii) will be blocked. Rejected call requests from mobiles in category (i) are allowed to overflow to the neighbouring overlaying macrocell. The calls will be accepted by the macrocell if resources are available on the HAPS (see Section 7.8.2.1). Otherwise, the admission request will fail and the calls will be blocked.

The reference CAC procedure for the hierarchical system is summarised in the flowchart in Figure 7-3.
Chapter 7. CAC Schemes for HAPS and Terrestrial Tower-based Hierarchical UMTS

7.9 Proposed Call Admission Control Schemes

7.9.1 Centralised Power Reservation

In the proposed hierarchical cell structure, mobiles arriving to the overlaying area have two chances of seeking admission into the system, first to their target layer based on speed sensitive layer selection, and the alternate layer if their target layer does not have enough resources to accommodate them.

However, mobiles arriving to the coverage areas served exclusively by HAPS has only one
admission attempt since it is impossible for them to overflow to the microcell layer. Therefore, the chances for this group of mobiles to gain access to the system will be much lower as compared to the mobiles arriving to the overlaying areas. Hence, to ensure that the system's grade of service is not deteriorated seriously by mobiles arriving to the HAPS exclusive area, one of the main CAC design considerations has to be on how to reduce the blocking probability for this group of mobiles.

In this work, we enhance the reference CAC scheme and propose three CAC schemes that centrally reserve a fraction of the platform power resource to accommodate new mobiles arriving to the service area served exclusively by the HAPS. The power resource reservation will be carried out when the platform power utilisation is nearing its limit so that new mobiles arriving to the non-overlaying HAPS service area will have a smaller chance of being blocked. The power is reserved by handing down slow-speed users in the overlaying areas from the macrocell layer to the microcell layer to free resources in the macrocell layer.

The HAPS platform power can be reserved efficiently and can be used to accommodate mobiles arriving to any HAPS cell since this reserved power is centralised onboard the HAPS platform and therefore can be used on a “power-on-demand” basis by all HAPS base stations, as explained in Chapter 6. Therefore, with centralised power reservation, less platform power needs to be reserved as compared to the case where resources are reserved in every cell independently. Consequently, with centralised resource reservation, the number of mobiles to be handed down is smaller than that required with distributed resource reservation, leading to lower handover rate.

7.9.2 Centralised Handing Down of Mobiles

We note that for HAPS UMTS, base stations are collocated. Therefore, during the resource reservation process, calls can be centrally and sequentially processed for handing down very efficiently. Also, the central admission controller has at its disposal the properties of all the mobiles in the overlaying area (e.g., speed, bit rate, etc.) so it not only can coordinate the entire handing down process centrally but also has flexibility in choosing which particular mobile/group of mobiles to hand down in order to meet specific system performance requirements, e.g., low handover rate. By consolidating the mobile properties centrally and carefully selecting the types of mobiles to be handed down to the microcell layer and the order of doing so, the central admission controller can ensure that minimal impact to the microcell layer will be made so that good overall system performance can be maintained. Such coordination is difficult to implement in traditional terrestrial tower-based systems because of the large signalling overheads and delay
between geographically separated base stations.

We propose three centralised resource reservation schemes based on different methods of managing the mobiles to be handed down as follows.

7.9.3 CAC with Centralised Resource Reservation, Random Model (RR-RA)

Our first proposed CAC scheme is the Centralised Resource Reservation, Random Model (RR-RA). In this scheme, the reference CAC scheme is enhanced as follows. When the current platform power utilisation, \( P_{PF} = \sum_{i=1}^{n} P_i \), has reached a percentage \( \beta \) of its peak value \( P_{PF}^i \), mobiles in the overlaying area served by HAPS with speeds < \( z_{th} \) will be handed down to the microcell layer one by one in random order until enough resources are freed from the HAPS layer, subject to the availability of resources in the microcell layer.

If we let \( I_{hd} \) be the set of mobiles in the overlaying area served by HAPS with speeds < \( z_{th} \), we can summarise the RR-RA scheme as follows.

For every time step, the RR-RA scheme does the following:

(i) If \( P_{PF} \geq \beta P_{PF}^i \), proceed to step (ii). Otherwise, proceed to step (vii).

(ii) Identify all mobiles in the set \( I_{hd} \). If \( I_{hd} = \{ \} \), go to step (vii).

(iii) Randomly select a mobile \( x \) such that \( x \in I_{hd} \), which has not been previously processed. If all mobiles in \( I_{hd} \) have been processed, go to step (vii).

(iv) Determine whether there are enough resources in the microcell layer to accommodate mobile \( x \) using the CAC criteria in (7.10).

(v) If (7.10) is satisfied, mobile \( x \) is handed down to microcell layer. All platform and base stations' transmit powers to all mobiles are updated, i.e., power vectors \( p \) and \( s \) are updated.

(vi) If \( P_{PF} \geq \beta P_{PF}^i \), repeat step (iii).

(vii) RR-RA scheme terminates.

By freeing power resources on the platform, the scheme ensures that the HAPS will have enough
power resources to accommodate mobiles arriving to the coverage area served exclusively by the HAPS.

However, this scheme will result in an increase the system handover rate, mainly due to the handing down signalling load. We note that $\beta$ should be a relatively high value so that resource reservation is performed not all the time but only when the HAPS platform resource is nearing its limit. Handing down mobiles frequently when there is still enough resources on the HAPS will generate unnecessary signalling load. Also, we note that it is acceptable for slow mobiles to reside in the macrocell layer since slow mobiles will not generate a large number of handovers from cell crossings in the macrocell layer.

7.9.4 CAC with Centralised Resource Reservation, Traffic Selection (RR-TS)

The Centralised Resource Reservation, Traffic Selection (RR-TS) scheme is an improvement of the RR-RA scheme. In this scheme, instead of handing down mobiles in the set $I_{hd}$ in random order when $P_{PF} \geq \beta P_{PF}^I$, mobiles in the set $I_{hd}$ having higher bit rates and hence higher power requirements are given preference in handing down in order to reduce the number of handovers required to recover the resources in the HAPS layer. This approach will allow us to hand down a minimum number of mobiles since on average, each high bit rate user utilises more resources than a lower bit rate user. Therefore, handing down a high bit rate user might free more power resources per handover execution than handing down several lower bit rate users. Resources can then be recovered more quickly with minimal handover executions. The RR-TS scheme can be summarised as follows:

For every time step, the RR-TS scheme does the following:

(i) If $P_{PF} \geq \beta P_{PF}^I$, proceed to step (ii). Otherwise, proceed to step (viii).

(ii) Identify all mobiles in the set $I_{hd}$. If $I_{hd} = \emptyset$, go to step (viii).

(iii) Rank the mobiles in the set $I_{hd}$ according to their service bit rates in descending order.

(iv) Select the mobile $x \in I_{hd}$ that tops the ranking list, i.e., the highest bit rate mobile that has not been previously processed. If all mobiles in $I_{hd}$ have been processed, go to step (viii).

(v) Determine whether there are enough resources in the microcell layer to accommodate mobile $x$ using the CAC criteria in (7.10).
Chapter 7. CAC Schemes for HAPS and Terrestrial Tower-based Hierarchical UMTS

(vi) If (7.10) is satisfied, mobile x is handed down to the microcell layer. All platform and base stations' transmit powers to all mobiles are updated, i.e., power vectors p and s are updated.

(vii) If $P_{PF} \geq \beta P^p_{PF}$, repeat step (iv).

(viii) RR-TS scheme terminates.

By minimising the number of handing down operations, the RR-TS scheme is expected to achieve lower overall system handover rate as compared to the RR-RA scheme.

7.9.5 CAC with Centralised Resource Reservation, Speed Selection (RR-SS)

The second approach in improving the RR-RA scheme is to allow users with the lowest travelling speeds to be handed down to the microcell layer first. In the Centralised Resource Reservation, Speed Selection (RR-SS) scheme, when $P_{PF} \geq \beta P^p_{PF}$, mobiles in the set $I_{hd}$ will be ranked according to their travelling speeds in ascending order. The slowest mobile is handed down to the microcell layer first followed by the next slower one and so on in order to ensure that the group of mobiles that are handed down are collectively the slowest mobiles out of the potential set of mobiles that can be handed down.

The RR-SS scheme can be summarised as follows:

For every time step, the RR-SS scheme does the following:

(i) If $P_{PF} \geq \beta P^p_{PF}$, proceed to step (ii). Otherwise, proceed to step (viii).

(ii) Identify all mobiles in the set $I_{hd}$. If $I_{hd} = \{}$, go to step (viii).

(iii) Rank the mobiles in the set $I_{hd}$ according to their speeds in ascending order.

(iv) Select the mobile $x \in I_{hd}$ that tops the ranking list, i.e., the slowest mobile that has not been previously processed. If all mobiles in $I_{hd}$ have been processed, go to step (viii).

(v) Determine whether there are enough resources in the microcell layer to accommodate mobile x using the CAC criteria in (7.10).
(vi) If (7.10) is satisfied, mobile \( x \) is handed down to the microcell layer. All platform and base stations' transmit powers to all mobiles are updated, i.e., power vectors \( p \) and \( s \) are updated.

(vii) If \( P_{pf} \geq \beta P_{pf}^t \), repeat step (iv).

(viii) RR-SS scheme terminates.

Compared to the RR-RA scheme, the RR-SS scheme ensures that only the slowest mobiles are handed down. Therefore, these mobiles will generate fewer cell crossings in the microcell layer as compared to the mobiles picked randomly by the RR-RA scheme. Hence, the overall system handover rate is expected to decrease.

**7.10 Simulation Environment**

Using the dynamic HAPS UMTS system level simulator, we evaluate and compare the performances of the RR-RA, RR-TS and RR-SS schemes in a mixed traffic environment. In this section, we describe the simulation models used.

**7.10.1 Cell Model**

The simulation area consists of three circular HAPS macrocells near the nadir, which are approximated to be equally sized and circular in shape. The antenna radiation pattern used for cell projection has a sharp roll off of 60 dB/decade and conforms to the ITU specifications described in Section 2.5.2.3. The maximum main lobe gain \( (G_m) \) of the phased array antenna is chosen to be 36.7 dB. Assuming that the gain at cell boundaries is -13 dB with respect to \( G_m \), the radius of the cells projected by the HAPS at an altitude of 22 km is 1 km.

Seven terrestrial tower-based microcells are embedded in the macrocell layer, directly under the nadir of the HAPS. The radius of the microcells is taken to be 0.2 times that of the HAPS macrocells.

**7.10.2 Traffic Model**

Two real time circuit switched services are considered, \( d_1 \) (30 kbps) and \( d_2 \) (60 kbps). Call arrivals to both layers are generated according to independent Poisson processes. Once calls are admitted, the call holding times are independently and exponentially distributed with a mean call
duration of 120 s for both services. The data activity factors of d1 and d2 are 0.5 and 1 respectively.

7.10.3 Mobility Model

7.10.3.1 Initial Speed Distribution

We consider two populations of mobiles, which are classified as slow-speed and fast-speed mobiles. For the macrocell layer, the proportions of slow-speed and fast-speed mobiles are 20% and 80% respectively. For the microcell layer, the proportions of slow-speed and fast-speed mobiles are 80% and 20% respectively. Within the slow-speed and fast-speed categories, a continuous distribution of initial mobile speeds is assumed. For service type d1, the initial speeds of the mobiles are Gaussian distributed with means of $\mu_s = 5$ km/h and $\mu_f = 45$ km/h for slow-speed and fast-speed mobiles respectively. For service type d2, the initial speeds of the mobiles are Gaussian distributed with means of $\mu_s = 5$ km/h and $\mu_f = 15$ km/h for slow-speed and fast-speed mobiles respectively. The standard deviation of the mobiles' speeds is assumed to be $\sigma = 10$ km/h for all cases. Table 7-1 and Table 7-2 summarise the initial speed assumptions used in the simulation for the microcell and macrocell layers respectively.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Data Type</th>
<th>Slow-speed mobiles (80%)</th>
<th>Fast-speed mobiles (20%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro</td>
<td>d1 (30 kbps)</td>
<td>$\sim N(5, 10^2)$ km/h</td>
<td>$\sim N(45, 10^2)$ km/h</td>
</tr>
<tr>
<td></td>
<td>d2 (60 kbps)</td>
<td>$\sim N(5, 10^2)$ km/h</td>
<td>$\sim N(15, 10^2)$ km/h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer</th>
<th>Data Type</th>
<th>Slow-speed mobiles (20%)</th>
<th>Fast-speed mobiles (80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro</td>
<td>d1 (30 kbps)</td>
<td>$\sim N(5, 10^2)$ km/h</td>
<td>$\sim N(45, 10^2)$ km/h</td>
</tr>
<tr>
<td></td>
<td>d2 (60 kbps)</td>
<td>$\sim N(5, 10^2)$ km/h</td>
<td>$\sim N(15, 10^2)$ km/h</td>
</tr>
</tbody>
</table>

7.10.3.2 Other Mobility Characteristics

At the start of a call, a mobile chooses a random starting location (uniformly distributed over each layer's service area) and direction of motion (uniformly distributed over [0, 360°]). The overflow speed threshold, $z_{th}$, is taken to be 35 km/h. The speed of a mobile remains constant throughout
the duration of a call. The average distance travelled before a mobile changes its travelling
direction is 2 km for both layers. The new direction is generated by a uniform distribution over [-
45°, 45°] with reference to the previous direction. Hard handovers between adjacent cells are
assumed.

7.10.4 Channel Model

The HAPS channel model used is based on the satellite channel model proposed by Lutz, where
the mobile experiences periods of good (line-of-sight) and bad (shadowed) states. The channel
parameters such as the state change statistics, duration of good/bad states as well as the mean and
variance of the lognormal shadowing variations in the bad state are based on values obtained via
CCSR’s measurement campaign carried out for mobile satellite systems operating at S-band. The
suburban environment is assumed in our simulation.

For the terrestrial tower-based channel, the path loss model used is given in (5.6) with \( f_c = 2000 
MHz \) and \( \Delta h_b = 15 \text{ m} \). The mean and standard deviation of the lognormal shadowing is assumed
to be 0 dB and 8 dB respectively. The shadowing correlation distance is 20 m.

7.10.5 Other Simulation Parameters

The remaining simulation parameters are summarised in Table 7-3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcell base station power</td>
<td>15 W</td>
</tr>
<tr>
<td>HAPS platform power</td>
<td>30 W</td>
</tr>
<tr>
<td>( \beta )</td>
<td>0.9</td>
</tr>
<tr>
<td>d1 bit rate</td>
<td>30 kbps</td>
</tr>
<tr>
<td>( \frac{E_b}{I_0} )</td>
<td>6.2 dB</td>
</tr>
<tr>
<td>d2 bit rate</td>
<td>60 kbps</td>
</tr>
<tr>
<td>( \frac{E_b}{I_0} )</td>
<td>5.2 dB</td>
</tr>
</tbody>
</table>
### 7.10.6 Congestion Control

Due to link gain variations caused by the mobility of the mobiles and/or varying channel and traffic conditions, even if no new mobiles are admitted, a feasible power vector might not be found at a particular instant in a particular layer. In this case, call removal in that layer is required to recover the link, where the criterion for call removal is another issue. In our evaluation, no priorities are given to any data types and a simple stepwise call removal algorithm is implemented where the mobile in that layer which has the worst link gain condition is outaged (i.e., have its downlink traffic channel switched off) until the required SIR levels are achieved in the remaining links in that layer. A mobile that is in outage continuously for 5 s will be dropped from the network.

### 7.10.7 Performance Measures

The performance indicators that are used to evaluate the proposed CAC schemes are as follows:

- Call blocking probability ($P_b$): The probability that a new call is denied access to the hierarchical network.
- Call dropping probability ($P_d$): The probability that a call is dropped from the hierarchical network as a result of being continuously outaged for 5 s.
- Grade of service (GoS): The GoS is defined by the cost function $\text{GoS} = P_b + 10P_d$. A larger weighting factor is given to the dropping probability as it is much more annoying for a mobile to lose an ongoing call than to be denied access to the hierarchical network.
- System handover rate: The number of handovers per mobile per second.

### 7.11 Comparison between Reference and Proposed CAC Schemes

Throughout the simulation, the traffic load for the d2 service is kept at 5 Erlangs/cell for the macrocell layer and 2 Erlangs/cell for the microcell layer. The traffic load for the d1 service is kept at 10 Erlangs/cell for the macrocell layer and is varied from 2-6 Erlangs/cell for the microcell layer. The hierarchical system's blocking probability, dropping probability, GoS and handover rate for the reference and proposed CAC schemes are obtained and presented in Figure 7-4 to Figure 7-10.
From Figure 7-4 and Figure 7-5, we see that by reserving some platform resources for mobiles entering the service area served exclusively by HAPS (i.e., mobiles that do not have an alternate layer to overflow), the RR-RA, RR-TS and RR-SS schemes are able to significantly lower the overall blocking probability since this ensures that there are always some resources available to accommodate these mobiles. However, all three schemes will increase the overall system handover rate, mainly due to the handing down signalling load, as shown in Figure 7-10.

As the microcell layer is now more heavily loaded, the system dropping probability will increase, as shown in Figure 7-6 and Figure 7-7. However, the results show that the increase in dropping probability is minimal. The significant reduction in blocking probability and minimal increase in dropping probability results in overall improvements in the grades of service achievable by the RR-RA, RR-TS and RR-SS schemes, as depicted in Figure 7-8 and Figure 7-9.

![Blocking probability comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes for d1](image-url)
Figure 7-5: Blocking probability comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes for d2

Figure 7-6: Dropping probability comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes for d1
Figure 7-7: Dropping probability comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes for d2

Figure 7-8: Grade of service comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes for d1
Figure 7-9: Grade of service comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes for d2

Figure 7-10: System handover rate comparison between reference, RR-RA, RR-TS and RR-SS CAC schemes
7.12 Relative Performances of the Proposed Schemes

Comparing the three centralised resource reservation CAC schemes, we note that the RR-TS and RR-SS schemes achieve slightly lower blocking probabilities than the RR-RA scheme. This can be explained as follows. The RR-TS scheme tends to hand down mainly d2 mobiles that utilise more power per link than do d1 mobiles. This is in contrast to the RR-RA scheme which hands down both d1 and d2 mobiles with no particular preference. Therefore, for the RR-TS scheme, the resolution of the reduction in platform power per handed down mobile is likely to be larger most of time than that for the RR-RA scheme. This might cause the platform power to be lower than the necessary threshold level of $\beta_{PPF}$. When this happens, more platform power resources are available, resulting in lower blocking probabilities. For the RR-SS scheme, the slowest mobiles are given priority to be handed down, but because most of the d2 mobiles have speeds lower than those of the d1 mobiles, the RR-SS scheme is likely to hand down mainly d2 mobiles as well. Therefore the RR-SS scheme achieves a similar effect on blocking probability as the RR-TS scheme.

We also observe that the RR-TS and RR-SS schemes have slightly higher dropping probabilities than the RR-RA scheme. This is because the RR-TS and RR-SS schemes usually hand down more d2 users than the RR-RA scheme, and these d2 users will likely consume higher powers in the microcell layer than do d1 users, causing more call drops.

However, considering both performances in blocking and dropping probabilities, the performances in GoS among the three different centralised resource reservation schemes are comparable, as shown in Figure 7-8 and Figure 7-9.

With regard to the system handover rate, we note that among the three schemes, the RR-RA scheme achieves the highest handover rate, while the RR-SS scheme achieves the lowest handover rate. This is explained as follows.

Compared to the RR-RA scheme, the RR-TS scheme gives d2 mobiles that are utilising larger amounts of resources than d1 mobiles priority to be handed down. Therefore, it ensures that the minimum number of mobiles is handed down to recover the HAPS power resources, resulting in lower overall system handover rate. For the RR-SS scheme, the slowest mobiles are given priority to be handed down, thus ensuring that cell crossings in the microcell layer are kept to a minimum.
In fact, the RR-SS scheme is an improved version of the RR-TS scheme. This is because most of the d2 mobiles have speeds lower than those of the d1 mobiles, so d2 mobiles are likely to be ranked as the slowest speed mobiles most of the time as well by the RR-SS scheme. Hence, the RR-SS scheme will achieve a similar effect as giving priority to the slowest speed d2 mobiles to be handed down to the microcell layer. Therefore, both microcell crossings and handing down executions are minimised. The result is that the RR-SS scheme can further improve the handover rate as compared to the RR-TS scheme. The RR-RA scheme on the other hand, does not optimise the number of mobiles to be handed down. Therefore, it cannot match the RR-TS and RR-SS schemes in terms of achievable handover rate.

7.13 Discussion

This study on CAC for HAPS and terrestrial tower-based hierarchical UMTS allows us to draw the following conclusions:

- In a hierarchical system involving contiguous HAPS macrocells and terrestrial tower-based hotspot microcells, mobiles arriving to the service area served exclusively by HAPS have a high probability of being blocked because they cannot overflow to an alternate layer.

- As resources are centralised on the HAPS, it is possible to effectively monitor the HAPS power resource utilisation and reserve resources on the HAPS for these mobiles by handing down slow-speed mobiles in the overlaying area that are served by HAPS to the microcell layer. Resource reservation using this approach is also efficient because the reserved resources can be shared among all base stations, hence minimising the amount resources that needs to be reserved and consequently reducing the handover rate. The proposed centralised resource reservation schemes achieve better GoS at the expense of higher handover rate (mainly due to the handing down signalling load).

- Due to the HAPS's centrally managed base stations, it is possible to centrally process the handing down procedure and rank all potential mobiles that meet the handing down criterion (i.e., speed < \( z_{th} \)) according to their bit rates and travelling speeds.

- By handing down mobiles in the order of decreasing bit rate (RR-TS scheme), we can minimise the number of handing down executions and hence further reduce the handover rate as compared to the case where mobiles are handed down in no particular order (RR-RA scheme).

- By handing down mobiles in the order of increasing speed (RR-SS scheme), the number of cell crossings contributed by the handed down mobiles in the microcell layer can be
minimised. In addition, as high bit rate mobiles tend to be slow-moving as well, both microcell crossings and handing down executions are minimised, resulting in a further reduction in handover rate as compared to the RR-TS scheme.

7.14 Conclusion

In this chapter, we have studied the problem of CAC for HAPS and terrestrial tower-based hierarchical UMTS. We have proposed three CAC schemes with centralised resource reservation (RR-RA, RR-TS and RR-SS) to achieve improved system grades of service over the reference CAC scheme. We have also explained how centralised resource reservation can be performed more efficiently than distributed resource reservation because the HAPS power resources are centralised onboard the platform so the reserved resources can be used in all HAPS cells in a "power-on-demand" basis.

All three CAC centralised resource reservation schemes outperform the reference CAC scheme in terms of GoS at the expense of increased handover rates. As HAPS can centrally process the handing down process, centralised resource reservation schemes with mobile selection (RR-TS and RR-SS) can be implemented which can further reduce the increases in handover rate contributed by the centralised resource reservation schemes.
Chapter 8

8 Conclusions and Future Work

8.1 Conclusions

8.1.1 Problem Statement

In this work, our objective is to develop CAC schemes customised to the HAPS environment so as to optimise system performance and maximise the capacity supportable by HAPS UMTS. A review of existing work shows that several CAC schemes have been proposed in literature for terrestrial tower-based UMTS. These schemes are expected to work in the HAPS UMTS environment because HAPS UMTS and terrestrial tower-based UMTS share the same RTT. However, these existing CAC schemes when applied directly to the HAPS UMTS environment may not yield optimum performance. Therefore, in this research, we focus on identifying the unique characteristics of HAPS UMTS and then exploiting these unique characteristics to develop CAC schemes that work specifically in the HAPS UMTS environment to achieve more optimum system performance.

8.1.2 Approach and Significant Findings

We begin by analysing the HAPS reverse link and forward link interference geometry. We find that the interference in HAPS UMTS is determined by the antenna radiation pattern rather than the terrain features of the HAPS coverage area. Due to this HAPS characteristic, the reverse link performance for HAPS UMTS is better than that for terrestrial tower-based UMTS. Specifically, the other-cell interference factor, which is inversely proportional to the supportable capacity, is lower for HAPS UMTS than for terrestrial tower-based UMTS. Our analysis shows that HAPS UMTS can support at least 14.4% higher capacity than terrestrial tower-based UMTS.

The dependence of the interference in HAPS UMTS on antenna gain rather than shadowing also leads us to identify distance based power control as a potential class of power control scheme that can be implemented effectively in the HAPS UMTS environment. Distance based power control schemes are not appropriate in shadowed terrestrial tower-based UMTS because when shadowing
is present, the distance between a mobile and its base station alone is not a good indication of the power required by the mobile. In contrast, due to the unique HAPS interference geometry, distance based power control schemes can be implemented effectively for HAPS. We optimise the nth-power-of-distance power control scheme for the HAPS UMTS environment and also propose an optimum power control scheme for HAPS based on the HAPS antenna radiation pattern. The optimised nth-power-of-distance scheme and the optimum power control schemes are shown to achieve capacity improvements of 86% and 96% respectively as compared to the case with no power control. The effects of power control stepping on the performances of these two power control schemes are also quantified. For an outage probability of 0.01, and with power control step sizes of 0.5 dB – 1.5 dB, the nth-power-of-distance power control scheme can maintain at least 81.5% of the system capacity obtainable with perfect power control. While for the optimum power control scheme, at least 85.3% of the system capacity can be maintained.

Our next step is to develop a HAPS UMTS system level simulator to enable us to evaluate CAC schemes for HAPS UMTS. The system level simulator is designed to model the dynamic HAPS UMTS mobile environment and takes into account the following characteristics: cell structure, user arrival, traffic activity, propagation channel and user mobility. We have included GUI and animation into the system level simulator to verify the operation of the simulator and to make it user friendly.

In designing CAC schemes exclusive to HAPS UMTS, we note that one of the unique characteristics of HAPS is that all base stations are collocated. This property enables efficient signalling and exchange of information between base stations and therefore facilitates the implementation of centralised CAC schemes.

We first investigate a centralised total received power based CAC schemes where all incoming calls to the service area are handled by a central call admission controller. We propose the CRP-RA scheme, which centrally manages the total received power levels in all cells and processes incoming calls centrally but in no particular order of preference. Due to the collocation of base stations, the central admission controller is able to update the base station total received powers on a call-by-call basis so the interference information available for CAC decision for every arriving call is accurate resulting in correct CAC decisions. This is in contrast to distributed global CAC schemes proposed for terrestrial tower-based UMTS where each base station manages its interference independently and carries out CAC for calls arriving to its cell in a distributed manner. For the distributed global CAC scheme, as the CAC process is not coordinated across all
base stations, a base station will not know the outcome of the admission decisions made by other base stations. This means that the information on other cells' total received powers used by a base station for admission decision will not be the most updated. This will result in CAC errors. Distributed global schemes are more likely to make wrong admissions resulting in lower blocking probability but increased dropping probability. Whereas for the proposed CRP-RA scheme, more accurate CAC decisions means that the blocking probability is slightly increased, but correct admissions result in lower dropping probability. With significant reduction in dropping probability, the CRP-RA scheme is able to achieve better GoS as compared to the distributed global scheme. With centralised processing of call admissions, the central admission controller can also control the order of call admission, e.g., prioritise the incoming calls and select specific calls to process first. To exploit this capability, we enhance the CRP-RA scheme and propose the CRP-RK scheme which prioritises the incoming calls according to the current interference status of their target base stations, with calls entering cells with the lowest total received powers being processed first. The CRP-RK is able to pack more calls into the system while balancing the load among all cells. Therefore, it can achieve lower blocking and dropping probabilities and hence provide better GoS than the CRP-RA scheme.

Considering the forward link, we note that another unique characteristic of HAPS is that all base stations' transmit antenna beams originate from the same phased array antenna onboard the platform, so it is possible for the base stations to share the limited power resource available onboard the HAPS. In this case, the conventional method of allocating fixed amounts of power to individual base stations (i.e., the CTP-BS scheme) may not be the most optimum approach. We propose the CTP-PF CAC scheme, which considers the total platform output power available for traffic channels as a single resource to be shared among all base stations according to their demand. Results obtained show that CTP-PF scheme outperforms the CTP-BS scheme in blocking and dropping probabilities mainly because the CTP-PF scheme is more flexible in the allocation of downlink output power as compared to the CTP-BS scheme. With reduced blocking and dropping probabilities, better grade of service for the system can be achieved by the CTP-PF scheme. In terms of power savings, we find that to achieve the same levels of GoS, the platform power required by the CTP-PF scheme is only approximately 24% of the total platform power required by the CTP-BS scheme for the cellular environment that we have evaluated.

The HAPS's collocation of base stations and ability to share platform power resources can also be exploited in a HAPS and terrestrial tower-based hierarchical system. The hierarchical cell structure considered is a homogenous layer of HAPS macrocells overlaying isolated terrestrial
hotspot microcells. For this cell structure, we note that mobiles arriving to the non-overlaying areas served only by HAPS cannot overflow to an alternate layer and hence will experience high blocking probability as compared to mobiles arriving to the overlaying areas, especially when the HAPS’s power resource is nearing its limit. The overall system’s grade of service can be improved if these mobiles can be guaranteed a fraction of the platform resources. This is the basis of our proposed three CAC schemes with centralised resource reservation (RR-RA, RR-TS and RR-SS). As power resources are centralised on the HAPS, power can be efficiently reserved by ensuring that a fraction of the total power resource is made available to accommodate these mobiles. This can be done easily by monitoring the total platform power utilisation. When the total platform power utilisation exceeds a threshold value, slow-moving mobiles served by HAPS but are within the coverage area of the microcell layer are handed down to the microcell layer to free resources in the macrocell layer. The reserved power can be efficiently used by all HAPS cells on a “power-on-demand” basis to accommodate mobiles arriving to the exclusive HAPS area served by any HAPS base station. Therefore, the amount of platform power that needs to be reserved can be smaller than that required if power reservation is performed independently at individual base stations. The results obtained show that all three CAC schemes with centralised resource reservation outperform the reference CAC scheme in terms of GoS at the expense of increased handover rates, mainly due to the handing down signalling load. We also note that as HAPS base stations are collocated, the HAPS can centrally process and prioritise specific mobiles to be handed down according to performance requirements such as minimising the handover rate. In particular, the proposed RR-TS and RR-SS schemes give handing down priorities to the highest bit rate mobile and slowest moving mobile respectively whereas the RR-RA scheme hands down mobiles in no particular order. Both the RR-TS and RR-SS schemes can further reduce the increase in handover rate contributed by RR-RA scheme. For the RR-TS scheme, as high bit rate users occupying more HAPS resources are handed down first, the number of mobiles being handed down is minimised. While for the RR-RS scheme, the mobiles handed down to the microcell layer are the lowest possible so these mobiles will generate the least number of handovers as they traverse the microcells. In addition, the slowest mobiles identified by the RR-SS scheme are likely to be high bit rate users as well, so the RR-RS scheme can also be viewed as an improved RR-TS scheme, where the number of mobiles to be handed down is also minimised at the same time. Therefore, the RR-RS scheme has the lowest handover rate among the three proposed schemes.

8.1.3 Implications of Research

Based on our findings, we can summarise the unique HAPS UMTS properties and their implications in resource management in Table 8-1.
Table 8-1: Unique HAPS UMTS properties and their implications in resource management

<table>
<thead>
<tr>
<th>Unique HAPS UMTS Properties</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interference is dependent on antenna radiation pattern rather than the terrain features of the coverage area.</td>
<td>• Phased array antenna design is critical in ensuring good system performance.</td>
</tr>
<tr>
<td></td>
<td>• Based on the ITU recommended antenna specifications with 60 dB/decade roll-off and -13 dB cell intersection, HAPS UMTS can support higher capacity than terrestrial tower-based UMTS.</td>
</tr>
<tr>
<td></td>
<td>• Distance based power control performs favourably in HAPS UMTS.</td>
</tr>
<tr>
<td></td>
<td>• Optimum power control schemes must be tailored to the antenna radiation pattern of the HAPS.</td>
</tr>
<tr>
<td>Base stations are collocated.</td>
<td>• Centralised CAC schemes can be implemented effectively and efficiently due to minimal signalling overheads and delay.</td>
</tr>
<tr>
<td></td>
<td>• Centralised CAC schemes allow HAPS to coordinate call admission centrally with updated cell interference information ⇒ accurate CAC decisions and improved system performance.</td>
</tr>
<tr>
<td></td>
<td>• In hierarchical systems with resource reservation, it is possible to prioritise mobiles centrally and ensure optimum handing down of mobiles according to specific performance requirements, e.g., minimising the handover rate.</td>
</tr>
</tbody>
</table>
Chapter 8. Conclusions and Future Work

<table>
<thead>
<tr>
<th>Unique HAPS UMTS Properties</th>
<th>Implications</th>
</tr>
</thead>
</table>
| Base station antennas are collocated on the same platform. | • Sharing of the limited platform power resource is possible.  
• "Power-on-demand" where power is allocated to individual cells based on their demand.  
• Significant improvement in system performance and/or power savings can be achieved with platform power sharing.  
• In hierarchical systems with resource reservation, the amount of power reserved can be minimised since the reserved power can be shared by all HAPS cells. |

8.2 Future Work

The work completed in this research can be extended to the following areas:

• **Predictive CAC for HAPS**: Since the interference geometry of HAPS UMTS depends only on the antenna radiation pattern, it is possible for a mobile to track the differences between the received pilot strengths from its serving base station and its neighbouring base stations and obtain an accurate indication of its next potential serving cell. Furthermore, with centralised management of the HAPS base stations, this next-cell information can be relayed to all cells expediently and accurately and be incorporated into the CAC criteria so that resources can be reserved for handover calls dynamically.

• **Integrated multi-layer CAC for HAPS UMTS**: It is envisaged that satellite megacells, HAPS macrocells, terrestrial tower-based microcells and indoor picocells are likely to be jointly deployed in an integrated cellular communications system. Hence, the CAC issue of such an integrated multi-layer network needs to be addressed so as to ensure that the resources available can be optimally utilised and a uniform QoS can be achieved among all cells and layers.

• **CAC for HAPS and terrestrial tower-based hierarchical UMTS operating in the same frequency band**: For operators that are allocated with only a pair of carriers, the same frequency band will have to be used for both layers in a HAPS and terrestrial tower-based hierarchical cell structure. In such a deployment scenario, the management of inter-layer interference between the HAPS and terrestrial tower-based cells is extremely important since this
interference, together with intra-layer interference, directly affects the supportable capacity. Therefore, proper cell planning is required to ensure optimum placement of the terrestrial tower-based cells with respect the HAPS cells so that good isolation between the two layers can be achieved. In addition, the CAC scheme will have to be carefully designed to direct calls to the appropriate layer so as to minimise the overall interference level in order to ensure that the QoS requirements of calls can be met.
References


[34] N. Dimitriou and R. Tafazolli, "Local and global transmitted power based call admission control with priorities in IMT-2000 wideband CDMA systems", in *Proc. 5th CDMA International Conference 2000*.


Appendix A

A.1 Typical Good and Bad Durations for HAPS Channel

Table A-1 shows the typical durations of good and bad states under various environments, as obtained via CCSR’s measurement campaign for mobile satellite systems operating at S-band.

Table A-1: Good and bad durations for different environments

<table>
<thead>
<tr>
<th>Elevation angle Environment</th>
<th>15° Good duration (m)</th>
<th>15° Bad duration (m)</th>
<th>30° Good duration (m)</th>
<th>30° Bad duration (m)</th>
<th>60° Good duration (m)</th>
<th>60° Bad duration (m)</th>
<th>80° Good duration (m)</th>
<th>80° Bad duration (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>74.1085</td>
<td>4.7503</td>
<td>46.9197</td>
<td>16.9221</td>
<td>890.0721</td>
<td>9.498</td>
<td>111.5165</td>
<td>2.8658</td>
</tr>
<tr>
<td>Lightly wooded</td>
<td>4.0605</td>
<td>7.3545</td>
<td>3.8567</td>
<td>4.8669</td>
<td>5.7035</td>
<td>1.5304</td>
<td>84.6854</td>
<td>0.7177</td>
</tr>
</tbody>
</table>