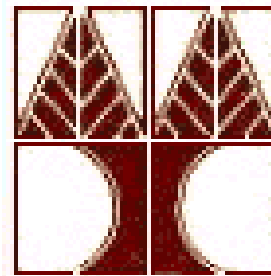


Master's Thesis

**A NEW EFFICIENT HANDOVER ALGORITHM FOR
MBMS ENABLED 3G MOBILE CELLULAR
NETWORKS**

Christopher Christophorou

UNIVERSITY OF CYPRUS



DEPARTMENT OF COMPUTER SCIENCE

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**A New Efficient Handover Algorithm for MBMS
Enabled 3G Mobile Cellular Networks**

Christopher Christophorou

Supervising Professor
Andreas Pitsillides

This thesis is submitted to the Graduate Faculty of University of Cyprus in partial fulfillment of the requirements for the Degree of Master of Science at Computer Science Department

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Abstract

Initially, 3rd Generation (3G) Mobile Networks (also known as UMTS – Universal Mobile Telecommunications System) offered Telephony and Bearer Services¹ for *Point-to-Point* communications using Dedicated Resources (Dedicated Channels - DCH) for the data transmission. Lately, with the introduction of technologies such as, IP Video Conferencing, Streaming Video and others, there is an increasing need for communication between one sender and many receivers, leading to the need of *Point-to-Multipoint* transmission. For the efficient distribution of these types of services in UMTS Network, the 3GPP organization proposed some enhancements on the UMTS Release-6 architecture that led to the definition of the Multimedia Broadcast Multicast Service (MBMS) system. MBMS is a Point-to-Multipoint service in which data is transmitted from a single source entity to multiple recipients, allowing the network resources to be shared.

With the introduction of Multimedia Broadcast Multicast Service (MBMS) in 3rd Generation (3G) Networks (UMTS), the Radio Network Controller (RNC) on a per cell basis can use either Dedicated or Common (Forward Access Channel – FACH) resources to distribute the same content in a Cell. The use of Common Resources aims to overcome network congestion when a large number of users in a Cell request the same content, but if there are not enough users to justify the high power transmission of the Common Channel, then it is more efficient for the content to be provided on a Point-to-Point fashion (Dedicated Resources).

Thus the mobile MBMS users that are on the move may have to deal with dynamic changes of network resources when crossing the cell edge (from Common to Dedicated resources and vice versa). This introduces new mobility issues regarding the handover procedure (MBMS Handovers), since until now, handover in UMTS Network have been considered only between Cells supporting the service on Dedicated Resources (DCH). Usually, the handover decision making is based on a comparison between an observed value and a *predetermined threshold* chosen in a manner so as to maximize the overall

¹ Bearer Services are services that allow transmission of user-information signals between user-network interfaces in a series of data units, such as blocks, messages, or frames.

system capacity. The current Handover Algorithm efficiently achieves that when the handover is performed between Dedicated resources, but using the same algorithm when the handover is performed between Dedicated and Common resources the result will not be so efficient.

This thesis proposes an enhanced *MBMS Handover Algorithm* which efficiently achieves increased cell capacity when the mobile users have to deal with these new types of MBMS Handovers. In order to accomplish this, new parameters have to be considered and a different approach has to be followed. Moreover, the new MBMS Handover Algorithm, instead of using a predefined threshold for the handover decision as the Current Handover Algorithm does, will use a dynamic estimation scheme that will take into consideration these new parameters with the purpose of maximizing the overall system capacity.

Abbreviations

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
BS	Base Station
CBS	Cell Broadcast Service
CDMA	Code Division Multiple Access
CN	Core Network
CPICH	Common Pilot Channel
CRNC	Controlling RNC
DCH	Dedicated Channel
DRNC	Drift RNC
ETSI	European Telecommunication Standards Institute
FACH	Forward Access Channel
GGSN	Gateway GPRS Support Node
GMM	GPRS Mobility Management
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile telecommunications
IGMP	Internet Group Management Protocol
IMSI	International Mobile Subscriber Identity
ITU	International Telecommunication Union
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
MBMS RAB	Multimedia Broadcast Multicast Service Radio Access Bearer
MCCH	MBMS Point to Multipoint Control Channel
MT	Mobile Termination
MTCH	MBMS Point to Multipoint Traffic Channel
NRT	Non-Real Time

P-t-M	Point-to-Multipoint
P-t-P	Point-to-Point
RAB	Radio Access Bearer
RAN	Radio Access Network
RACH	Random Access Channel
RB	Radio Bearer
RLC	Radio Link Control
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RRC	Radio Resource Control
RRM	Radio Resource Management
RT	Real Time
SGSN	Serving GPRS Support Node
SIR	Signal to Interference Ratio
SRNC	Serving RNC
TE	Terminal Equipment
TMGI	Temporary Mobile Group Identity
TRX	Transmitter-Receiver
TTP	Traffic Termination Points
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USIM	Equipment's Universal Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network (U-TRAN)
WCDMA	Wideband - Code Division Multiple Access

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Chapter 1

1 Introduction

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1.1 Overview

Nowadays, mobile communications are extensively used and they are seen as one of the most advanced forms of telecommunications. 1st Generation (1G) and 2nd Generation (2G) [1] mobile telecommunication systems were essentially developed for handling only voice services. Now, with the convergence between telecommunication, computer and multimedia worlds, mobile phones must support a variety of multimedia mobile services at high data rates. The need to provide the flexibility needed to cope with this variety of services has led to the definition of 3rd Generation (3G) digital cellular systems standardized in Europe by ETSI (European Telecommunication Standards Institute) as UMTS (Universal Mobile Telecommunications System) [4].

UMTS is an evolution from GSM (2G) [5] Circuit Switched networks towards Packet Switched technologies offering higher transmission rates. A UMTS network (Figure 1) consists of three interacting domains. These are the Core Network (CN), the UMTS Terrestrial Radio Access Network (U-TRAN) and the User Equipment (UE). The main function of the Core Network (CN) is to provide switching, routing and transit for user traffic. The UTRAN part provides the air interface access method, Mobility Management and Radio Resource Management (RRM) for User Equipment (UE). The U-TRAN is divided into RNSs (Radio Network Subsystem). One RNS consists of a set of radio elements called Base Stations (or officially Node B) and their corresponding controlling element that is called Radio Network Controller (RNC).

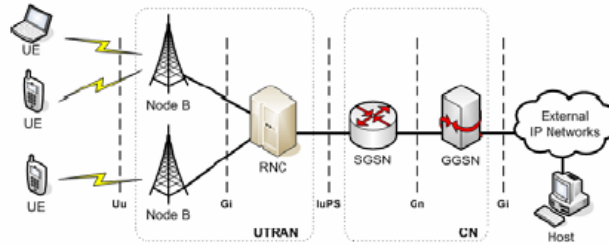


Figure 1. UMTS Network Architecture

Initially, the UMTS Network offered Tele- (e.g. Voice and SMS) and Bearer Services for Point-to-Point communications using the *Unicast* [7] method (Only Dedicated Resources were allocated) for data transmission. Later, with the introduction of technologies such as, IP Video Conferencing, Streaming Video and others, there was an increasing need for communication between one sender and many receivers, leading to the need of Point-to-Multipoint transmission. *Multicast* and *broadcast* [8] are two alternative delivery methods for the efficient transmission [9] of these types of services that distributes the service content using a shared transport path. The delivery of the service content to more than one user simultaneously using a shared transport path is attractive for several reasons. First of all, higher data rate rich-media services are made feasible without increasing the total network capacity since the network infrastructure and the radio bandwidth are used more efficiently and also users can benefit from consuming shared content in that higher data rates and faster downloads can be achieved.

The need for the network to support a variety of multimedia mobile services at high data rates in the radio access layer resulted in the choice of Code Division Multiple Access (CDMA) for the radio resource allocation used in 3rd Generation (3G) Cellular networks. A consequence of using CDMA is that capacity of 3G systems is not hard limited. This means that an additional user entering the system cannot be blocked because of the limited amount of hardware (Channels). If a sufficient number of spreading codes is available, the noise rise due to increased load will be the main capacity-limiting mechanism in the network.

In UMTS, radio bandwidth is a limiting resource and the available radio resources in a Cell can support only a handful number of high data-rate user simultaneously. With the increasing use of high bandwidth applications in 3rd Generation (3G) mobile Networks, especially with a large number of users receiving the same high data rate services, efficient

information distribution is essential [10]. Therefore, Broadcast and Multicast are methods to decrease the amount of data within the network and use resources more efficiently [11]. The benefit of Multicast and Broadcast on the air interface is that many users can receive the same data on a *Common Channel*, thus not clogging up the air interface with multiple transmissions of the same data. In order for the UMTS to take advantage of these benefits, is therefore likely to have an interface to Multicast and Broadcast methods in general. To provide Multicast and Broadcast type of data transmission in UMTS, the 3GPP organization proposed some enhancements on the UMTS Release-6 architecture that led to the definition of the *Multimedia Broadcast/Multicast Service (MBMS)* system 0. MBMS is a Point-to-Multipoint service in which data is transmitted from a single source entity to multiple recipients, allowing the network resources to be shared.

When using MBMS Services, the main task of UTRAN is to create and maintain *MBMS Radio Access Bearers (MBMS RAB)* (See Section 2.3 & 2.6.2.1) for communication between the User Equipments (UEs) interested in the specific MBMS Service and the Core Network (CN), so that the *End-to-End MBMS QoS requirements* are fulfilled in all respects. With *MBMS RAB*, the CN is given an “illusion” about a fixed communication path to MBMS UEs, thus releasing it from the need to take care of radio communication aspects. The *MBMS RAB* consists of one *MBMS In Bearer* between the SGSN and the RNC and one or more *Radio Bearers* between the RNC and the UEs. For radio efficiency reasons, the Radio Network Controller (RNC) on a per cell basis can use either Dedicated (One Point-to-Point Radio Bearer (DCH) for each UE in the Cell) or Common (One Point-to-Multipoint Radio Bearer (FACH) for all the UEs in the Cell) resources to distribute the same content [6]. The use of common resources aims to overcome network congestion when a large number of users in a cell request the same content, but if there are not enough users to justify the high power transmission of the Common Channel, the content will be provided on a Point-to-Point fashion. The terms *Point-to-Point* and *Point-to-Multipoint Radio Bearer* can be interpreted in the following way:

- *Point-to-Point Radio Bearer* will be a Dedicated Channel (DCH) that is bi-directional with Inner and Outer loop power control. DCH is a Point-to-Point channel; hence it suffers from the inefficiencies of requiring multiple DCH to carry common data to a group of receivers. DCH also consists of an uplink channel, which is used to feedback power control information among other control or data signals to the cellular network.

- *Point-to-Multipoint Radio Bearer* will use common channel in the downlink only. The Common Transport channel that has been proposed by the 3GPP is the Forward Access Channel (FACH). Even with a large number of multicast receivers, only one FACH is required for the transmission of the MBMS service, with no load on the uplink connections. Data transmitted on the FACH cannot be guaranteed to be reliably received by the multicast receivers as there is no channel for the feedback of received quality back to the network. Also fast power control cannot be applied on FACH channel.

1.2 Motivation

3rd Generation (3G) mobile networks currently support only Point-to-Point Services. With the introduction of Point-to-Multipoint high data rate services, such as, IP Video Conferencing and Streaming Media, there is a strong interest to provide Multimedia Broadcast Multicast Service (MBMS) over 3G Networks. The investigation of how the 3G system has to be enhanced in order to provide this MBMS service started from the “3rd Generation Partnership Project” (3GPP) [2] and “3rd Generation Partnership Project 2” (3GPP2) [3].

Still many design issues need to be considered before the multicast services can be deployed in 3G Networks. For example, it has not been yet fully investigated how the RNC should select between the use of Point-to-Point and Point-to-Multipoint Radio Bearer to deliver the MBMS Service thus efficiently use the radio-network resources. Furthermore, it has not been decided yet, whether to use the existing IGMP Joining mechanism or define a new MBMS Specific Joining mechanism. Also Mobility Management and Handover in MBMS System are still some open and critical issues that have to be considered.

In view of the fact that in the future users are expected to be charged for such multicast services, it is a challenge to work out the open issues in order to achieve the required Quality of Service.

1.3 Scope of the Thesis

The freedom to be able to provide continuity of mobile services to a user travelling over cell boundaries in a cellular infrastructure has frequently been advertised as the main

advantage of the wireless systems. Handovers are the key concept of providing this continuity. The term “handover” refers to the whole process of tearing down an existing connection from the Old Cell and replacing it by a new connection in the New Cell into which the user is handed over. As we have said above, with the introduction of Multimedia Broadcast Multicast Service (MBMS) System in 3rd Generation (3G) Networks (UMTS), the Radio Network Controller (RNC) for radio efficiency reasons can use either Dedicated or Common resources to distribute the same content in a Cell. As a consequence, the mobile users that are on the move and receive an MBMS Service may have to deal with dynamic changes of network resources (from Common to Dedicated resources and vice versa) when crossing the cell edge. This introduces new types of MBMS Handover since until now, handover in UMTS Network have been considered only between Dedicated Resources (*From Point-to-Point (DCH) To Point-to-Point (DCH) Radio Bearer*)[12][13] .

This thesis proposes an enhanced MBMS Handover Algorithm which efficiently achieves increased cell capacity when the mobile users have to deal with these new types of MBMS Handover:

- From Point-to-Point (DCH) To Point-to-Multipoint (FACH)
- From Point-to-Multipoint (FACH) To Point-to-Point (DCH)

In order to accomplish this, some new parameters have to be considered and a different approach than the one used with the current Handover Algorithm has to be followed. Moreover, the new MBMS Handover Algorithm, instead of using a predefined threshold for the handover decision as the current handover algorithm does, will use a dynamic estimation scheme that will take into consideration all these new parameters with the purpose of maximizing the overall system capacity.

The thesis is organized as follows: Chapter 2 provides some background knowledge concerning the domain of the study done. Chapter 3 makes a brief introduction on the general principles of the current handover algorithm. Also an introduction on the MBMS Handover issues is made here. Chapter 4 describes the Proposed MBMS Handover Algorithm while the Performance Evaluation of the proposed scheme is done in Chapter 5. In this chapter the Scenarios used are described along with the analysis and evaluation of the Simulation results. Finally, Chapter 6 provides a conclusion on the proposed MBMS Handover Algorithm presented.

Chapter 2

2 Background Knowledge

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2.1 Cellular Networks

The fundamental principle of radio communication is that it utilizes radio waves as a transmission medium. Based on the cellular concept, a large area is divided into a number of sub-areas called cells [17]. Each cell has its own Base Station, which is able to provide a radio link for specific number of simultaneous users by emitting a low-level transmitted signal. The cellular concept solution resolves the basic problems of radio systems in terms of radio system capacity constrains, but at the same time it encounters other problems, such as interference due to the cellular structure, including both Inter- and Intra-cell interference (Figure 2), problems due to mobility and Cell-Based radio resource scarcity.

In a cellular system, if the same frequency is used in every Cell then the mobile station, which is connected on the radio network, encounters the problem of channel interference, including adjacent channel (inter-cell) interference and co-channel (intra-cell) interference. This problem is solved by utilizing the “frequency reuse technique”. In this technique in each cell of cluster pattern (Figure 3) a different frequency is used. As long as the cells are separated and the signal strength calibrated, there will not be harmful Inter-cell interference. The frequency reuse factor is an essential parameter of radio network planning in cellular system, which operates, on frequency sharing principles (e.g. GSM). Figure 4,

shows the typical layout of a seven-way frequency reuse system often used in GSM networks. *Cell 1* makes use of frequency $F1$, *Cell 2* makes use of frequency $F2$ and so on. In this example every seventh cell reuses a certain frequency, hence this architecture is said to have a frequency reuse factor equal with 7 (Figure 3).

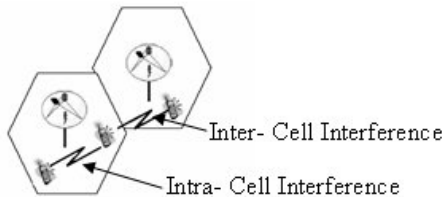


Figure 2. Inter- and Intra- cell interference

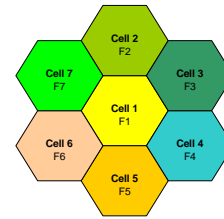


Figure 3. Cluster pattern of frequency reuse factor equal with 7 (GSM)

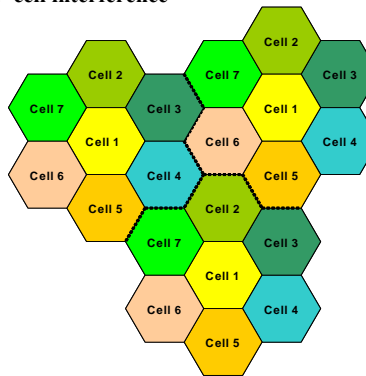


Figure 4. A seven-way frequency reuse system often used in GSM networks

In UMTS cellular systems the radio spectrum can be used even more efficient by applying WCDMA (Wideband - Code Division Multiple Access), resulting in a frequency reuse factor of 1 (Figure 5) meaning that all Base Stations in cells transmit on the same frequency and also all UEs share a common frequency within the network. WCDMA also enables different data rates for different services in a more flexible way.

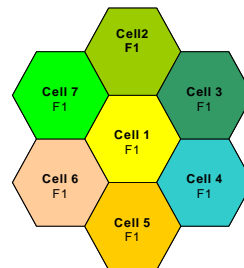


Figure 5. Cluster pattern of frequency reuse factor equal with 1 (UMTS)

The advantages of UMTS Cellular systems include not only a better efficiency in spectrum reuse, but also a higher immunity against the fading due to multipaths, better and easier employment of sectorization and the adoption of more robust handover procedures (*Soft Handover*).

2.2 Wideband Code Division Multiple Access (W-CDMA)

In order for the UMTS network to support a variety of multimedia mobile services at high data rates in the radio access layer resulted in the choice of Code Division Multiple Access (CDMA) as the multiple access scheme used in 3rd Generation (3G) networks.

WCDMA is a 3G standard based on CDMA that increases the throughput of data transmission of CDMA by using a wider 5MHz carrier than the standard CDMA, which uses a 200 KHz carrier, hence the name W (Wideband) - CDMA. It was adopted as a standard by the ITU (*International Telecommunication Union*) [14] under the name "IMT-2000 Direct Spread". WCDMA is the technology used in UMTS, and with data rates up to 2Mbits it has the capacity to easily handle bandwidth-intensive applications such as video, data, and image transmission necessary for mobile internet services.

2.2.1 WCDMA Radio Channels

The WCDMA radio channels *allocate bandwidth* for users and the allocated bandwidth and its controlling functions are handled with the term “Channel”. The channel organization the WCDMA uses is a three-layer one (Figure 6). There are *Logical channels*, *Transport channels* and *Physical channels*. From these, the Logical channels describe *the type of information to be transferred*, Transport channels describe *how the Logical channels are to be transferred* and the Physical channels are the “*Transmission media*” providing *the radio platform through which the information is actually transferred*. The term Physical channels means *different kinds of bandwidths* allocated for different purposes over the Uu interface (Between the Base Station and the UE).

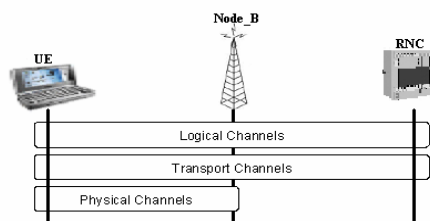


Figure 6. Three-layer organization of WCDMA Radio Channels

Figure 7 below shows the way the different channels are mapped into each other. See Appendix A for more information.

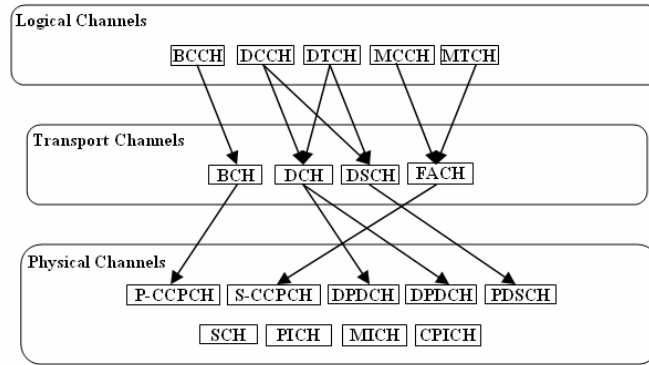


Figure 7. Mapping between different Channels

2.3 UMTS Service and Bearer Architecture [17]

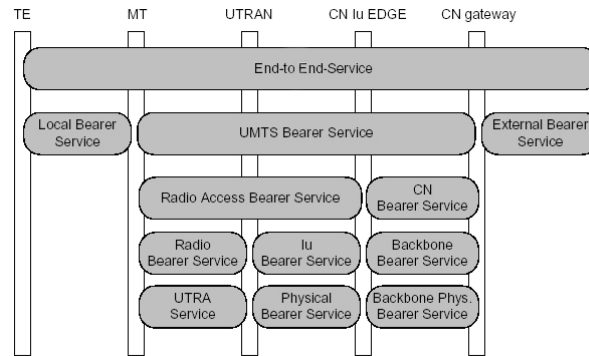


Figure 8. UMTS service and Bearer Architecture

The 3G Network mainly acts as an infrastructure providing facilities, adequate bandwidth and quality for the end-users and their applications. This facility provision, bandwidth allocation and connection quality is commonly called *Quality of Service (QoS)*. If we think of an End-to-End Service between users, the Service, set its requirements concerning QoS (e.g. minimum bit rate, no buffering, symmetric traffic, guaranteed bit rate) and this requirement must be met everywhere in the network. The various parts of the UMTS network contribute to fulfilling the QoS requirements of the services in different ways.

To model this, as shown in Figure 8, the *End-to-End Service* requirements have been divided into three entities: *Local Bearer Service* (between TE and MT), *UMTS Bearer Service* (between CN and MT) and *External Bearer Service* (between CN and other networks).

The *Local Bearer service* contains the mechanisms on how the end-user service is mapped between the Terminal Equipment (TE) and Mobile Termination (MT). For example, if we have one Terminal Equipment that has a numeric keypad and limited screen size with fixed character amount and one Terminal Equipment that supports java, thus utilizes more flexible user interface alternatives like colour screen, full keypad and more powerful applications, and we are using both of them to browse on the internet on the same site, the quality of the webpage displayed on the screen will be better (with more colour, and pictures) on the second Terminal even though we are browsing the same webpage.

UMTS Bearer Service contains mechanisms to allocate QoS over the UMTS network consisting of UTRAN and CN. Since UMTS network attaches itself to external networks, the end-user QoS must be handled towards the other networks too. This is taken care by the *External Bearer Service*.

Within the UMTS network, the QoS handling in UTRAN is different than in CN. From the Core Network point of view, UTRAN creates an “illusion” of a fixed bearer, providing adequate QoS for the end-user service. This is called *Radio Access Bearer (RAB) Service*. Within the Core Network an own type of Bearer service called *CN Bearer Service* is used. This division between *Radio Access Bearer (RAB) Service* and *CN Bearer Service* is required for the reason that the CN Bearer Service is quite constant in nature since the Backbone Bearer Service providing physical connections is also stable. Within UTRAN, the *Radio Access Bearer (RAB) Service* experiences more changes as function of time as the mobility of the UE makes this Bearer of service more complicate and set different challenges of QoS.

2.4 UMTS Terrestrial Radio Access Network (U-TRAN)

The main task of UTRAN is to create and maintain *Radio Access Bearers (RAB)* for communication between User Equipment (UE) and the Core Network (CN) so that End-to-End QoS requirements are fulfilled in all respects. With RAB, the CN elements are given an “illusion” about a fixed communication path to UE, thus releasing them from the need to take care of radio communication aspects.

As can be seen in Figure 1, UTRAN is located between two open interfaces being *Uu* with the UE and *Iu* with the CN. From the Bearer Architecture point of View (Figure 8), the main task of UTRAN is to provide Bearer Service over these interfaces. In this respect, the UTRAN controls the *Uu* interface thus providing the *Radio Bearer* service, but in *Iu* interface the *Iu Bearer* service provision is done in co-operation with the CN.

A remarkable role to the Bearer Architecture has the Radio Network Controller (RNC), since the RNC and the CN map the End-to-End QoS requirements over the *Iu* interface with the establishment of *Iu Bearer* and the RNC takes care of satisfying the QoS requirements over the radio path by establishing a *Radio Bearer (RB)*. These two Bearers (*Radio Bearer & Iu Bearer*) exist in the system because *Iu Bearer* is more stable in nature than the *Radio Bearer (RB)*. This is due to the fact that RNC must reconfigure the Radio Bearer every time the UE moves from one Cell to another, while the *Iu Bearer* remains stable.

2.4.1 U-TRAN Architecture

The U-TRAN (Figure 9) is divided into RNSs (Radio Network Subsystem). One RNS consists of a set of radio elements called Base Stations (or officially Node B), realizing the *Uu* interface, and their corresponding controlling element that is called Radio Network Controller (RNC). The RNSs are communicating with each other through *Iur* interface, forming connection between two RNCs. This *Iur* open interface carries both signalling and traffic information.

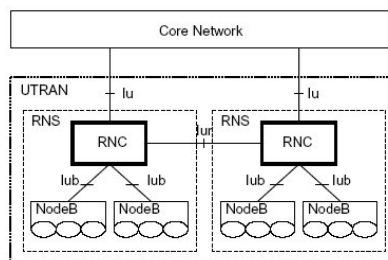


Figure 9. U-TRAN Architecture

2.4.1.1 Base Station (Node B)

The main task of Base Station (BS) is to establish the physical implementation of the *Uu* interface (Communication with the UE) and the implementation of *Iub* interface (Communication with the RNC). Realization of the *Uu* interface means that the Base Station implements WCDMA radio access *Physical Channels* and transfer information

from Transport Channels to the Physical Channels based on arrangements determined by the RNC (QoS parameters, Channel data rate, Spreading code etc.).

The term Physical Channels means different kinds of bandwidth allocated for different purposes over Uu interface. In other words the Physical Channels form the physical existence of Uu interface between the UE domain and Access Network domain (UTRAN). The physical channels exist in the Uu interface, and the RNC is not necessarily aware of their structure at all.

Instead of Physical Channels the RNC sees Transport Channels. These channels carry information flows over the Uu interface and the physical element, mapping this information flows to the Physical channels in the Base Station.

2.4.1.1.1 Base Station Structure

The Base Station Structure is shown in Figure 10. From the point of view of the radio network and its control, Base station consists of several other entities, called cells. A cell is the smallest radio network entity, having its own identification number (Cell ID), which is publicly visible for the UE. The term Sector stands for the physical occurrence of the cell that is the radio coverage of the cell.

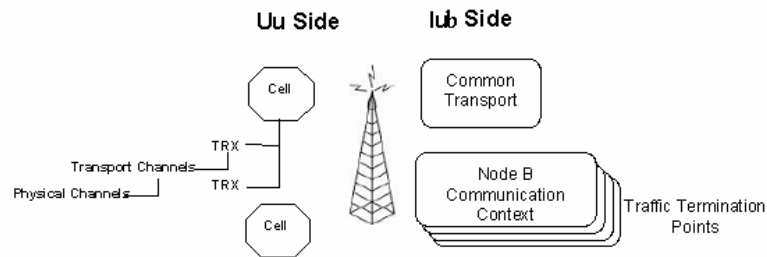


Figure 10. Base Station Structure

Every cell has one *Scrambling Code*. UE recognize a cell by two values, Scrambling code (when logging into a cell) and Cell ID (Indicates the *location* of the cell in the network topology). One cell may have several Transmitter-Receiver (TRXs also called carriers) under it. One TRX maintains physical channels through the Uu interface and these carry the Transport Channels, containing actual information, which may be either Common (for all UE in Cell) or Dedicated (for one or a specific number of UE). The TRX is physically a part of the BS performing various functions such as converting data flows from terrestrial

Iub connection to radio path (WCDMA) and vice versa. The Node_B is also responsible for executing the Inner Loop Power Control task.

The *Scrambling Code* is used in the downlink (From Base Station to User Equipment) direction for Cell separation. Every WCDMA Cell uses one downlink Scrambling Code, which is *locally unique* and acts basically like a Cell ID. Under this Scrambling code, the cell has a set of *Channelisation Codes*, which is orthogonal in nature and used for Channel Separation purposes. Orthogonality as a term means that the channelisation codes are selected in such a way that they interfere with each other as little as possible. This is necessary in order to have a good channel separation.

In WCDMA, the users transmitting and receiving use the whole available frequency band simultaneously in time. To separate different transmissions spread over the frequency band, *Spreading Codes* are used. A Spreading Code can be imagined to be like a “key” which is used both by the mobile and the network. Both ends of the connection (UE and BS) use this “key” to extract the correct wideband transmission away from the frequency band, since the transmitted wideband signal may contain many mobile-network connections.

Every Downlink Scrambling code has a set of Channelisation codes under it and every Call/Transaction requires one Channelisation Code to operate. In practice, one *Spreading Code* is actually *Scrambling Code x Channelisation Code*. If Channelisation Codes are not used, the Spreading Code is equal with the Scrambling Code. This is the case of the BCH.

On the Iub side, a BS is a collection of two entities, *Common Transport* and a number of *Traffic Termination Points (TTP)*. The *Common Transport* represents those transport channels (FACH, RACH) that are common for all UE in the Cell and those used for initial access. One TTP consists of a number of Node B Communication Contexts. *Node B Communication Contexts* in turn consists of all dedicated resources required when the UE is in dedicated mode. Thus one Node B Communication Context may contain at least one Dedicated Channel (DCH).

2.4.1.2 Radio Network Controller (RNC)

The RNC is the switching and controlling element of the UTRAN. It is located between the Iub and Iu interface (Figure 9). The RNC sees the Base Station as two entities, being

Common Transport and Node B Communication Contexts. The RNC, controlling these two entities for a Base Station, is called *Controlling RNC (CRNC)*. Besides load and congestion control the CRNC also handles Admission Control and Code Allocation for the cells served by the controlled Node B's.

The RNC is a switching point between the *Iu Bearer* and *Radio Bearer(s)*. One radio connection between the UE and RNC, carrying user data is a *Radio Bearer (RB)*. Since UTRAN utilizes macrodiversity, the UE may have several Radio Bearers between itself and the RNC. This situation is known as Soft Handover. The RNC holding the Iu Bearer for a certain UE is called *Serving RNC (SRNC)* (Figure 11). This RNC is responsible for executing tasks as handover decisions and Outer Loop power control. For each connection between a UE and UTRAN there is only one SRNC.

Every other RNC that controls cells used by the mobile is referred to as *Drift RNC (DRNC)*. An RNC can act as a Drift RNC because the mobile user roamed into cells controlled by another RNC while the connection with the core network is still made through the RNC controlling the “old” cells.

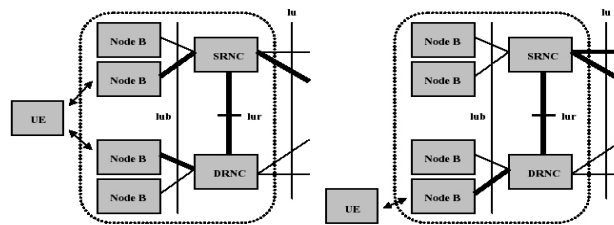


Figure 11. Logical Roles of RNC

The major functionality of the RNC is the *Radio Resource Management (RRM)*. The RRM is a collection of algorithms used to guarantee the stability of the radio path and the QoS of radio connection by efficient sharing and managing of radio resources.

2.5 Radio Resource Management

The Radio Resource Management (RRM) [17] is a responsibility solely taken care of by the UTRAN. RRM is located in both UE and RNC inside UTRAN. It contains various algorithms, which aim to stabilize the radio path enabling it to fulfil the QoS criteria set by the Service using the radio path. The RRM algorithms must deliver information over the

radio path, which is named *UTRA Service* (Figure 8). The control protocol used for this purpose is the **Radio Resource Control (RRC)** protocol.

The RRM algorithms are:

- Handover Control
- Power Control
- Admission Control and Packet Scheduling
- Code Management

2.5.1 Handover Control

The basic concept of handover control is that when the subscriber moves from the coverage area of one cell to another, a new connection with the new target cell has to be set-up and the connection with the old cell may be released.

There are many reasons why handover procedures may be activated. The basic reason behind a handover is that the air interface connection between the UE and UTRAN does not fulfil the QoS criteria set for that connection and thus the UE or the UTRAN initiates actions in order to improve the connection.

For example Signal Quality Reason handover occurs when the quality or the strength of the radio signal falls below certain parameters specified in the RNC. Traffic Reason handover occurs when the traffic capacity of a cell has reached its maximum or is approaching it. In such a case, the UE near the edges of the cell with high load may be handed over to neighbouring cells with less traffic load.

The number of handovers depends on the degree of UE mobility. It is obvious that the faster the UE is moving, the more handovers it causes to the UTRAN. The decision to perform a handover is always made by the RNC that is currently serving the subscriber.

In the present study we are going to concentrate on Handover Control in MBMS enabled 3G Mobile Networks. So we will study the Handover Control in Chapter 3 with more detail.

2.5.2 Power Control

The main reasons for implementing Power Control are the “near-far” problem, the *interference-depended* capacity of the WCDMA and the *limited power source of UE*. For that reasons, the radio transmission power should be optimize, meaning that the power of every transmitter is adjusted to the level requested QoS. In Wideband Code Division Multiple Access (WCDMA) systems, Power Control is applied with purpose to reduce the intra-cell interference.

Wideband Code Division Multiple Access (WCDMA) is an interference-limited and not bandwidth-limited. So system capacity is maximized if the transmitted power of the signal of each terminal is controlled so that its signal arrives at the Base Station with the minimum *Signal to Interference Ratio (SIR)*. Let assume that a terminal is transmitting a signal to a Base Station. If the terminal’s signal arrives at the Base Station with a too low power value, then the required QoS for the radio connection cannot be met. If the received power value is too high, the performance of the terminal is good; however, interference to all other terminal is increased and may result in unacceptable performance for other users, unless their number is reduced. So, system capacity is maximized if the transmitted power of each terminal is controlled so that its signal arrives at the BS with the minimum required Signal to Interference Ratio (SIR).

Due to the fact that in the WCDMA system the total bandwidth is shared simultaneously, other users can be experienced a noise-like interference from a specific user. In case the power control mechanism is missing, common sharing of the bandwidth creates a severe problem, referred to as the near-far effect. In near-far situation, the signal of the terminal that is close to the serving BS may dominate the signal of those terminals, which are far away from the same BS causing then interference in their signal.

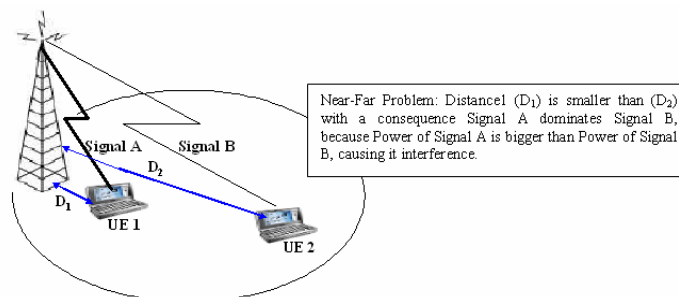


Figure 12. Near-Far Problem

To manage the power control properly in WCDMA, the system uses two different defined Power Control mechanisms. These power control mechanisms are:

- Open Loop Power Control (OLPC)
- Closed Loop Power Control (CLPC), → *Inner* and *Outer* Loop Power Control.

These Power Control Mechanisms work together, in order to keep the target SIR in acceptable level. Also these Power Control mechanisms (OLPC and CLPC) working together have considerable impact on the terminal's (UE) battery-life and overall system capacity.

2.5.2.1 Open Loop Power Control (OLPC)

In the *Open Loop Power Control (OLPC)*, which is basically used for the uplink power adjusting, the UE adjusts the power based on an estimate of the received signal level for the BS CPICH (Common Pilot Channel) when the UE is in idle mode and prior to Physical Random Access Channel (PRACH) transmission. In addition to that, the UE receives information about the allowed power parameters from the cell's Broadcast Common Channel (BCCH) when in idle mode. The UE evaluates the path loss occurring and based on this difference together with figures received from the BCCH and the UE it is able to estimate what might be an appropriate power level to initialize the connection.

For example, in the OLPC, the UE estimates the transmission signal strength by measuring the received power level of the Common Pilot Channel Signal from the BS in the downlink, and adjusts its transmission power in a way that is inversely proportional to the pilot signal power level. Consequently, the stronger the received pilot signal, the lower the UE transmitted power. This three-step procedure is shown in Figure 13.

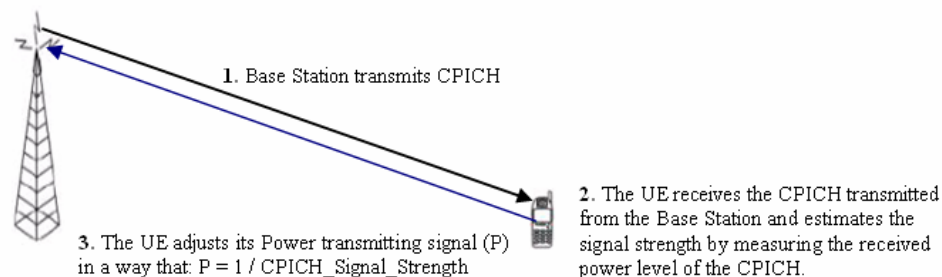


Figure 13. Open Loop Power Control (OLPC)

For the reason that fading characteristics of the radio channel vary rapidly and independently for the uplink and the downlink, Open Loop Power Control alone is not adequate for adjusting the UE transmission power. In order to compensate the rapid changes in the signal strength Close Loop Power Control (CLPC) is also needed.

2.5.2.2 Closed Loop Power Control (CLPC)

In contrast with Open Loop Power Control, Closed Loop Power Control is utilized for adjusting the power when the radio connection has already been established. Its main target it's to compensate the effect of rapid changes in the radio signal strength (due to the radio path environment, mobility etc.) and hence it should be fast enough to respond to these changes. *Closed Loop Power Control* includes *Inner* and *Outer* Loop Power Control.

2.5.2.2.1 Inner Loop Power Control

In the case of uplink CLPC mechanism, the BS commands the UE to either increase or decrease its transmission power with a cycle of 1.5 KHz (1500 times per second) by 1, 2 or 3 dB step-sizes. This decision whether to increase or decrease the power, is based on the received SIR estimated by the BS. When the BS receives the UE signal it compares the signal strength with the pre-defined threshold value at the BS. If the UE transmission power exceeds the threshold value, the BS sends a Transmission Power Command (TPC) to the UE to decrease its signal power. If the UE transmission power is lower than the threshold target, the BS sends a TPC to the UE to increase its signal power.

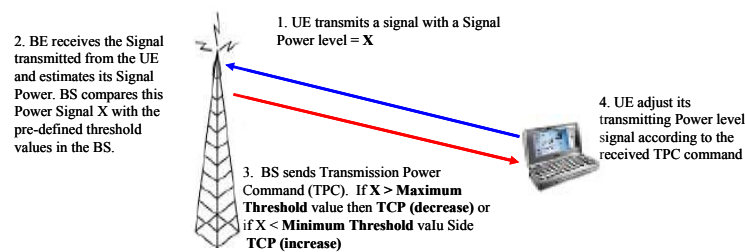


Figure 14. Inner Loop Power Control

In the case of downlink CLPC mechanism the roles of the BS and the UE are interchanged. That is, the UE compares the received signal strength from the BS with a predefined threshold and sends the TPC to the BS to adjust its transmission power accordingly.

The Inner Loop is the fastest loop in WCDMA power control and hence it is occasionally referred to as the Fast Power Control.

2.5.2.2.2 Outer Loop Power Control

The main target of Outer Loop Power Control is to keep the target SIR for the uplink Inner Loop Power Control in an appreciated quality level. Thanks to the macro-diversity, the RNC is aware of the current radio connection conditions and quality. Therefore, the RNC is able to define the allowed power levels of the cell and target SIR to be used by the BS when determining the TPCs (Transmission Power Commands). In order to maintain the quality of the radio connection, the RNC uses this power control method to adjust the target SIR and keep the variation of the quality of the connection in control. In fact, Outer Loop Power Control fine-tunes the performance of the Inner Loop Power Control.

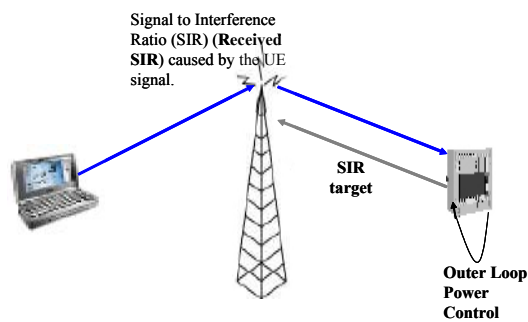


Figure 15. Outer Loop Power Control

This method aims at maintaining the quality of communication, while preventing capacity waste and using as low power as possible. With a frequency varying between 10 and 100 Hz, the received and the desired quality of both uplink and downlink SIR are compared. If the received quality is better than the quality that has to be achieved, the SIR target is decreased; in the other case the SIR target is increased.

2.5.3 Admission Control and Packet Scheduling

The main task of Admission Control (AC) is to estimate whether a new call can have access to the system without sacrificing the bearer requirements of existing calls. Thus the AC algorithm, should predict the load of the cell if the new call is admitted. It should be noted that the availability of the terrestrial resources (Iu Bearer) is verified, too. Based on the Admission Control, the RNC either grants or rejects access.

The Admission Control is responsible for the handling of packet connections with burst traffic having a very random arrival time, number of packet call per session, reading time, as well as number of packets within a call. Therefore the AC must utilize very sophisticated traffic models in order to control optimally the requested RAB(s), by scheduling the Non-Real Time (NRT) RABs and accepting, queuing or rejecting the Real Time (RT) RABs. It is the responsibility of the Admission Control to keep and control the QoS of the accepted RABs and their influence on the overall performance of the UTRAN.

2.5.4 Code Management

Both the Channelisation and Scrambling codes used in the Uu interface connections are managed both by the RNC. The Uu interface requires two kinds of codes for proper functionality (Scrambling code and Channelisation Code). Every cell uses one **Scrambling code**; the UE is able to make separation between cells by recognizing this code. Under every scrambling code, the RNC has a set of Channelisation codes. This set is the same under every Scrambling code.

The Broadcast Channel (BCH) information is coded with a scrambling code value, thus the UE must find the correct scrambling code value first in order to access the cell. When a connection between the UE and the network is established, the channels used must be separated. The channelisation codes are used for this purpose. The information sent over the Uu interface is spread with a spreading code per channel and the *Spreading code* used is *Scrambling code X Channelisation code*.

2.6 Multimedia Broadcast Multicast Service (MBMS)

MBMS is a Point-to-Multipoint service in which data is transmitted from a single source entity to multiple recipients. Transmitting the same data to multiple recipients allows network resources to be shared. MBMS is a new service introduced in 3GPP UMTS Release 6 specifications [18]. There are two modes of operation in MBMS:

- *Broadcast mode*, which allows sending audio and video. The already existing Cell Broadcast Service (CBS) is intended for messaging only. The broadcast mode is expected to be a service without charging and there are no specific activation requirements for this mode.

- *Multicast mode* allows sending multimedia data for the end users that are part of a multicast subscription group. End users need to monitor service announcements regarding service availability, and then they can join the currently active service. From the network point of view, the same content can be provided in a Point-to-Point fashion if there are not enough users to justify the high power transmission of the Point-to-Multipoint Channel. Charging is expected to be applied for the multicast mode.

When the multicast mode is used, the mobile network has to handle group communication issues on network layer and below. Since only one flow of packets for each group is sent through the network and is replicated at each branch, the network needs to know about group members for each branch. Traffic shall only be forwarded on branches leading to group members. An important aspect of the membership handling is keeping track of moving members. Members change their point of attachment to the network and hence network branches and serving nodes. To ensure that all members are being reached, the membership information in each node must be up to date, when the user plane is established. Group Membership information is maintained in each intermediate node on the transmission path. The information is stored in MBMS specific contexts called *MBMS Bearer Contexts* (Called *MBMS Service Context* in RNC) and *MBMS UE Context*. Also the UE needs to store membership and lower layer specific information locally. During the UE mobility from one Cell to another, the contents in these MBMS Specific Contexts has to be updated.

In order to avoid congestion of the paging channels, one solution is to allocate one common identity to all members of each multicast group, which are served by the same SGSN. This Temporary Mobile Group Identity (TMGI) which is globally unique for each MBMS service is used for MBMS Notification purpose.

2.6.1 MBMS QoS Distribution Tree

MBMS data will be distributed to multiple users through an MBMS Distribution Tree that can go through many RNCs, many SGSNs and one or more GGSNs. Furthermore some bearer resources may be shared between many users accessing the same MBMS Bearer Service in order to save resources. As a result, each branch of the MBMS distribution tree shall be established with the same QoS. When a branch of the MBMS distribution tree has

been created, it is not possible for another branch (e.g. due to arrival of a new UE or change of location of a UE with removal of a branch and addition of a new one) to impact the QoS of already established branches. There is no QoS value negotiation between UMTS network elements. This implies that some branches may not be established if QoS requirement cannot be accepted by the concerned network node. Also in RAN there is no QoS (re-)negotiation feature for the MBMS bearer service.

2.6.2 MBMS in the U-TRAN

When using MBMS Services, the main task of U-TRAN is to create and maintain *MBMS Radio Access Bearers (MBMS RAB)* for communication between the User Equipments (UEs) interested in the specific MBMS Service and the Core Network (CN) so that end-to-end QoS requirements are fulfilled in all respects. With *MBMS RAB*, the CN elements are given an “illusion” of a fixed communication path to UEs, thus releasing them from the need to take care of radio communication aspects (e.g. Maintenance of Radio Bearers).

2.6.2.1 MBMS Radio Access Bearer (MBMS RAB)

For each MBMS Service, data is transferred via an *MBMS Radio Access Bearer (MBMS RAB)* between the SGSN and the UEs. The MBMS RAB consists of one *MBMS Iu Bearer* between the SGSN and the RNC and one or more *MBMS Radio Bearers* between the RNC and the UEs (See Figure 16).

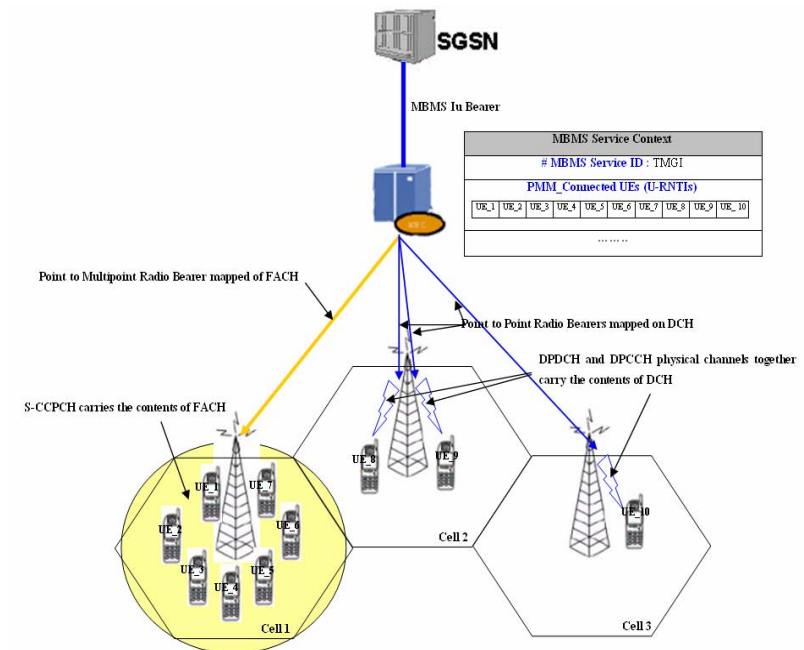


Figure 16. MBMS Radio Access Bearer

Each RNC controlling one or several cells within an MBMS Service Area, maintains an *MBMS Service Context* for each MBMS Bearer Service. Each MBMS Service Context is associated with a unique *MBMS Service ID*. This MBMS Service ID corresponds to the TMGI (Temporary Mobile Group Identity).

The *MBMS Service Context* in the CRNC contains a list of PMM_Connected mode UEs only (No RRC Idle UEs are contained in the MBMS Service Context), which are present in a Cell controlling by the Controlling-RNC and have activated the same MBMS Bearer Service. The Controlling-RNC based on information in its *MBMS Service Context* selects on a per cell basis the appropriate Radio Bearer type that would consume less radio bandwidth, either *Point-to-Point* or *Point-to-Multipoint* Radio Bearer, for MBMS transmission in each cell. The terms Point-to-Point and Point-to-Multipoint can be interpreted in the following way:

- *Point-to-Point* Radio Bearer will be a Dedicated Channel (DCH) that is bi-directional with Inner and Outer loop power control. DCH is a Point-to-Point channel; hence it suffers from the inefficiencies of requiring multiple DCH to carry common data to a group of receivers. However, DCH can employ fast closed-loop power control and Soft handover mechanisms, to achieve a highly reliable channel. DCH also consists of an uplink channel, which is used to feedback power control information among other control or data signals to the cellular network.
- *Point-to-Multipoint* Radio Bearer will use common channel in the downlink only. The Common Transport channel that has been proposed by the 3GPP is the Forward Access Channel (FACH) and it aims to overcome network congestion when a large number of users request the same content. Even with a large number of multicast receivers, only one FACH is required for the transmission of the MBMS service, with no load on the uplink connections. Data transmitted on the FACH cannot be reliably received by the multicast receivers as there is no channel for the feedback of received quality back to the network. Also fast power control cannot be applied on FACH channel.

When the *MBMS RAB* is established between the SGSN and the UEs, the SGSN sends the MBMS data received from the GGSN on the RNC once. From there, the RNC duplicates the received MBMS data from the SGSN and sends these data on the established MBMS Radio Bearers.

Chapter 3

3 Handover Control

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Handover Control aims to provide continuity of mobile services to a user travelling over cell boundaries in a cellular infrastructure. For a user having an ongoing communication and crossing the Cell edge, it is more favourable to use the radio resources in the new cell, also called the Target cell, because the quality of the signal strength perceived in the “old” cell is decreasing as the user penetrates the target cell. The whole process of tearing down the existing connection in the current cell and establishing a new connection in the appropriate cell is called “handover”.

3.1 Handover Process

The basic handover process consists of three main phases. These are *Measurement* phase, *Decision* phase and *Execution* phase.

Handover Measurement provision is a very important task for the system performance. This is because the signal strength of the radio channel may vary drastically due to fading and signal path loss, resulting from the cell environment (e.g. buildings, mountains) and user mobility. For the handover purposes and during the connection the UE continuously measures the CPICH (Common Pilot Channel) signal strength concerning the *neighbouring cells*, and reports the results to the Serving RNC (SRNC).

Decision phase consists of the assessment of the overall QoS of the connection and comparing it with the requested QoS attributes and estimates measured from the neighbouring cells. Depending on the outcome of this comparison, the handover procedure

may or may not be trigger. The SRNC checks whether the values indicated in the measurement reports meet the QoS specified for the end-user service. If not, then it allows the *Execution* of the handover.

3.2 Handover Process Description

The Handover procedure is composed of a number of single functions:

- Measurements
- Filtering of Measurements
- Reporting of Measurement results
- The Handover Algorithm
 - If the (Active Set size = 1) then Hard Handover [19] will be performed.
 - If the (Active Set size > 1) then Soft Handover [19] will be performed.
- Execution of Handover

Before starting the in-depth analysis of these functions some terms used for describing the handover process the following have to be defined:

- *Active set*: List of cells having a connection with the User Equipment (UE).
 - In case of Hard Handover Algorithm, the Active Set size is equal to 1. This is due to the fact that during Hard Handover the mobile UE can have radio links only with one Base Station.
 - In case of the Soft Handover the Active Set size varies from 1 to 3.
- *Monitored set*: List of (neighbouring) cells whose Common Pilot channel (CPICH) is continuously measured but not strong enough to be added to the Active Set.

3.2.1 Measurements

Accurate measurements of the Common Pilot Channel (CPICH) Signal Strength form the main input for obtaining the RRC Measurement Report are necessary for making handover decisions. Cell measurements are filtered in the UE and based on the measurement reporting criteria a report is sent to UTRAN. This report constitutes the basic input to the Handover Algorithm. Based on the Cell measurements, the Handover algorithm evaluates if any cell should be Added to (Radio Link Addition), Removed from (Radio Link Removal), or Replaced in (Combined Radio Link Addition and Removal) the Active Set using the "Active Set Update" procedure.

It is important to apply filtering on the handover measurements to average out the effect of fast fading. Measurement errors can lead to unnecessary handovers. Appropriate filtering can increase the performance significantly. As long filtering periods can cause delays in the handovers, the length of the filtering period has to be chosen as a trade-off between measurement accuracy and handover delay. Also the speed of the user matters, the slower the user equipment is moving the harder it is to average out the effects of fast fading. Often a filtering time of 200ms is chosen.

3.2.2 Handover Algorithm (Current)

In the current Handover Algorithm [19], the handover decision making is based on a comparison made between an observed value and a *predetermined* threshold, where the threshold value is typically chosen in a manner so as to *maximize the system capacity*. Based on the CPICH Ec/No measurements of the set of cells monitored, the mobile station decides which of three basic actions to perform; it is possible to *Add*, *Remove* or *Replace* a Node B in the Active cell. These tasks are respectively called Radio Link Addition and Radio Link Removal, while the latter is Combined Radio Link Addition and Removal. In the case where the Active Set size is set equal to 1 (Hard Handover), the UE can have radio link connections only with one Node B. That means that during the movement of the UE from one Cell to another, all the old radio links in the UE with the old Cell are removed before the new radio links with the new Cell are established. So in this case only the *Replacement* of a Node B can be performed.

Discussing the scenario below gives a good insight into the algorithm itself. This scenario can be based on a user following a trajectory as shown below. Figure 17 also shows how the CPICH (Common Pilot Channel) strengths of the different cells evolve in time along with the general principles of adding, replacing or removing a Cell from the Active Set.

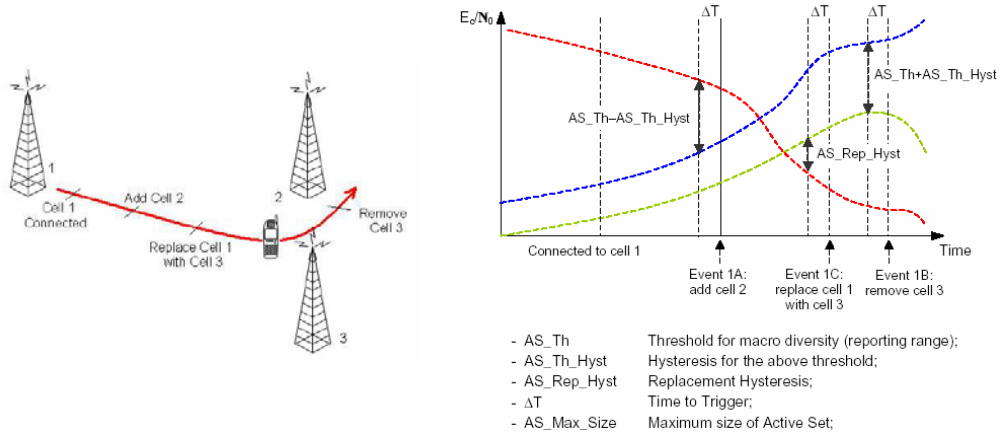


Figure 17. Current Handover Control Algorithm

The value of *Macrodiversity Threshold* (AS_Th) together with the *Macrodiversity Hysteresis* (AS_Th_Hyst), is used while evaluating the CPICH measurements of the Node_Bs in the Active and Monitored Sets in order to determine whether there are any conditions that will trigger 1A (Cell Addition) and/or 1B (Cell Removal) events to be reported to RNC. Roughly stated AS_Th is the maximum difference in SIR two pilot signals can have so their cells can coexist in the Active Set.

The value of Replacement Hysteresis (AS_Rep_Hyst) is used while evaluating the CPICH measurements of the Node-Bs in the Active and Monitored Sets in order to determine whether there are any conditions that will trigger a 1C event (Cell Replacement). In other words, if the best CPICH measurement in the Monitored Set is better than the worst measurement in the Active Set by this value then the cells of these two measurements are reported to RNC for an Active Set Replacement.

The conditions of how a Radio Link is Added, Removed or Replaced from the Active Set are shown below:

- If $Pilot_Ec / No > Best_pilot_Ec / No - (AS_Th - AS_Th_Hyst)$ for a period of ΔT and the Active Set is not full ($< AS_Max_Size$), the Cell is added to the Active set. This is called *Event 1A* or *Radio Link Addition*.
- If $Pilot_Ec / No < Best_pilot_Ec / No - (AS_Th + AS_Th_Hyst)$ for a period of ΔT , then the cell is removed from the active set. This is called *Event 1B* or *Radio Link Removal*.

- If the Active Set is full ($= AS_Max_Size$) and $Best_candidate_pilot_Ec / No > Worst_Old_pilot_Ec / No + AS_Rep_Hyst$ for a period of ΔT , then the weakest cell in the Active Set is replaced by the strongest candidate cell. This is called *Event 1C* or *Combined Radio Link Addition and Removal*.

Where:

$Pilot_Ec/No$ is the measured and filtered quantity of Ec/No of CPICH;

$Best_pilot_Ec/No$ is the strongest measured cell in the Active Set;

$Best_candidate_pilot_Ec/No$ is the strongest measured cell in the Monitored Set;

$Worst_Old_pilot_Ec/No$ is the weakest measured cell in the Active Set.

3.3 MBMS Handover Issues

Above, an introduction on the Handover Control has been made providing the reader with the fundamentals of handover. However, the handover issue in MBMS system has not been discussed in detail yet.

With the introduction of MBMS Service in UMTS Networks, the RNC can use either Dedicated (One Point-to-Point Radio Bearer for each UE) or Common resources (One Point-to-Multipoint Radio Bearer for all the UEs) to distribute the same content in a Cell. This is done for radio efficiency reasons. For example, if there are not enough users to justify the high power transmission of the Common Channel, the content will be provided on a Point-to-Point fashion. As a consequence, the mobile users that are on the move and receive an MBMS Service may have to deal with dynamic changes of network resources (from Common to Dedicated resources and visa versa) when crossing the cell edge. This introduces new types of MBMS Handovers since until now, handover in UMTS Network have been considered only between Dedicated Resources.

Thus in addition with the *From Point-to-Point (DCH) To Point-to-Point (DCH)* type of handover that is already defined in [19], there are three new types of Handover that have to be considered:

- From Point-to-Point (DCH) To Point-to-Multipoint (FACH)
- From Point-to-Multipoint (FACH) To Point-to-Point (DCH)
- From Point-to-Multipoint (FACH) To Point-to-Multipoint (FACH)

When a handover event is initiated, some signalling has to carry out in order for the UE to successfully handover into the new Cell. In the current study, we are interested for the handover between different kind of resources (From Common to Dedicated and vice versa) Therefore only the following two types of MBMS Handover are going to be considered:

- From Point-to-Point (DCH) To Point-to-Multipoint (FACH)
- From Point-to-Multipoint (FACH) To Point-to-Point (DCH)

In section 3.3.1 the signalling carried out concerning these two types of MBMS Handover is going to be illustrated.

3.3.1 MBMS Handover Signalling Description

While the UE is moving from one Cell to another will measure the signal strength of the CPICHs of the neighbouring Cells. Based on these measurements and by the information retrieved from the *MBMS Point-to-Multipoint Control Channel (MCCH)* (See Appendix B) it will trigger the appropriate MBMS Handover type and send a *UmtsC_Rrc_Measurement_Report* to the RNC. The RNC, upon receiving this report, will check if that UE supports an MBMS Service. If so, the RNC will check the type of the Radio Bearer that the MBMS Service is supported in the Target Cell (Figure 18), in order to define the type of MBMS Handover that is going to be performed. According to the needs of our study only the following two cases are going to be studied.

- From Point-to-Point (DCH) To Point-to-Multipoint (FACH)
- From Point-to-Multipoint (FACH) To Point-to-Point (DCH)

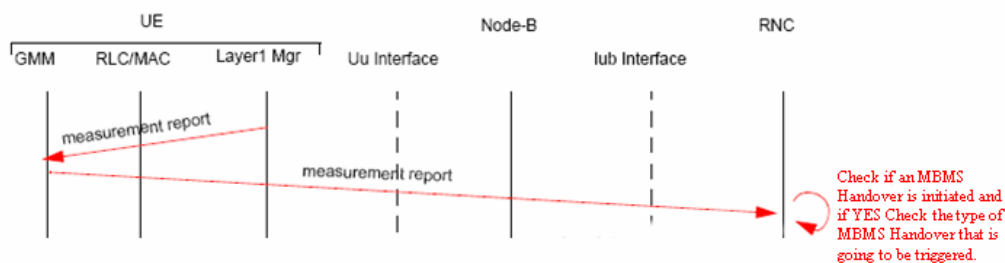


Figure 18. Measurement Report Received

3.3.1.1 From DCH to FACH Handover Signaling

If the *From Point-to-Point (DCH) To Point-to-Multipoint(FACH)* MBMS Handover is going to be performed, then the signalling illustrated in Figure 19 will carried out. In this case due to the fact that the *Point-to-Multipoint Radio Bearer is already established* in the

Target Cell, the RNC upon receiving the *UmtsC_Rrc_Measurement_Report* would not have to request the addition of a new Radio Link in the Point to Multipoint Cell. Thus in this type of MBMS Handover, Admission Control is not needed. The RNC will just include the Point-to-Multipoint's Radio Bearer (FACH) configuration in the *RRC Physical Channel Reconfiguration* message and sent it to the UE. The UE upon receiving the message will retrieve the included FACH configuration (Spreading Code, Channel's data rate, etc.) and reconfigure its GMM and RLC/MAC Layers in order to be able to receive the MBMS content through the FACH Channel in the Target Cell. The UE, at the same time, will send an *RRC Physical Channel Reconfiguration Complete* message to the RNC in order to inform it that the UE is now receiving the MBMS Service data through the Common Channel. The RNC upon receiving this message will update the *MBMS Service Context* of the associate MBMS Service and the *RNC Context* of the related UE. At the end the RNC will release the Point-to-Point Radio Bearer that was established in the Old Cell for new Admissions.

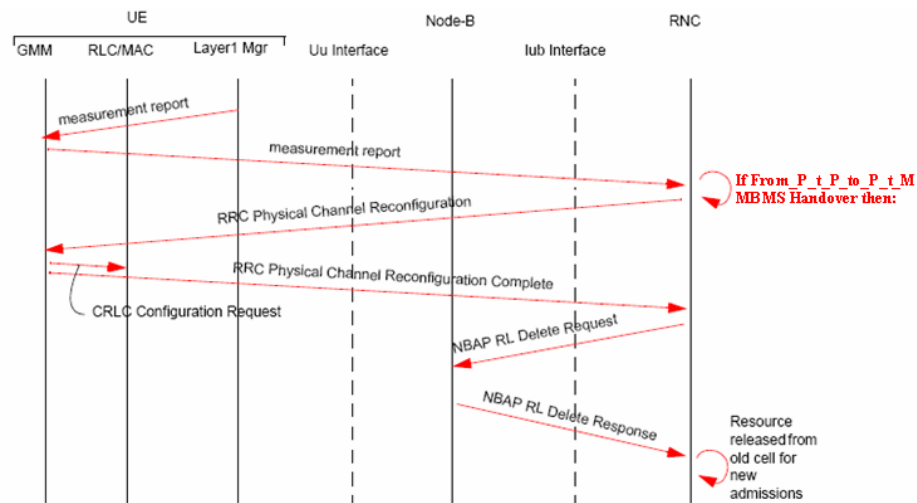


Figure 19. From Point-to-Point To Point-to-Multipoint Handover Signalling

3.3.1.2 From FACH to DCH Handover Signaling

If the *From Point-to-Multipoint To Point-to-Point* MBMS Handover is going to be performed, then the signalling illustrated in Figure 20 will be carried out. In this case, the RNC upon receiving the *UmtsC_Rrc_Measurement_Report* would have to request the addition of a new Radio Link in the Target Cell. Thus the RNC will perform an Admission Control in order to check if there are enough downlink and uplink resources to allocate for the establishment of a new *Point-to-Point Radio Bearer* (DCH) with this UE. If so, the

RNC will request the Target Node_B for the addition of a new Radio Link (allocate spreading code and channel) for this UE. The Target Node_B will establish the new Radio Link and response to the RNC including the appropriate information (DCH Configuration). The RNC, upon receiving the response, will *create an RLC profile* for this UE and send an *RRC Physical Channel Reconfiguration* message to the UE providing it with the new DCH's configuration. The UE upon receiving the message will retrieve the included DCH configuration (Spreading Code, Channel's data rate, etc.) and reconfigure its GMM and RLC/MAC Layers in order to be able to receive the MBMS content through the new DCH Channel in the Target Cell. The UE, at the same time, will send an *RRC Physical Channel Reconfiguration Complete* message to the RNC in order to inform it that the UE has been reconfigured and is ready to start receiving the MBMS Service through the Point-to-Point Radio Bearer established in the new Cell. The RNC upon receiving the message from the UE will update the *MBMS Service Context* of the associate MBMS Service and the *RNC context* entry of the related UE and start sending the MBMS data to the UE through the new Point-to-Point Radio Bearer. Since the UE was receiving the MBMS Service from a Point to Multipoint Radio Bearer in the Old Cell, the signalling stops here (*No any resources are going to be released*).

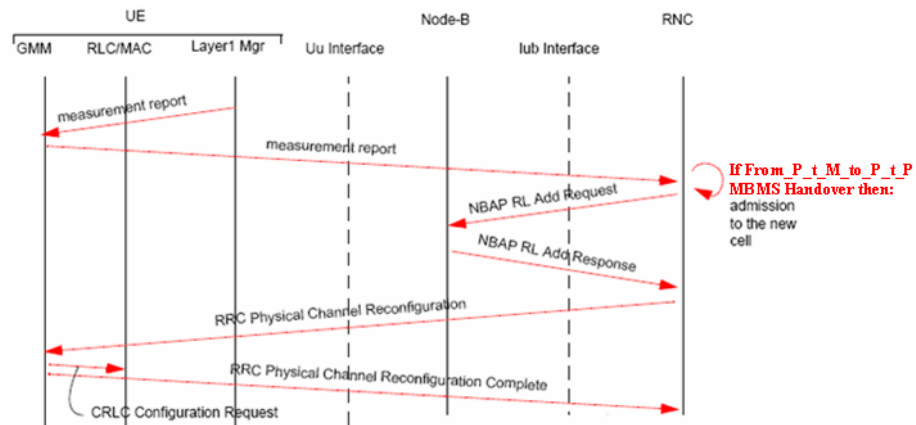


Figure 20. From Point-to-Multipoint To Point-to-Point Handover Signalling

Chapter 4

4 Proposed MBMS Handover Algorithm

4.1	Common (FACH) Vs Dedicated (DCH) Resources	37
4.2	Description of the Proposed MBMS Handover Algorithm	41
4.3	Problems & Solutions of the Proposed MBMS Handover Algorithm	61

Usually, the handover decision making is based on a comparison between an observed value and a *predetermined* threshold chosen in a manner so as to *maximize the overall system capacity*. The Current Handover Algorithm [19] efficiently achieves that when the handover is performed between Dedicated resources, but using the same algorithm when the handover is performed between Dedicated (DCH) and Common (FACH) resources the result will not be so efficient (See Section 5.2 – Performance Evaluation) .

This Chapter proposes an enhanced MBMS Handover Algorithm which efficiently achieves increased cell capacity in the Point to Point Cells when the mobile users have to deal with dynamic changes of network resources (*From Common to Dedicated resources and vice versa*) when crossing the cell edge and one of the following type of MBMS Handover is going to be executed:

- From Point-to-Point (DCH) To Point-to-Multipoint (FACH) Cell
- From Point-to-Multipoint (FACH) To Point-to-Point (DCH) Cell

In order to accomplish increased Cell Capacity in the Point to Point Cells, new parameters have to be considered and a different approach has to be followed. The key of accomplishing this capacity achievement is the full utilization of the broadcast nature of Common resources (See Section 4.1).

4.1 Common (FACH) Vs Dedicated (DCH) Resources

The main difference with the Dedicated (DCH) and Common (FACH) channels is that FACH (Forward Access Channel) does not allow the use of fast power control or no power control at all. Thus, as FACH needs to be received by all Terminals in the Cell, also those near the Cell's border, it needs to use more or less the full power level. Fast power control is perhaps the most important aspect in WCDMA. This is because it *optimizes* the radio transmission power in order to increase the overall system capacity, meaning that the power used by the Base Station in order to reach the mobile terminal will be adjusted and be at a level which aims to ensure the QoS level requested without causing additional interference. Even though FACH does not provide this “valuable” feature, it provides some other benefits that should be taken into consideration when an MBMS Handover is executing. In order to see the benefits that could be obtained from the broadcast nature of Common Resources scenario shown in Figure 21 was simulated.

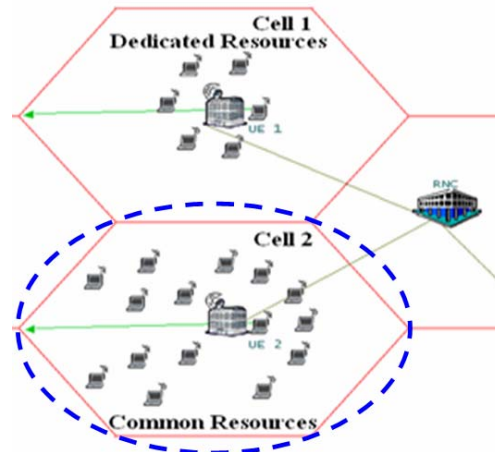


Figure 21. Common Vs Dedicated Resources Scenario

In this Scenario, UE_1 (in Cell_1) and UE_2 (in Cell_2) follow the same trajectory, (a trajectory that passes near their attached Base Station and heading towards the border of the Cell that they camps in), as shown in Figure 21. The UEs receive the same MBMS Streaming Video of 8 Kbytes/second. The Cells Coverage is 1000 meters and the Path-loss Model used is “Pedestrian Outdoor”. Cell_1 uses Dedicated Resources (Point to Point Cell) while Cell_2 uses Common Resources (Point to Multipoint Cell) to distribute the same MBMS Service content in the Cell. Three instances of the same scenario have been simulated using different number of users in each Cell at different positions (Cell 1: 2, 4, and 6 users, Cell 2: 10, 13 and 15 users).

In Figure 22 the distance of UE 1 and UE 2 from their attached Base Station, during the simulation time, is illustrated. As they follow the same trajectory with the same speed and start at equal distances from their attached Base Station their distance from their attached Base Station will be the same during simulation time.

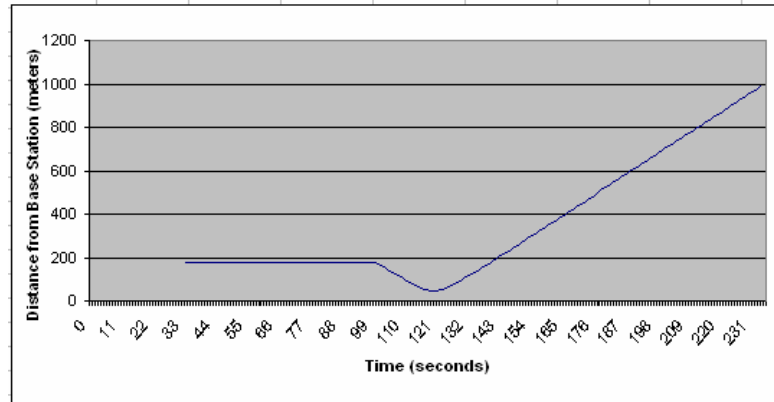


Figure 22. UE 1 & UE 2 Distance from their attached Base Station

Results concerning the QoS level of the received signal (Traffic Received) and the Total downlink Transmitted Carrier Power used from each Cell have been collected and presented below.

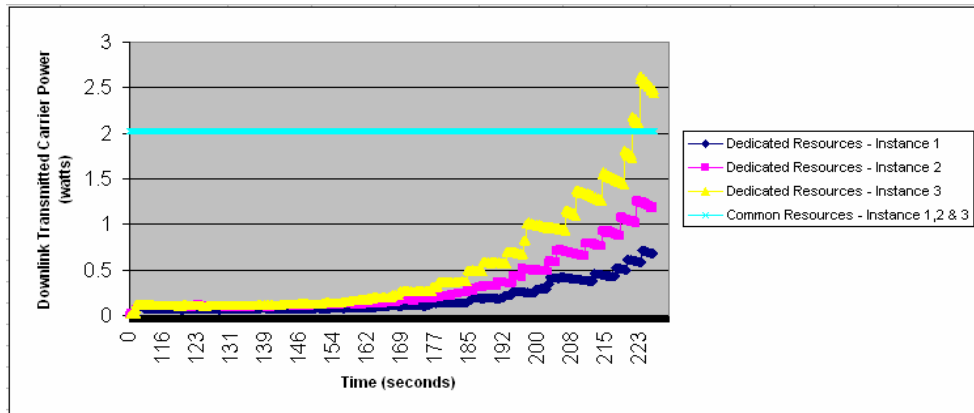


Figure 23. Downlink Transmitted Carrier Power used-Common Vs Dedicated Resources (watts)

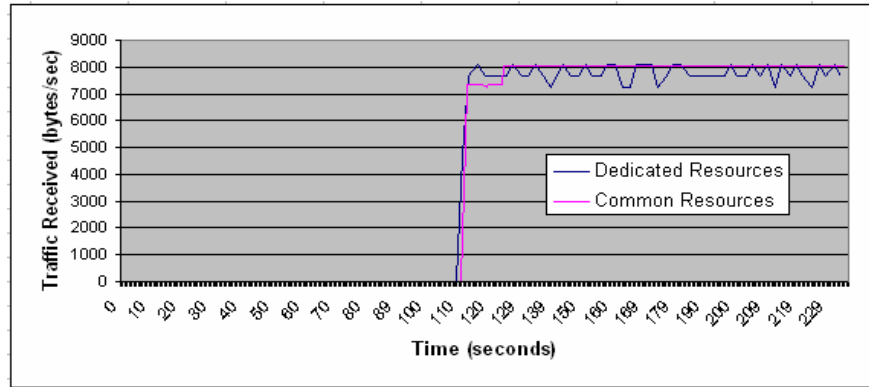


Figure 24. Traffic Received-Common Vs Dedicated Resources (bytes/sec)

From the results illustrated above (Figure 22 - Figure 24) the following observations have been made:

- As FACH is a Common Channel (FACH) and needs to be received by all Terminals in the Cell, **including those near the Cell's border**, it requires more radio resources (power) than a Dedicated Channel (DCH). Therefore few Dedicated Channels (DCHs) might outperform one Common Channel (FACH) in terms of radio resource efficiency (See Instance 1 and Instance 2). On the other hand if the number of users is increasing it is more efficient to use a Common Channel for the data distribution (See Instance 3). *This is also the radio efficiency criterion used by the RNC in order to choose between Common and Dedicated Resources for the distribution of the MBMS Service in the Cell.*
- The proportion of the available Downlink Transmission Power allocated for Common resources (FACH) is fixed and at a level aimed to ensure the QoS level requested throughout the Coverage of the Point to Multipoint Cell despite the number and the location of the Users in the Cell.
- The Downlink Transmission Power allocated for Dedicated Resources (DCH) is variable and rising exponentially while the UE distance from its attached Base Station is increasing. Moreover, the more the UEs in the Cell thus the higher the interference, the more exponential the increase in the total power required.

Let us now how we can maximize the overall system capacity by taking full advantage of the Common Resources broadcast nature (Point-to-Multipoint Radio Bearers) during an MBMS handover. In the following scenario (Figure 25) UE_1 is moving from a Point-to-Point Cell towards a Point-to-Multipoint Cell towards the spot A. The spot A is located on

the Border of the Point to Multipoint Radio Bearer at distance equal to 750 meters from the Base Station of the Point-to-Point Cell.

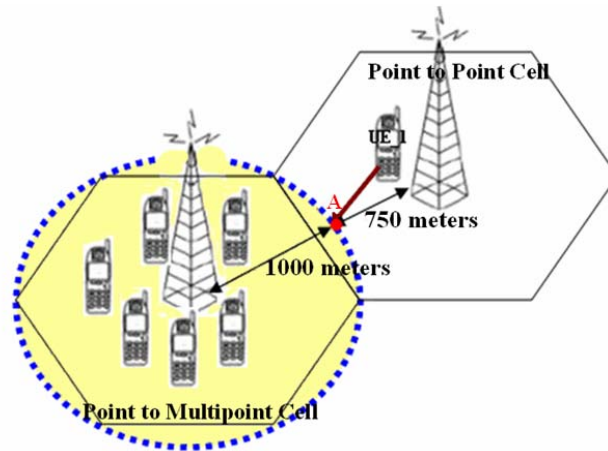


Figure 25. Taking advantage of Common Resources Scenario

By taking into consideration the observations made above, in order to maximize the overall system capacity (minimizing the total Transmitted Carrier Power) while at the same time satisfying the QoS level requested for the MBMS Service, the handover should be executed as close as possible to the Point to Point Base Station but not outside of the Point-to-Multipoint Cell Coverage. Thus the proper place to switch channels (execute the handover) is “on the border of the Point-to-Multipoint Cell” (E.g. Spot A), at distance equal with the Coverage of the Point-to-Multipoint Cell from the Point-to-Multipoint Base Station. Since accuracy like that is very difficult to be achieved (execute the handover exactly on the border of the Point to Multipoint Cell), due to the dynamic nature of the Cell environment, and also due to the fact that in the measurement estimations of using the GPS technology we could have some error (up to three meters of error) by saying “on the border” we will mean at distance equal with Coverage of the Point-to-Multipoint Cell ± 5 meters from the Point-to-Multipoint Base Station, giving a space of 8 meters for error margin.

Therefore, by taking full advantage of the Point-to-Multipoint Radio Bearers (Common Resources) and executing the handover on the border of the Point to Multipoint Cell, significant enhancement could be provided to the downlink performance by reducing the interference caused in the Point-to-Point Cells and achieving less power consumption per subscriber. This will release the Base Station power for servicing more users, resulting in the enhancement of the overall system capacity by also maintaining a satisfactory call quality.

4.2 Description of the Proposed MBMS Handover Algorithm

Before starting the in-depth analysis of the proposed MBMS Handover Algorithm is worth mentioning that the proposed algorithm can be used only when the MBMS mobile users are moving from Dedicated (DCH) to Common (FACH) resources and vice versa. Furthermore, for simplicity reasons we assume that the Coverage of the Cells supporting the MBMS Service on Common Resources (Point to Multipoint Cells) will be presented as homogeneous circles and also that the UE will be on Line of Sight (LOF) with the Point-to-Multipoint Base Station.

As we have seen in Section 4.1, when an MBMS Handover is executing, the best position to perform the handover is on the border of the Point-to-Multipoint Cell. Since it is difficult to achieve this using the Current Handover Algorithm (due to the approach used), a different approach has to be followed.

A first solution to this would be to trigger the Handover on the border of the Cell that supports the MBMS Service on Common Resources (See Figure 26). This seems to be a good idea but if we think more about this solution we will see that this is not the “best” one. For example if the *From Point-to-Point (DCH) To Point-to-Multipoint (FACH)* MBMS Handover is going to take place and the MBMS Handover is triggered on the Border of the Cell that supports the MBMS Service on Common Resources the switching from the *Point-to-Point(DCH)* to the *Point-to-Multipoint (FACH)* Radio Bearer will take place at some distance away from the border. This will happen since some delay will be caused from the time the Handover is triggered until the UE switch channels (From DCH to FACH) (*Handover Delay*). During that Handover delay time, the UE will continue listening to the Point-to-Point Radio Bearer time even though it has crossed the border and moving into the Coverage of the Point-to-Multipoint Cell. Given that the Downlink Transmission Power allocated for a Point-to-Point Radio Bearer increases exponentially while the UE is moving away from the Point to Point Base Station, this solution will cause additional interference in the Point-to-Point Cell since the Point-to-Multipoint Radio Bearer will not be fully utilized.

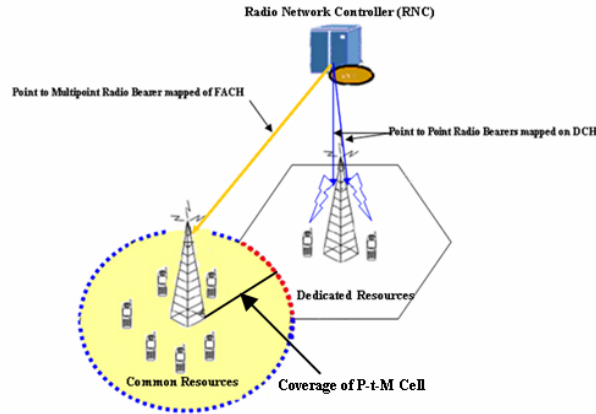


Figure 26. Solution 1: Trigger MBMS Handover on the Border of the Point to Multipoint Cell

Therefore, in order for the MBMS Handover to be executed on the border of the Point to Multipoint Cell, it should be triggered at some distance (*Safety Distance*) before the mobile user enters (If the UE is moving from Dedicated to Common Resources) or leaves (If the UE is moving from Common to Dedicated Resources) the Coverage of the Point to Multipoint Cell. By doing this, all the MBMS Handover Signalling needed (See 3.3.1) in order to switch Channels will take place at the proper time so just upon entering the Point to Multipoint Cell Coverage the UE to be able to switch channels.

Therefore, another and better solution is to trigger the Handover close to the Border of the Point-to-Multipoint Cell, at a distance (**D**) equal with the *Coverage of the P-t-M Cell* ± *Safety Distance* from the Point to Multipoint Base Station (See Figure 27). The “±” sign means that according to the type of MBMS Handover that is executing, the estimation of the distance **D** will differ (See section 4.2.1).

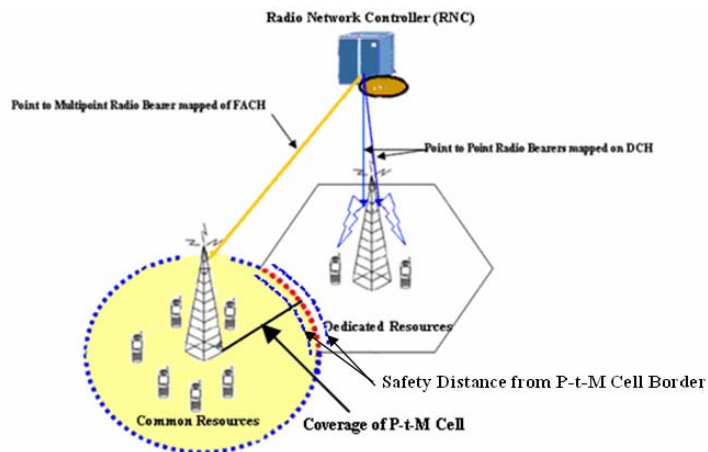


Figure 27. Solution 2: Trigger MBMS Handover near the Border of the Point to Multipoint Cell

The *Safety Distance* is a variable parameter and will be estimated during UE's mobility. In order to estimate the *Safety Distance* the Handover Delay (Δt), the *Speed* and the *Direction* of the UE are going to be considered. The *direction* of the UE can be expressed as the angle φ that is created between the straight line that connects the UE with the Point to Multipoint Base Station and the line showing the path of the UE (See Figure 28).

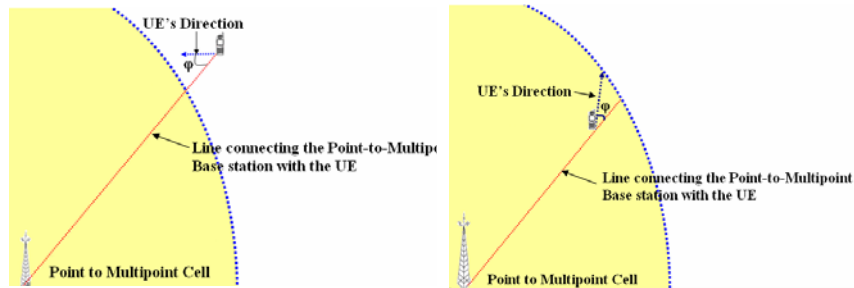


Figure 28. UE's Direction (From Dedicated To Common Resources and vice versa case)

Upon estimating the Safety Distance, the second step of the proposed approach is to estimate the distance D given by the *Coverage of the P-t-M Cell \pm Safety Distance* while the last step is to express the distance D at a value that the UE can measure during its mobility. For the handover purposes and during the connection the UE continuously measures the signal strength of the CPICH concerning the *neighbouring cells*. Therefore this distance will be expressed as the CPICH signal strength (dB) of the Point to Multipoint Base Station that the UE should measure at the estimated distance D . We will refer to this value as the “*MBMS Replacement Threshold*”.

Now while the UE is moving from one Cell to another it will continuously measure only the CPICH signal strength of the Point to Multipoint Base Station (See Figure 29). When the CPICH signal strength of the Point-to-Multipoint Base Station becomes equal to the MBMS Replacement Threshold the MBMS Handover will be triggered.

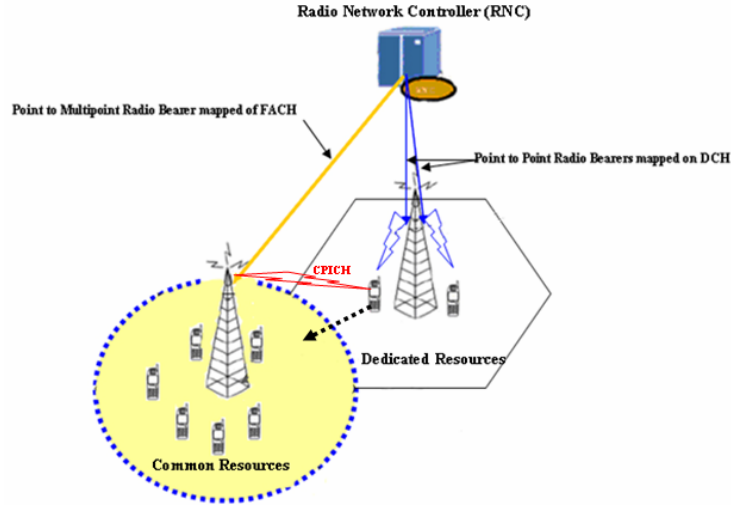


Figure 29. UE measures only the CPICH signal strength of the Point to Multipoint Base Station

Accurate measurements of the CPICH signal strength received from the Point to Multipoint Base Station form the main input making the MBMS handover decision. Therefore, it is important to apply *filtering* on the handover measurements to average out the effect of fast fading. Measurement errors can lead to unnecessary handovers and trigger the handover away from the border of the Point to Multipoint Cell. Appropriate filtering can increase the performance significantly. Long filtering periods can cause delays in the handovers, therefore the length of the filtering period has to be chosen as a trade-off between measurement accuracy and handover delay. Also the speed of the user matters, the slower the user equipment is moving the harder it is to average out the effects of fast fading. Often a filtering time of 200ms is chosen.

4.2.1 Estimating the Distance D

As we have said above, according to the type of MBMS Handover that is executing, the estimation of the distance D will differ. Let suppose that we want to estimate the distance D when the UE is moving from a *Point-to-Point Cell (Dedicated Resources)* towards a *Point-to-Multipoint Cell (Common Resources)* as shown in Figure 30. Since the UE will measure only the CPICH signal strength of the Point-to-Multipoint Base Station and the UE is currently located in the Point-to-Point Cell, the handover should be triggered at Δt time (equal to the Handover delay time) before the UE enters the Coverage of the Point-to-Multipoint Cell. Therefore, the *Safety Distance* ($Speed \times \Delta t$) should be *added* with the *Coverage of the P-t-M Cell* in order to find the distance D (*Coverage of the P-t-M Cell* +

Safety Distance) from the Point-to-Multipoint Base Station that the MBMS Handover should be triggered.

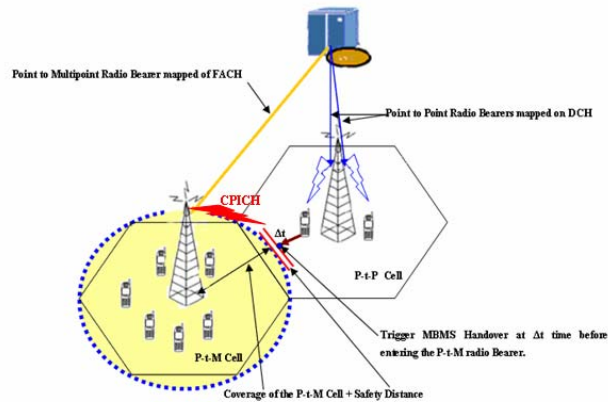


Figure 30. From Dedicated To Common Resources

On the other hand, if the UE is moving from a *Point-to-Multipoint Cell (Common Resources)* towards a *Point-to-Point Cell (Dedicated Resources)* as shown in Figure 31, the handover should be triggered at Δt time before the UE leaves the Coverage of the Point-to-Multipoint Cell. Therefore, the *Safety Distance* should be *subtracted* from the *Coverage of the P-t-M Cell* in order to find the distance D from the Point-to-Multipoint Base Station that the Handover should be triggered.

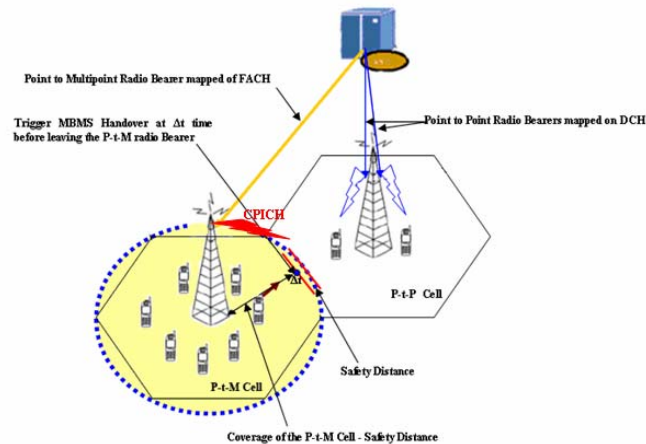


Figure 31. From Common To Dedicated Resources

The *Coverage of a Cell* is not the same for all Cells. Moreover, due to the “Cell Breathing” phenomenon, the Coverage of a cell might shrink or enlarge according to the current load in the Cell. Therefore the Coverage of the Point to Multipoint Cell cannot be known to the UE during its mobility. Somehow the UE has to be informed about this information before entering the Coverage of the Point to Multipoint Cell. This information will be broadcasted

from the *RNC* to the UEs periodically using the MCCH Channel (See Appendix B) of the appropriate MBMS Service. In order for this new feature to be included in the MCCH Channel, the MCCH must be enhanced. Due to the fact that the MCCH currently does not include this field, it should be enhanced in order to add one more field for the accommodation of this new parameter. Now, the UEs that are on the move can periodically retrieve this information from the MCCH Channel transmitted in the Cell in order to estimate as accurately as possible the *distance D*.

4.2.2 Estimating the Safety Distance

The purpose of the *Safety Distance* is to trigger the MBMS Handover before the UE reaches the border of the Point to Multipoint Radio Bearer so when the upon reaching the border to immediately switch channels. As we have said, the estimation of the *Safety Distance* depends on the *Speed* of the UE, the time needed (Δt) from the time the Handover event is triggered until the UE starts listening to the new Channel (*Handover delay*) and also the UE's *Direction* (*Angle φ*). If the Safety Distance is either overestimated or underestimated it will disturb the overall system efficiency. For example, according to the MBMS Handover case that is executing, if we *overestimate* the Safety Distance (thus triggering the Handover event earlier than we should) then:

- If the UE is executing a *From Point-to-Point (DCH) To Point-to-Multipoint (FACH)* type of MBMS Handover, then the UE will switch channels (From Dedicated to Common) *before entering* the Coverage of the Point-to-Multipoint Radio Bearer. Therefore, the UE will stop listening to the Point-to-Point Radio Bearer (DCH) and start listening to the Point-to-Multipoint Radio Bearer (FACH) before Point-to-Multipoint Radio Bearer signal strength becomes strong enough in order to satisfy the QoS level requested for the MBMS Service.
- If the UE is executing a *From Point-to-Multipoint (FACH) To Point-to-Point (DCH)* type of MBMS Handover then the UE will switch channels (From Common to Dedicated) at some distance *before leaving* the Coverage of the Point-to-Multipoint Radio Bearer. This will cause more interference to the Point-to-Point Cell since more power will be used in order to reach the UE at this distance, comparing with the power that would be used if the channel switching had been executed on the border of the Point-to-Multipoint Cell.

If the Safety Distance is *underestimated* (thus triggering the Handover event later than we should) then:

- If the UE is executing a *From Point-to-Point (DCH) To Point-to-Multipoint (FACH)* type of MBMS Handover then the UE will switch channels (From Dedicated to Common) at some distance *after entering* the Coverage of the Point-to-Multipoint Cell. This will cause more interference to the Point-to-Point Cell since more power will be used in order to reach the UE at this distance, comparing with the power that would be used if the channel switching had been executed on the border of the Point-to-Multipoint Radio Bearer.
- If the UE is executing a *From Point-to-Multipoint (FACH) To Point-to-Point (DCH)* type of MBMS Handover, then the UE will switch channels (From Common to Dedicated) *after leaving* the Coverage of the Point-to-Multipoint Cell. Therefore, the UE will continue listening to the Point-to-Multipoint Radio Bearer even though that its received signal strength would not be strong enough to satisfy the QoS level requested.

Thus in order to maximize the overall system capacity while at the same time satisfying the QoS level requested, the Safety Distance should be estimated as accurately as possible. For the estimation of the *Safety Distance* value two formulas will be defined. The one corresponds to the case where the UE is moving from a *Point-to-Point* (Dedicated Resources) to *Point-to-Multipoint* (Common Resources) Radio Bearer and the other for the opposite case.

For the formulas definition, we will suppose that the UE during its mobility always knows its *Current position* $(x1, y1)$, its *Previous position* $(x1', y1')$, the *Position of the Point to Multipoint Base Station* $(x2, y2)$, and the *Speed* that it is moving. Since the position of the Point to Multipoint Base Station is fixed its coordinates might be already installed by the operator in the User Equipment's Universal Subscriber Identity Module (USIM) card. On the other hand, the Current and Previous position of the UE changes during the UE mobility. Also the Speed of the UE is dynamic, but it is easy to be estimated if the UE knows its Current and Previous Position and the time needed to move between these two.

There are various methods to use when aiming to find out the geographic position of a cellular terminal. The most important ones are [17]:

- Time of Arrival (TOA) Positioning
- Time Difference of Arrival (TDOA) Positioning
- Angle of Arrival (AOA) Positioning
- Reference Node Based Positioning (RNBP)
- Global Positioning System (GPS) – Most accurate method of all (1 – 3 meters error)

All the positioning methods described above were investigated and discussed in the 3GPP from a standardization point of view. As a result the following methods were selected for UMTS networks:

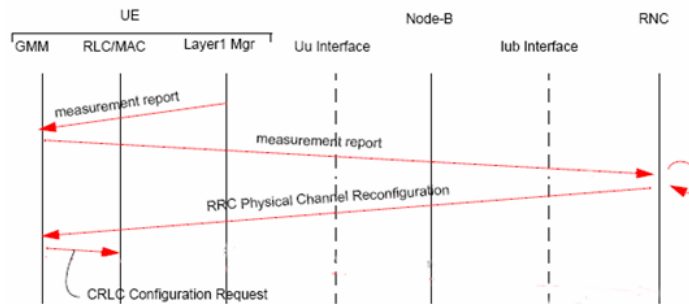
- Observed Time Difference of Arrival (OTDOA) positioning, which as the name suggests is based on the TDOA principle described above
- Assisted GPS positioning

4.2.2.1 Estimating the Handover Delay (Δt time)

The Handover delay (*Δt time*), that is the time needed from the time the handover is triggered until the UE starts listening to the new channel varies. Since it is difficult for the UE to estimate this value, the task of evaluating the Handover delay will be given to the RNC and it will be estimated periodically according to the current load in the Network and from previous times estimated for other UEs that executed a handover. Then this Handover Delay (Δt time) could be included, in the MCCH Channel (See Appendix B) of the appropriate MBMS Service and broadcasted to the UEs in the Cell. In order for this new feature to be included in the MCCH Channel, the MCCH must be enhanced. Due to the fact that the MCCH currently does not include this field, it should be enhanced in order to add one more field for the accommodation of this new parameter. Since this Δt time will be variable, the UEs that are on the move, can periodically retrieve this information from the MCCH Channel transmitted in the Cell in order to estimate as accurately as possible the *Safety Distance*.

According to the MBMS Handover case, the Handover signalling performed differs. For example, when a *From Point-to-Point (DCH) To Point-to-Multipoint (FACH)* MBMS Handover is executing, in order to estimate the total time needed from the time the

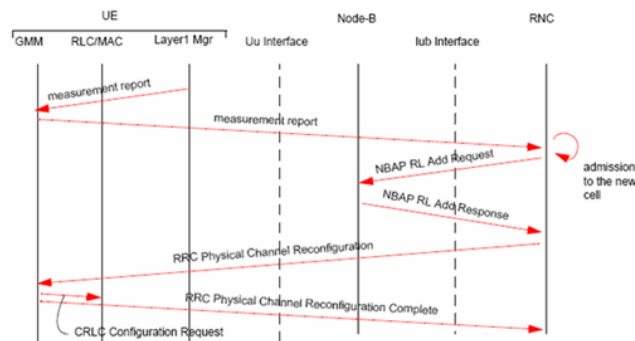
handover is triggered until the UE starts listening to Point to Multipoint Radio Bearer (FACH) in the new Cell, the Signalling illustrated in Figure 32 should be considered.



- Time needed for the Handover Measurement Report to be delivered to the RNC
- + Time needed for RNC to process the report
- + Time needed for RNC to establish a new Signalling Channel for the UE (Not shown)
- + Time needed for RRC Physical Channel Reconfiguration to be delivered to the UE
- + Time needed for UE to be reconfigured in order to receive the Common Channel.

Figure 32. From Point-to-Point (DCH) To Point-to-Multipoint (FACH) Signalling Analysis

On the other hand, in order to estimate the total time needed from the time the handover is triggered until the UE to start listening to the new Point to Point Radio Bearer (DCH) in the new Cell when a *From Point-to-Multipoint (FACH) To Point-to-Point (DCH)* MBMS Handover is executing, the Signalling illustrated in Figure 33 should be considered.



- Time needed for the Handover Measurement Report to be delivered to the RNC
- + Time needed for RNC to process the Report
- + Time needed for setting-up a connection between the RNC and the new Node B (Data & Signalling)
- + Time needed for RRC Physical Channel Reconfiguration to be delivered to the UE
- + Time needed for UE to be reconfigured in order to receive the Dedicated Channel.
- + Time needed for UE to send the RRC Physical Channel Reconfiguration Complete message to the RNC
- + Time needed for the RNC to start sending the MBMS data to the UE through the new Dedicated Channel.

Figure 33. From Point-to-Multipoint (FACH) To Point-to-Point (DCH) Signalling Analysis

4.2.2.2 Estimating the Direction of the UE (Angle ϕ)

Using the coordinates of the *Current* ($x1, y1$) and the *Previous* ($x1', y1'$) position of the UE and the coordinates of the *Position of the Point to Multipoint Base Station* ($x2, y2$) the *Direction* (Angle ϕ) of the UE can be estimated. As we have said, the Direction of the UE

is expressed as the angle ϕ that is created between the line that connects the Point to Multipoint Base Station with the Previous position of the UE and the line that that connects the Previous with the Current Position of the UE (See Figure 34 & Figure 35).

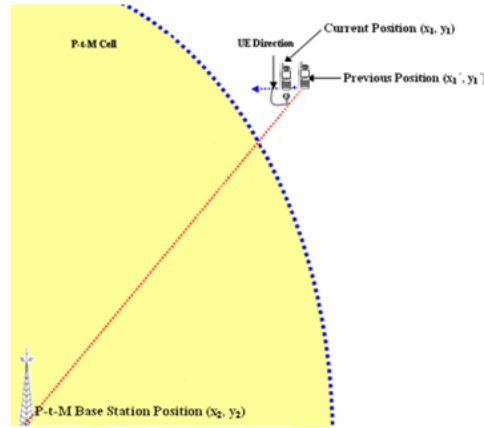


Figure 34. Estimating the Angle ϕ when the UE is moving from Dedicated to Common resources

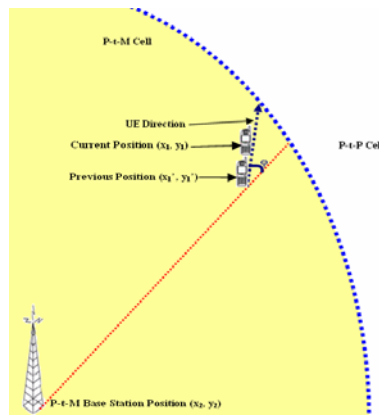


Figure 35. Estimating the Angle ϕ when the UE is moving from Common to Dedicated resources

In order to find the Angle ϕ we must first find the slope of these two lines that create this angle. These lines are:

- The line that connects the *Base Station* with the *Previous position* of the UE (**Line**)
- The line that connects the *Previous* with the *Current Position* of the UE (**Direction**)

Let's define the slope of **Line** with ***m1*** and the slope of **Direction** with ***m2***.

$$m1 = \frac{y1' - y1}{x1' - x1} \quad \& \quad m2 = \frac{y1' - y2}{x1' - x2}$$

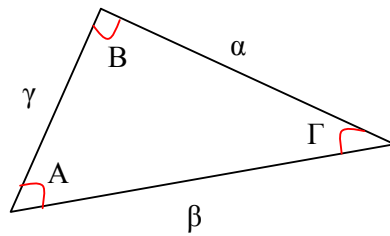
By knowing the slope of the two lines we can find the Angle ϕ , by using the following formulas.

$$\tan \varphi = \left| \frac{m_2 - m_1}{1 + m_1 m_2} \right| \Rightarrow \varphi = \arctan \left(\left| \frac{m_2 - m_1}{1 + m_1 m_2} \right| \right)$$

4.2.2.3 Safety Distance Definition Formulas

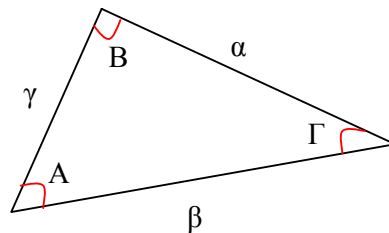
As we have said above, for the estimation of the *Safety Distance* value two formulas will be defined. The one corresponds to the case where the UE is moving from a *Point-to-Point* (Dedicated Resources) to *Point-to-Multipoint* (Common Resources) Radio Bearer and the other for the opposite case. In order to define these formulas trigonometry and more specifically the *Sine* and *Cosine Rules* are going to be used. The Sine and Cosine rules are described below.

Sine Rule Description:



$$\frac{a}{\sin A} = \frac{\beta}{\sin B} = \frac{\gamma}{\sin \Gamma}$$

Cosine Rule Description:



$$\alpha^2 = \beta^2 + \gamma^2 - 2 \cdot \beta \cdot \gamma \cdot \cos A$$

$$\beta^2 = \alpha^2 + \gamma^2 - 2 \cdot \alpha \cdot \gamma \cdot \cos B$$

$$\gamma^2 = \alpha^2 + \beta^2 - 2 \cdot \alpha \cdot \beta \cdot \cos \Gamma$$

4.2.2.3.1 From Dedicated to Common Resources Formula Definition

As we have seen in Section 4.2.1, for this type of MBMS Handover, the handover event should be triggered at some distance before the UE enters the coverage of the Point to Multipoint Cell in order for the UE to switch channel on the border of the Point to Multipoint cell.

Discussing the scenario below gives a good insight into the algorithm itself. In this scenario the UE is moving from a Cell that supports the MBMS service on Dedicated resources (Point-to-Point Radio Bearer) towards a Cell that supports the MBMS service on Common resources (Point-to-Multipoint Radio Bearer) as shown in Figure 36 and Figure 37. These figures also show how the CPICH (Common Pilot Channel) strengths of the Point to Multipoint Base Station evolve in time along with the general principles of the MBMS Handover.

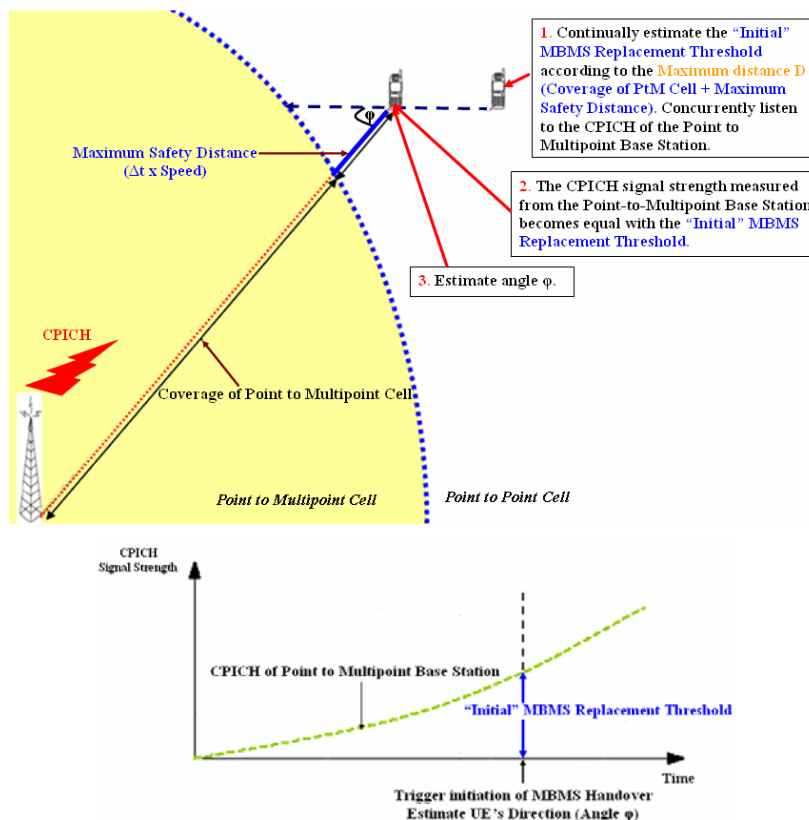


Figure 36. Moving from Dedicated to Common Resources: Safety Distance estimation 1

If the UE is moving some *Speed* and the *Handover Delay* is equal with Δt , then the UE will switch channels after it covers a $\Delta t \times \text{Speed}$ distance from the time the Handover is

triggered. This is also the *maximum* value that the Safety Distance can take. Since the Speed of the mobile user and the Handover delay caused are variable parameters the *Maximum Safety Distance* will vary while the mobile user is moving. Therefore the Maximum Safety Distance should be continually estimated by the UE during its mobility.

Now while the UE is moving towards the Point-to-Multipoint Cell, will continually estimate the *Initial "MBMS Replacement Threshold"* according to the *Maximum Distance D* (See Figure 36). The *Maximum Distance D* will be equal with the *Coverage of the Point to Multipoint Cell + Maximum Safety Distance*. At the same time, the UE will measure the CPICH signal strength received from the Point to Multipoint Base Station. When the measured CPICH signal strength becomes equal with the Initial "MBMS Replacement Threshold" the UE will be triggered to estimate its Direction (angle ϕ). If the angle ϕ is equal with 0° (Thus the UE is moving towards the Point to Multipoint Base Station), the Handover will be triggered immediately since the UE will reach the border after Speed $\times \Delta t$ distance.

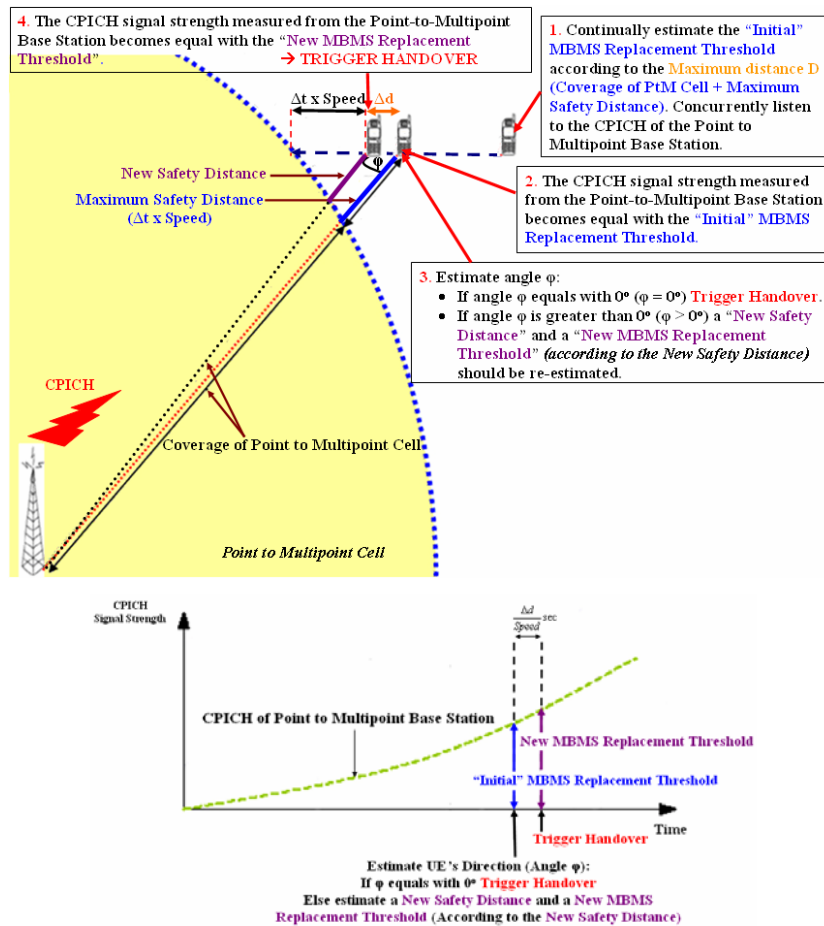


Figure 37. Moving from Dedicated to Common Resources: Safety Distance estimation 2

On the other hand, if the estimated angle φ is not equal with 0° the handover should not be immediately triggered. In this case the UE will have to cover a distance equal with $(\text{Speed} \times \Delta t) + \Delta d$ until it reaches the Border of the Point to Multipoint Cell. Since the UE will switch channels after a $\text{Speed} \times \Delta t$ distance, triggering the handover at that position, the channel switching will be performed at Δd distance outside of the Point to Multipoint Cell Coverage, resulting in a degrade on the quality of the received signal. So the UE will have to cover a Δd distance first before triggering the Handover. Therefore a *New Safety Distance* should be estimated, taking into consideration not only the Speed of the UE and the Handover Delay (Δt time), but also the UE's Direction in order for a *New MBMS Replacement Threshold* to be re-estimated based on the *New Distance D* (*Coverage of the P-t-M Cell + New Safety Distance*). After estimating the *New MBMS Replacement Threshold*, the UE will continue its trajectory and when the CPICH Signal Strength of the Point to Multipoint Base Station becomes equal with it the MBMS Handover will be triggered. The mathematical definition of the formula is illustrated in the following section.

4.2.2.3.1.1 Mathematical definition of the formula

In order to extract the formula that computes the “*New*” *Safety Distance* Figure 38 is going to be used. The steps followed in order to define the formula are described below.

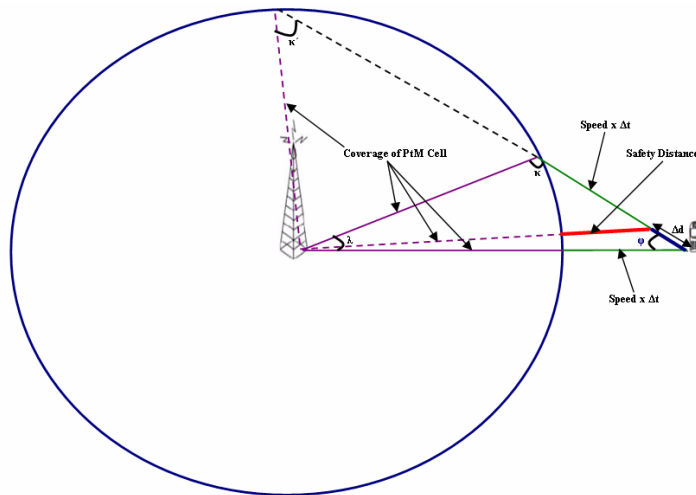


Figure 38. From Point-to-Point To Point-to-Multipoint Mathematical Model Schema

First we should find the distance Δd that the UE should cover before triggering the Handover. This distance will be estimated using the *Sine Rule*. The Sine Rule gives us the following:

$$\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\sin \kappa'} = \frac{\text{Coverage_of_PtM_Cell}}{\sin \varphi} = \frac{(\text{Speed} \times \Delta t) + \Delta d}{\sin \lambda}$$

According to the equation showed above we will first find the κ' , κ and λ angles.

$$\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\sin \kappa'} = \frac{\text{Coverage_of_PtM_Cell}}{\sin \varphi} \Rightarrow$$

$$\sin \kappa' = \frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi \Rightarrow$$

$$\kappa' = \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi\right)$$

Now that we have found the angle κ' we can easily find the κ angle.

$$\kappa = 180^\circ - \kappa' \Rightarrow$$

$$\kappa = 180^\circ - \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi\right)$$

The sum of λ , κ and φ angles of the triangle should be 180° .

$$\kappa + \lambda + \varphi = 180^\circ \Rightarrow \lambda = 180^\circ - (\varphi + \kappa) \Rightarrow$$

$$\lambda = 180^\circ - \left[\varphi + \left(180^\circ - \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi\right) \right) \right] \Rightarrow$$

$$\lambda = \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi\right) - \varphi$$

Now that we have found the angle λ we can find the Δd distance using the following.

$$\frac{\text{Coverage_of_PtM_Cell}}{\sin \varphi} = \frac{(\text{Speed} \times \Delta t) + \Delta d}{\sin \lambda} \Rightarrow$$

$$\Delta d = \frac{\text{Coverage_of_PtM_Cell} \times \sin \lambda}{\sin \varphi} - (\text{Speed} \times \Delta t) \Rightarrow$$

$$\Delta d = \frac{\text{Coverage_of_PtM_Cell} \times \sin \left[\arcsin\left(\frac{\text{Coverage_of_PtM_Cell} + (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi\right) - \varphi \right]}{\sin \varphi} - (\text{Speed} \times \Delta t)$$

By finding the Δd distance, we will use the **Cosine Rule** in order to find the **Safety Distance**. In the following formula we replaced **Speed x Δt** with the letter ***a***

$$(\text{Coverage_of_PtM_Cell} + \text{Safety_Distance})^2 = \Delta d^2 + (\text{Coverage_of_PtM_Cell} + a)^2 - 2 \times \Delta d \times (\text{Coverage_of_PtM_Cell} + a) \times \cos \varphi$$

$$\Rightarrow \text{Safety_Distance} = \sqrt{\Delta d^2 + (\text{Coverage_of_PtM_Cell} + a)^2 - 2 \times \Delta d \times (\text{Coverage_of_PtM_Cell} + a) \times \cos \varphi} - \text{Coverage_of_PtM_Cell}$$

4.2.2.3.2 From Common to Dedicated Resources Formula Definition

As we have seen in Section 4.2.1, for this type of MBMS Handover, the handover event should be triggered at some distance before the UE leaves the coverage of the Point to Multipoint Cell in order for the UE to switch channel on the border of the Point to Multipoint cell.

Discussing the scenario below gives a good insight into the algorithm itself. In this scenario the UE is moving from a Cell that supports the MBMS service on Common resources (Point-to-Multipoint Radio Bearer) towards a Cell that supports the MBMS service on Dedicated resources (Point-to-Point Radio Bearer) as shown in Figure 39 and Figure 40. These figures also show how the CPICH (Common Pilot Channel) strengths of the Point to Multipoint Base Station evolve in time along with the general principles of the MBMS Handover.

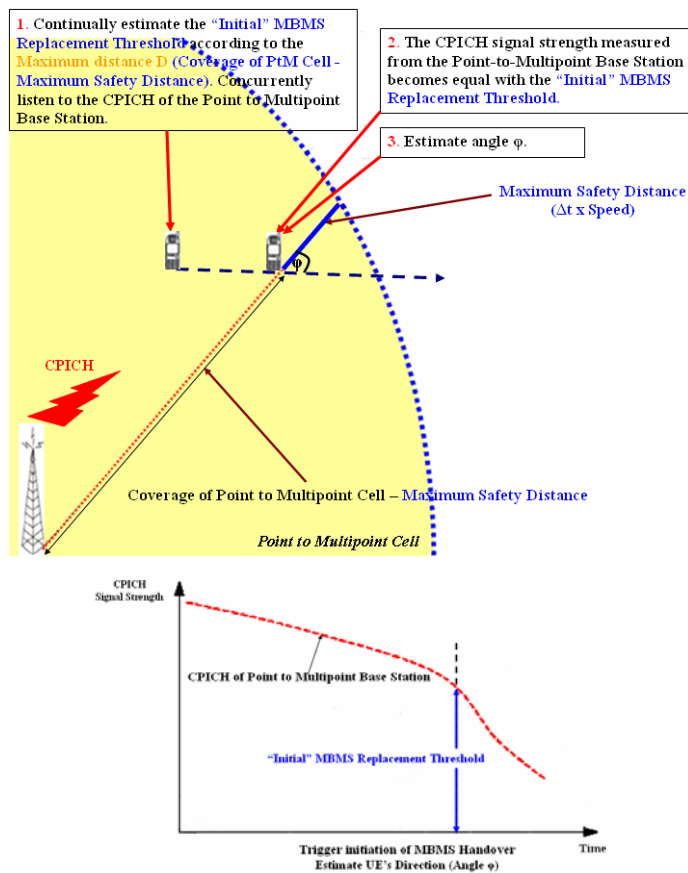


Figure 39. UE moving from Common to Dedicated resources: Safety Distance Estimation 1

If the UE is moving some *Speed* and the *Handover Delay* is equal with Δt , then the UE will switch channels after it covers a $\Delta t \times \text{Speed}$ distance from the time the Handover is triggered. This is also the *maximum* value that the Safety Distance can take. Since the Speed of the mobile user and the Handover delay caused are variable parameters the *Maximum Safety Distance* will vary while the mobile user is moving. Therefore the Maximum Safety Distance should be continually estimated by the UE during its mobility.

Now, while the UE is moving towards the Point-to-Point Cell will continually estimate the *Initial “MBMS Replacement Threshold”* according to the *Maximum Distance D* (See Figure 39). The *Maximum Distance D* will be equal with the *Coverage of the Point to Multipoint Cell - Maximum Safety Distance*. At the same time, the UE will measure the CPICH signal strength received from the Point to Multipoint Base Station. When the measured CPICH signal strength becomes equal with the Initial “MBMS Replacement Threshold” the UE will be triggered to estimate its Direction (angle φ). If the angle φ is equal with 0° (Which means that the UE is moving on the straight line that connects the Point to Multipoint Base Station with itself), the Handover will be triggered immediately since the UE will reach the border after $\text{Speed} \times \Delta t$ distance.

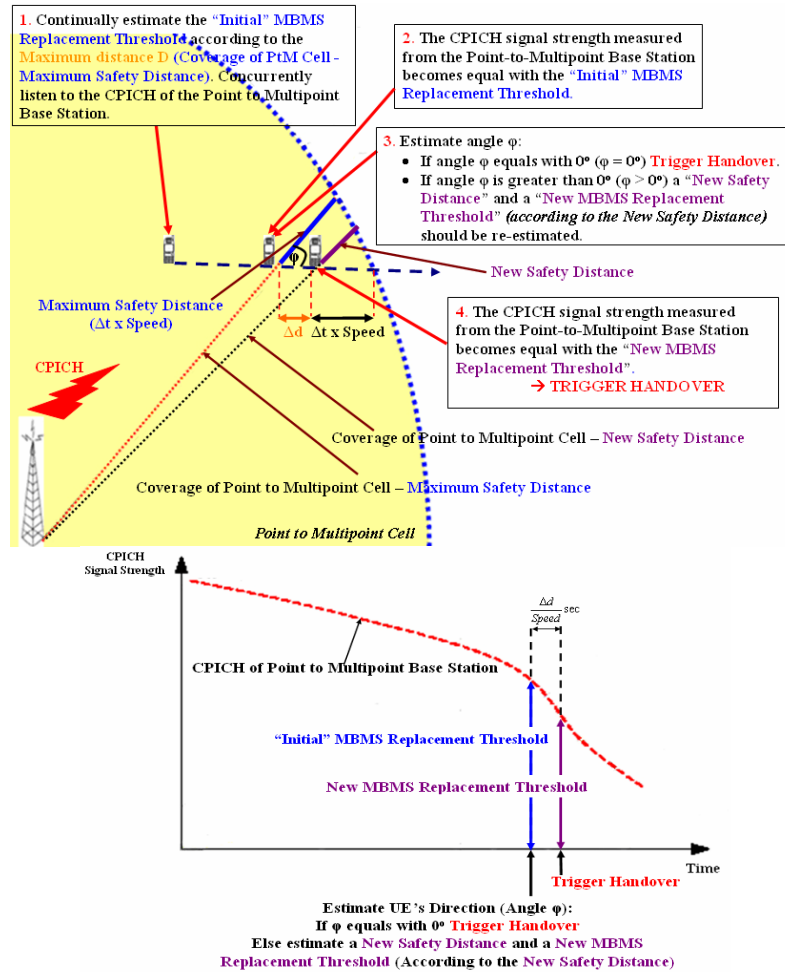


Figure 40. UE moving from Common to Dedicated resources: Safety Distance Estimation 2

On the other hand, if the estimated angle ϕ is not equal with 0° the handover should not be immediately triggered (See Figure 40). In this case the UE will have to cover a distance equal with $(\text{Speed} \times \Delta t) + \Delta d$ until it reaches the Border of the Point to Multipoint Cell. Since the UE will switch channels after a $\text{Speed} \times \Delta t$ distance, triggering the handover at that position, the channel switching will be performed at a Δd distance before the UE leaves the Coverage of the Point-to-Multipoint Cell, since the UE will manage to cover only $\text{Speed} \times \Delta t$ distance from the time the Handover is triggered until the switching from Common to Dedicated resources takes place. This will cause more interference in the Point-to-Point Cell since more power will be used in order to reach the UE at this distance, comparing with the power that would be used if the channel switching had been executed on the border of the Point-to-Multipoint Radio Bearer. So the UE will have to cover a Δd distance first before triggering the Handover. Therefore a *New Safety Distance* should be estimated, taking into consideration not only the Speed of the UE and the Handover Delay

(Δt time), but also the UE's Direction in order for a *New MBMS Replacement Threshold* to be re-estimated based on the *New Distance D (Coverage of the P-t-M Cell - New Safety Distance)*. After estimating the *New MBMS Replacement Threshold*, the UE will continue its trajectory and when the CPICH Signal Strength of the Point to Multipoint Base Station becomes equal with it the MBMS Handover will be triggered. The mathematical definition of the formula is illustrated in the following section.

4.2.2.3.2.1 Mathematical definition of the formula

In order to find the Safety Distance we must follow a number of steps. These steps are described below. First we should find the distance Δd that the UE should cover before triggering the Handover. The Δd distance will be estimated using the Sine Rule.

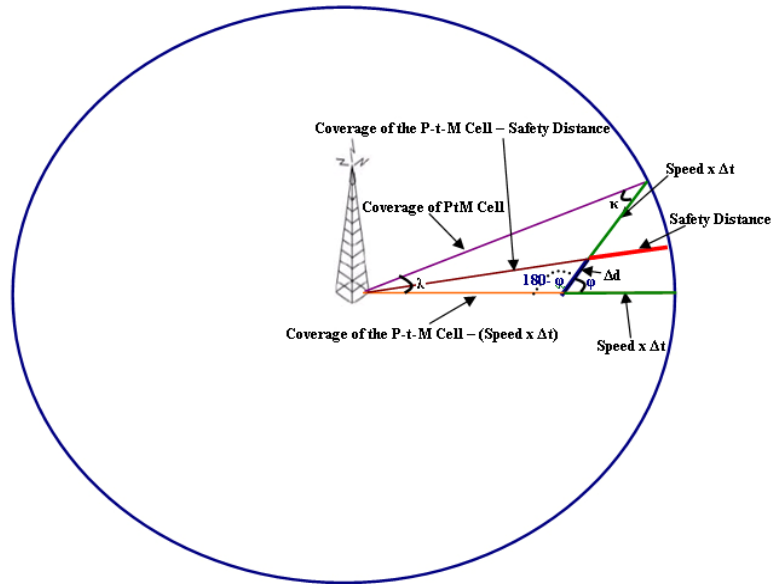


Figure 41. From Point-to-Multipoint To Point-to-Point Mathematical Model Schema

The Sine Rule gives us the following:

$$\frac{\text{Coverage_of_PtM_Cell} - (\text{Speed} \times \Delta t)}{\sin \kappa} = \frac{\text{Coverage_of_PtM_Cell}}{\sin(180 - \varphi)} = \frac{(\text{Speed} \times \Delta t) + \Delta d}{\sin \lambda}$$

According to the equation showed above we will first find the κ and λ angles.

$$\frac{\text{Coverage_of_PtM_Cell} - (\text{Speed} \times \Delta t)}{\sin \kappa} = \frac{\text{Coverage_of_PtM_Cell}}{\sin(180 - \varphi)} \Rightarrow$$

$$\sin \kappa = \frac{\text{Coverage_of_PtM_Cell} - (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin(180 - \varphi) \Rightarrow$$

$$\kappa = \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} - (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin(180 - \varphi)\right)$$

The sum of λ , κ and φ angles of the triangle should be 180° .

$$\kappa + \lambda + (180 - \varphi) = 180^\circ \Rightarrow \lambda = \varphi - \kappa \Rightarrow$$

$$\lambda = \varphi - \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} - (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin(180 - \varphi)\right)$$

Now that we have found the angle λ we can find the Δd distance using the following.

$$\frac{\text{Coverage_of_PtM_Cell}}{\sin(180 - \varphi)} = \frac{(\text{Speed} \times \Delta t) + \Delta d}{\sin \lambda} \Rightarrow$$

$$\Delta d = \frac{\text{Coverage_of_PtM_Cell} \times \sin \lambda}{\sin(180 - \varphi)} - (\text{Speed} \times \Delta t) \Rightarrow$$

$$\Delta d = \frac{\text{Coverage_of_PtM_Cell} \times \sin\left[\varphi - \arcsin\left(\frac{\text{Coverage_of_PtM_Cell} - (\text{Speed} \times \Delta t)}{\text{Coverage_of_PtM_Cell}} \times \sin \varphi\right)\right]}{\sin \varphi} - (\text{Speed} \times \Delta t)$$

Now that we have found the Δd distance, we will use the **Cosine Rule** in order to find the **Safety Distance**. In the following formula we replaced **Speed x At** with the letter **a**

$$(\text{Coverage_of_PtM_Cell} - \text{Safety_Dis tan ce})^2 = \Delta d^2 + (\text{Coverage_of_PtM_Cell} - a)^2 - 2 \times \Delta d \times (\text{Coverage_of_PtM_Cell} - a) \times \cos(180 - \varphi)$$

$$\Rightarrow$$

$$\text{Safety_Dis tan ce} = \text{Coverage_of_PtM_Cell} - \sqrt{\Delta d^2 + (\text{Coverage_of_PtM_Cell} - a)^2 + 2 \times \Delta d \times (\text{Coverage_of_PtM_Cell} - a) \times \cos \varphi}$$

4.2.3 Estimating the MBMS Replacement Threshold

Upon estimating the distance D, the ‘‘MBMS Replacement Threshold’’ will be estimated. In order to estimate this threshold value the *pathloss [20] between the UE and the Point to Multipoint Base Station* is the most important parameter that has to be considered. This pathloss can be estimated using the *propagation model* of the Cell environment defined by the International Telecommunications Union (ITU). For example, for a Pedestrian Outdoor propagation model, the pathloss (L_{PMax}) is estimated using the formula shown below. Where R is the distance between UE and Base Station in Km and *freq* is the Carrier frequency in MHz.

$$L_{PMax} = 40 \times \log_{10} R + 30 \times \log_{10} \text{freq} + 49$$

For *freq* equal with 2000 MHz used for UMTS band application and for R equal with the estimated distance D, the formula becomes as shown below:

$$L_{PMax} = 40 \times \log_{10} D + 148$$

By estimating the *pathloss* and by taking into consideration the initial CPICH Transmission Power of the Point to Multipoint Base Station (*tx_power*), the shadow fading value (*shadow_fade*), the band overlap value (*band_overlap*) and the Antenna Transmit (*tx_ant_gain*) and Receive (*rx_ant_gain*) gain values, the total downlink interference caused by other Node_Bs (*inoise*) and the in-band noise caused from background and thermal sources (*rx_bkgnoise*) the “MBMS Replacement threshold” is estimated. The “MBMS Replacement threshold” (RT) value is given using the formula shown below:

$$RT = 10 \times \log_{10} \left(\frac{tx_power \times band_overlap \times tx_ant_gain \times rx_ant_gain}{(inoise + rx_bkgnoise) \times pathloss \times shadow_fade} \right)$$

4.3 Problems & Solutions of the Proposed MBMS Handover Algorithm

Due to fact that with the proposed MBMS Handover Algorithm the switching of *Point-to-Point (DCH) to Point-to-Multipoint (FACH) Radio Bearer* and vice versa, is executed at the border of the Point-to-Multipoint Radio Bearer we have to considered the cases where the UE decides to immediately return back to the Old Cell. There are two cases that have to be considered when the Proposed MBMS Handovera Algorithm is used.

Problem 1: The UE is performing a *From Point-to-Multipoint (FACH) To Point-to-Point (DCH)* MBMS Handover. The UE upon leaving the Point-to-Multipoint Radio Bearer Coverage will stop listening to the Point-to-Multipoint Radio Bearer and start listening to the Point-to-Point Radio Bearer in the Target Cell. But what if the UE immediately decides to return back to the Point-to-Multipoint Cell? This would increase the interference in the Point-to-Point Cell (See Section 4.2.2, almost the same when the Safety Distance is underestimated) with also introducing unnecessary signalling load affecting the overall system capacity.

Solution: In order to prevent these problems, the UE upon start listening to the Point-to-Point Radio Bearer, will stop listening to the Point-to-Multipoint Radio Bearer but it will store the configuration of the Point-to-Multipoint Radio Bearer Locally. So in case that the UE decides to return back to the Point-to-Multipoint Cell it will send a message to the RNC to “freeze” the Point-to-Point Radio Bearer (See Problem 2 for the definition of “freeze”) and it will use the stored configuration of the Point-to-Multipoint Radio Bearer in order to

be reconfigured and be able to listen to the Point-to-Multipoint Radio Bearer again. So the interference will not be increased in the Point-to-Point Cell due to the fact that the time needed for the UE to be reconfigured will be negligible. Moreover, no signalling overhead will be caused in this case because the reconfiguration will take place locally in the UE. Thus with this solution the overall system capacity and the QoS level requested for the Service will not be affected.

Problem 2: The UE is performing *From Point-to-Point (DCH) To Point-to-Multipoint (FACH)* MBMS Handover. The UE upon entering the Coverage of the Point to Multipoint Cell will stop listening to the Point to Point Radio Bearer and start listening to the Point to Multipoint Radio Bearer in the new Cell. But what if immediately the UE decides to return back to the Point-to-Point Cell (leave from the Point to Multipoint Cell Coverage)? According to the 3GPP TR 25.922 the UE upon entering the Point-to-Multipoint Radio Bearer Coverage will stop listening to the Point-to-Point Radio Bearer and start listening to the Point to Multipoint Radio Bearer in the Target Cell. Moreover, the RNC will release the Point-to-Point Radio Bearer in the old Cell for new admissions. But what if the UE immediately decides to return back to the Point-to-Point Cell? This would decrease the quality of the connection (See Section 4.2.2, almost the same where the Safety Distance is underestimated) with also introducing unnecessary Signalling Load for the Request of a new Point-to-Point Radio Bearer affecting the overall system capacity.

Solution 2: In order to sort this problem, in order to smooth this signalling overhead, the UE upon handing over to the Point-to-Multipoint Radio Bearer will store the Configuration of the Point-to-Point Radio Bearer locally and the RNC instead of totally releasing the Point-to-Point Radio Bearer established for this UE in the Old Cell, it will just stop sending any data from this Radio Bearer (“freeze” this Radio Bearer), for a fixed amount of time (**Safety time**), associating the **IMSI** of the UE with it. Thus the Point-to-Point Radio Bearer in the Old Cell will not cause any interference to the Point-to-Point Cell since no power will be used to send any data through this Radio Bearer. At the time the RNC freezes the Point-to-Point Radio Bearer, a timer will be initiated (**Safety Timer**) counting the time that this Radio Bearer remains “frozen” - If the **Safety Timer** expires then the Point-to-Point Radio Bearer will be released for new admissions. If the UE decides to return back to the Point-to-Point Cell, it will sent to the RNC a message requesting to receive the MBMS data from the Point-to-Point Radio Bearer. This message will include

the **IMSI** of the UE along with the **Radio_Bearer_ID** of the “frozen” Point-to-Point Radio Bearer. If the message is received from the RNC before the **Safety Timer** expires, it will respond to the UE indicating that the “frozen” Point-to-Point Radio Bearer will be activated again and the RNC will start sending the MBMS data through it. The UE upon receiving this response from the RNC it will be reconfigured using the Point-to-Point Radio Bearer Configuration stored locally, in order to stop listening to the Point-to-Multipoint Radio Bearer and start listening again to the reactivated Point-to-Point Radio Bearer. So the quality of the connection will not be decreased since the time needed for the UE to be reconfigured will be negligible. Moreover, the overhead caused here will be negligible without affecting the total capacity of the System (Only two messages are used with small overhead).

Chapter 5

5 Performance Evaluation

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5.1 Introduction

Network *Capacity* and *Coverage* are vital parameters in order to measure Network Performance. When the uplink and the downlink coverage are compared it can be said that the main coverage constraint lies in the uplink direction. This is because the transmission power used in the mobile stations is significantly lower than those used in the Base Station. Since the MBMS is a Point-to-Multipoint service in which data is transmitted from a single source entity to multiple recipients in the *Downlink direction*, coverage will not be considered as a vital parameter of performance evaluation of the Proposed MBMS Handover Algorithm. Therefore the Network Capacity will be considered as the most important parameter to evaluate the proposed scheme.

Due to the interference determined nature of capacity in CDMA networks the available capacity per cell is not hard limited by the number of channels but determined by the total amount of *interference* in the system. The phenomenon where the capacity is limited by the amount of interference in the air interface, it is called Soft Capacity. Because the Base Station transmits to all the users on the same frequency, internal interference generated by the system is the most significant factor in determining system capacity and call quality. The transmit power that the Base Station uses for each user to be reached must be reduced to limit interference, however, the power should be enough to maintain the required E_c/N_0 (Signal to Noise ratio) for a satisfactory call quality.

The proposed MBMS Handover Algorithm can provide significant enhancement to the downlink performance by reducing the interference caused in the Point-to-Point Cells and achieving less power consumption per subscriber. This will release the Point to Point Base Station power for servicing more users, resulting in the enhancement of the overall system capacity while also maintaining a satisfactory call quality.

For the performance evaluation of the proposed scheme OPNET Modeller 11.0.A was used. As OPNET does not enable load calculations using Erlangs, we evaluated the performance of the proposed MBMS Handover Algorithm by comparing the amount of the total downlink power that becomes available when the proposed scheme is used compared to the current Handover Algorithm. Having seen that the power used for Common Resources is not affected by the number or the position of the UEs in the Cell, the evaluation will be focused on the Point to Point Cells.

In the following section, the Scenarios used for the evaluation of the proposed MBMS Handover are described and the results obtained from each scenario are illustrated.

5.2 Scenarios Description & Performance Evaluation

During this project a total of 11 simulation series were built and run in order to evaluate the performance evaluation of the Proposed MBMS Handover Algorithm. These scenarios were built in order to draw conclusions about the feasibility of the Proposed Scheme and its effect on the overall system Capacity when the UE is performing an MBMS Handover. The description of the scenarios and the results obtained are illustrated in the Sections below.

5.2.1 Scenario 1: From Dedicated to Common Resources (Angle $\phi = \sim 0^\circ$)

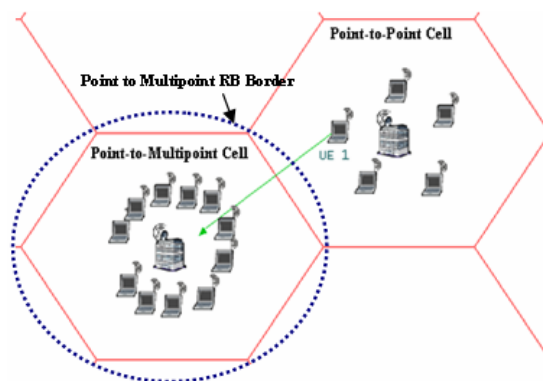


Figure 42. Moving from Dedicated to Common Resources (Angle $\phi = \sim 0^\circ$)

Scenario 1 shown in Figure 42 considers the case where UE 1 is moving from a Point-to-Point Cell (Dedicated Resources) towards a Point-to-Multipoint Cell (Common Resources). In this scenario all the other mobile terminals are static. UE 1 is following a trajectory that is moving towards the Point to Multipoint Base Station (Angle $\varphi = \sim 0^\circ$) and receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. The distance between the two Base Stations is about ~ 1680 meters. For this scenario three instances have been simulated (Low, Medium & High Load), with different number of users at different positions in the Point to Point Cell. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained for each instance are presented below.

5.2.1.1 Simulation Results: Current Vs Proposed Handover Algorithm

Instance 1: Low load in the Point to Point Cell (Figure 43- Figure 46)

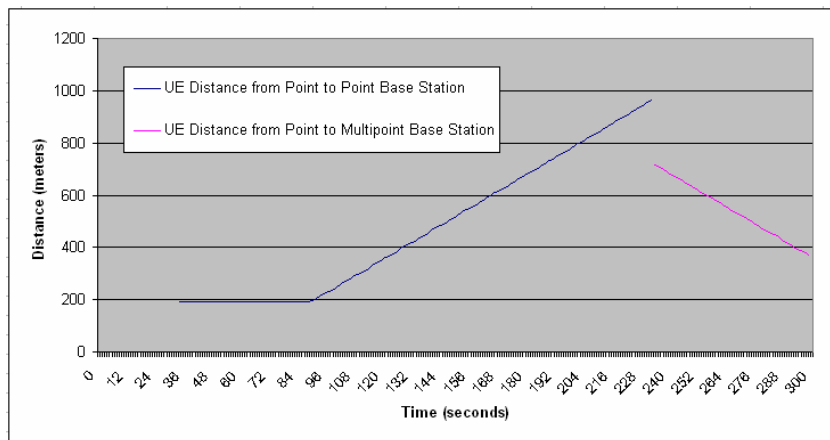


Figure 43. UE Distance from the two Base Stations (Scenario 1: Low Load – Current Handover Algorithm)

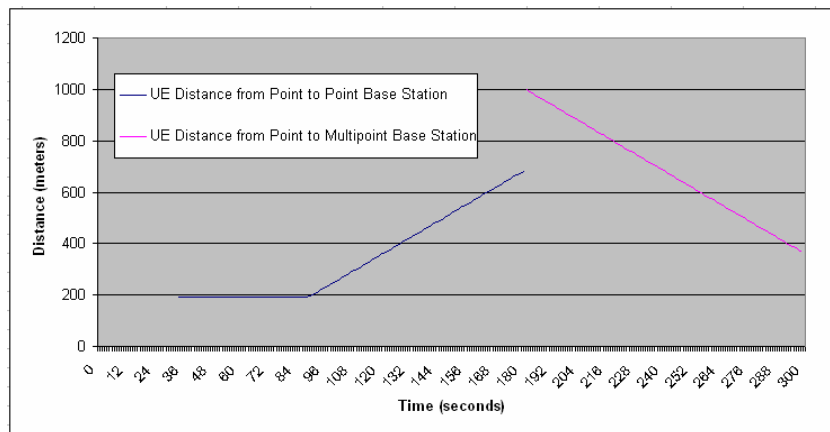


Figure 44. UE Distance from the two Base Stations (Scenario 1: Low Load – Proposed Handover Algorithm)

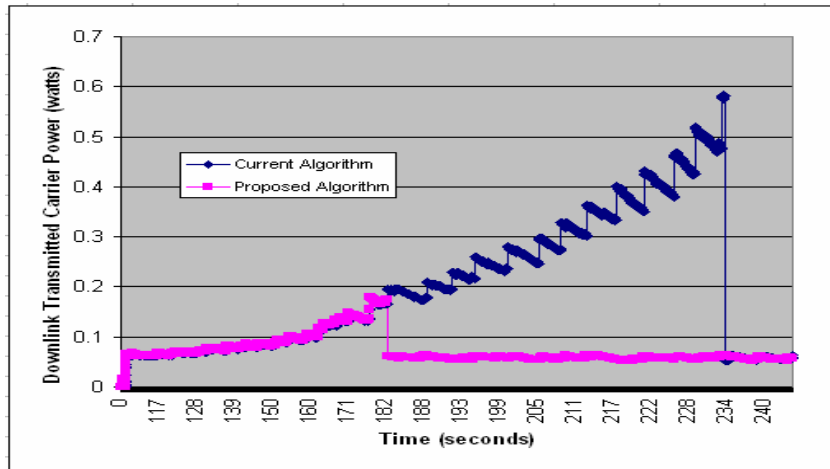


Figure 45. Total Downlink transmitted power used in Point to Point Cell (Scenario 1: Low Load)

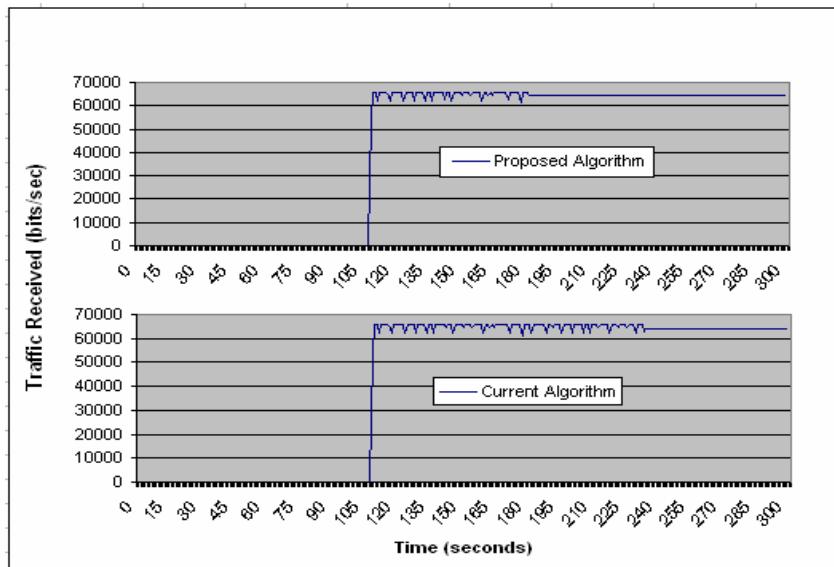


Figure 46. Traffic Received (Scenario 1: Low Load)

From the results shown above (Figure 43- Figure 46) the following observations have been made for Instance 1 of Scenario 1:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 0.59 watts
- Proposed MBMS Handover Algorithm: 0.19 watts (68% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm

- 964 meters from Point to Point Base Station
 - 717 meters from the Point to Multipoint Base Station
- Proposed MBMS Handover Algorithm:
 - 683 meters from the Point to Point Base Station
 - 998 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 233 second
 - Proposed MBMS Handover Algorithm: 182 second (Releasing Resources 51 seconds sooner)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

Instance 2: Medium load in the Point to Point Cell (Figure 47- Figure 50)

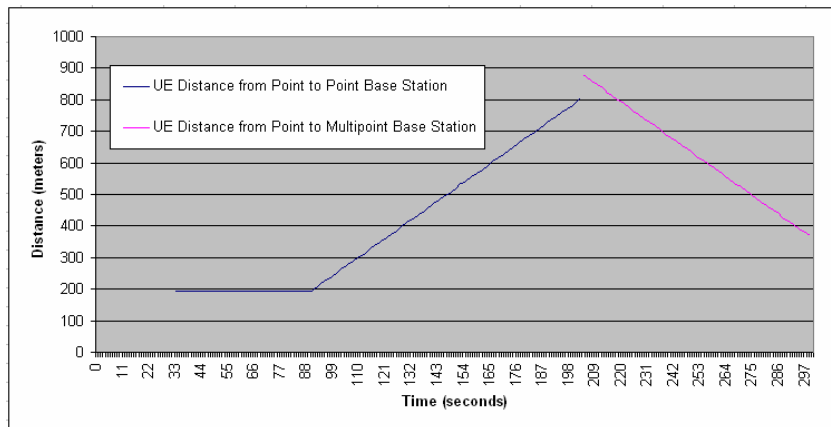


Figure 47. UE Distance from the two Base Stations (Scenario 1: Medium Load – Current Handover Algorithm)

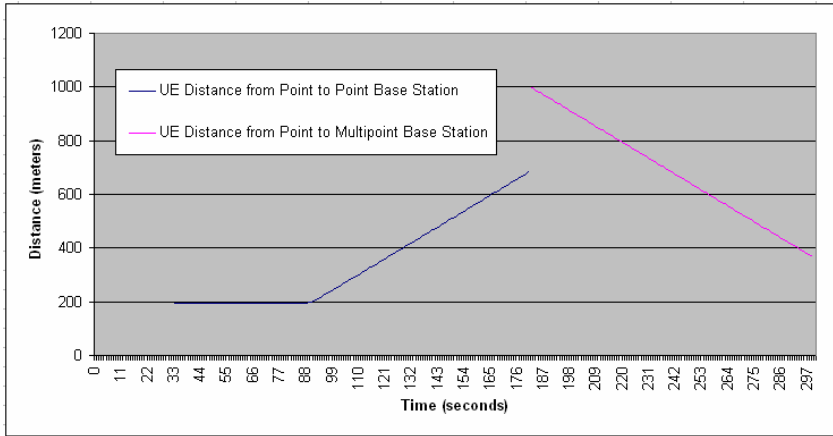


Figure 48. UE Distance from the two Base Stations (Scenario 1: Medium Load – Proposed Handover Algorithm)

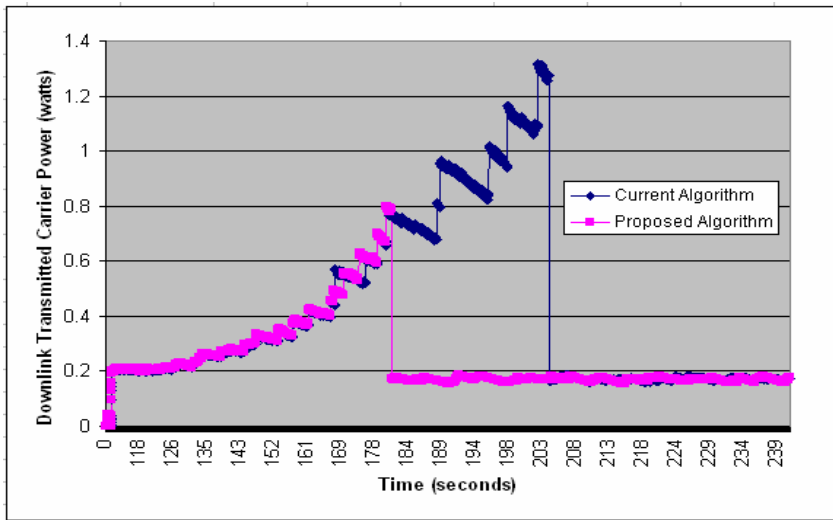


Figure 49. Total Downlink transmitted power used in Point to Point Cell (Scenario 1: Medium Load)

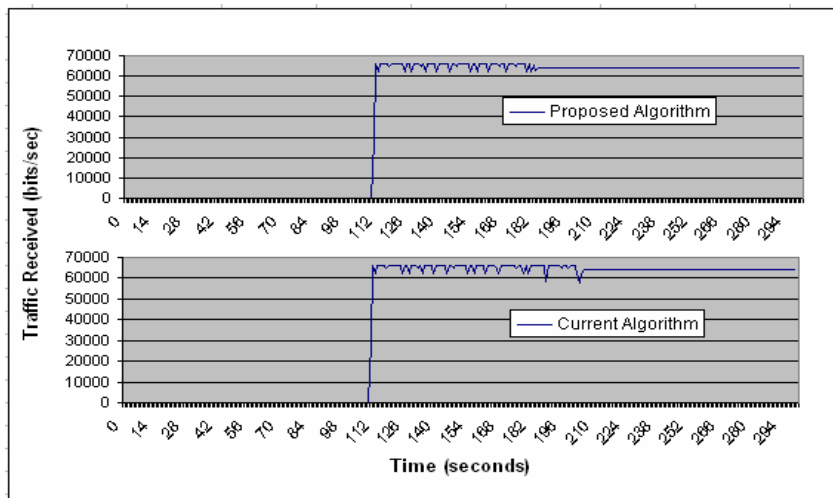


Figure 50. Traffic Received (Scenario 1: Medium Load)

From the results shown above (Figure 47- Figure 50) the following observations have been made for Instance 2 of Scenario 1:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 1.31 watts
- Proposed MBMS Handover Algorithm: 0.82 watts (38% decrease)

Handover Execution:

- Distance from Point-to-Point Base Station:
 - Current Handover Algorithm
 - 804 meters from Point to Point Base Station
 - 877 meters from the Point to Multipoint Base Station
 - Proposed MBMS Handover Algorithm:
 - 684 meters from the Point to Point Base Station
 - 997 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 204 second
 - Proposed MBMS Handover Algorithm: 182 second (Releasing Resources 22 seconds sooner)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

Instance 3: High load in the Point to Point Cell (Figure 51 - Figure 54)

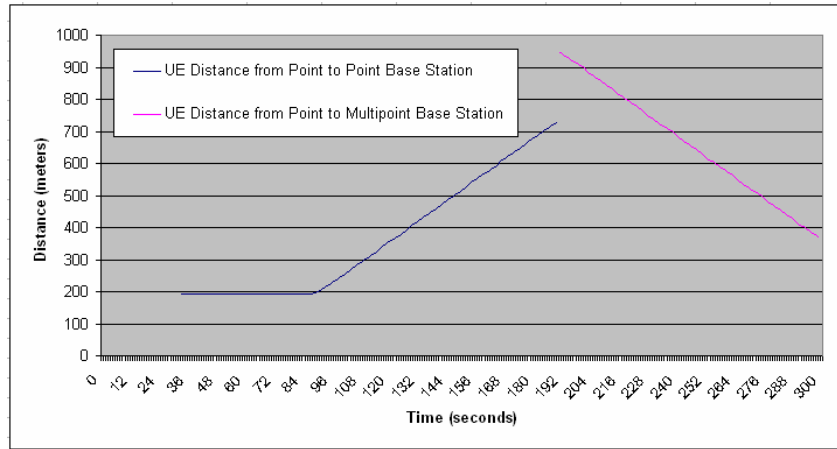


Figure 51. UE Distance from the two Base Stations (Scenario 1: High Load – Current Handover Algorithm)

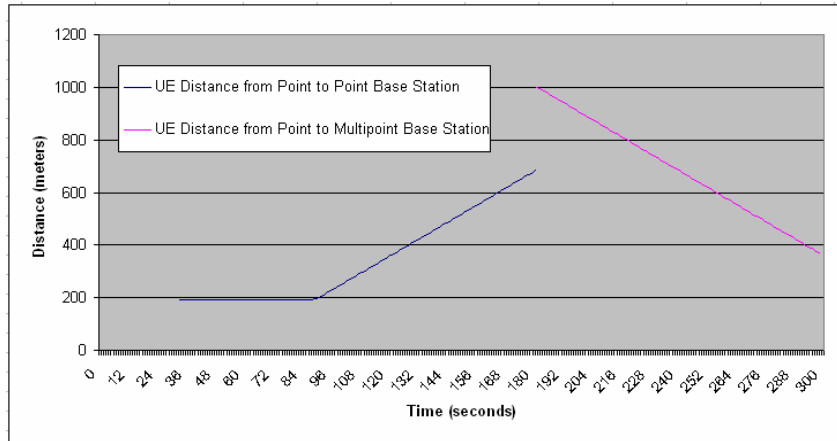


Figure 52. UE Distance from the two Base Stations (Scenario 1: High Load – Proposed Handover Algorithm)

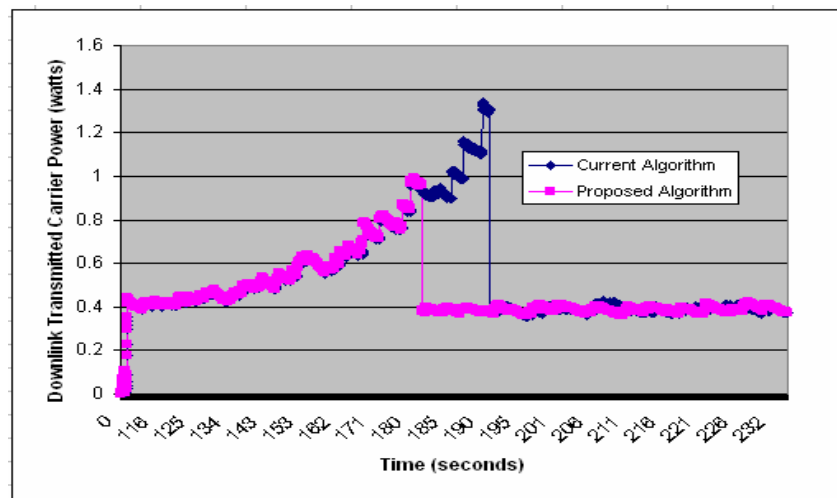


Figure 53. Total Downlink transmitted power used in Point to Point Cell (Scenario 1: High Load)

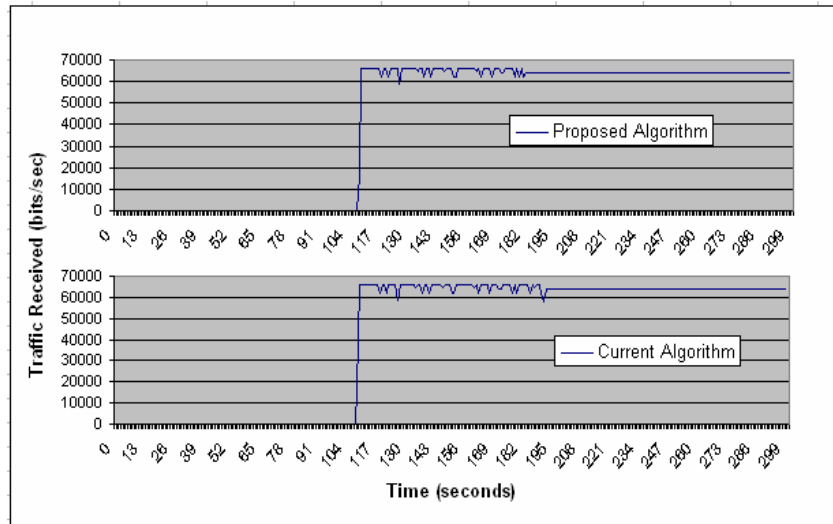


Figure 54. Traffic Received (Scenario 1: High Load)

From the results shown above (Figure 51 - Figure 54) the following observations have been made for Instance 3 of Scenario 1:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 1.37 watts
- Proposed MBMS Handover Algorithm: 1.01 watts (29% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 732 meters from Point to Point Base Station
 - 949 meters from the Point to Multipoint Base Station
 - Proposed MBMS Handover Algorithm:
 - 682 meters from the Point to Point Base Station
 - 999 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 191 second
 - Proposed MBMS Handover Algorithm: 182 second (Releasing Resources 9 seconds sooner)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

5.2.2 Scenario 2: From Dedicated to Common Resources (Angle $\phi > 0^\circ$)

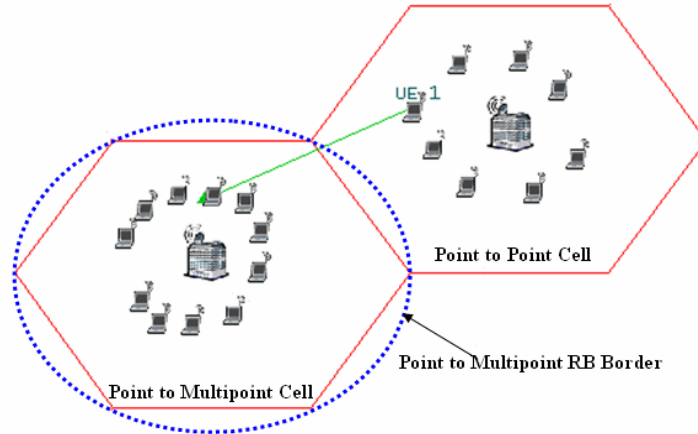


Figure 55. Moving from Dedicated to Common Resources (Angle $\phi > 0^\circ$)

Scenario 2 shown in Figure 55 considers the case where UE 1 is moving from a Point-to-Point Cell (Dedicated Resources) towards a Point-to-Multipoint Cell (Common Resources) but in this case the UE is not moving towards the Point to Multipoint Base Station (Angle $\phi > 0^\circ$). In this scenario all the other mobile terminals are static. UE 1 is following a trajectory as shown in the figure above and receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. The distance between the two Base Stations is about ~1770 meters. For this scenario two instances have been simulated (Medium & High Load), with different number of users at different positions in the Point to Point Cell. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained for each instance are presented below:

5.2.2.1 Simulation Results: Current Vs Proposed Handover Algorithm

Instance 1: Medium load in the Point to Point Cell (Figure 56 - Figure 59)

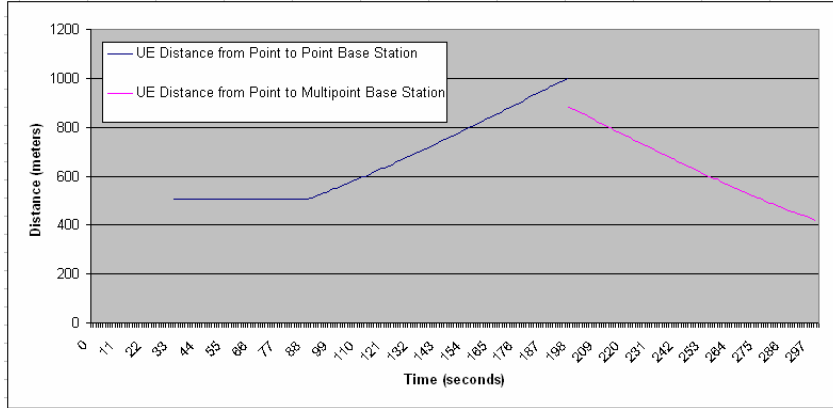


Figure 56. UE Distance from the two Base Stations (Scenario 2: Medium Load – Current Handover Algorithm)

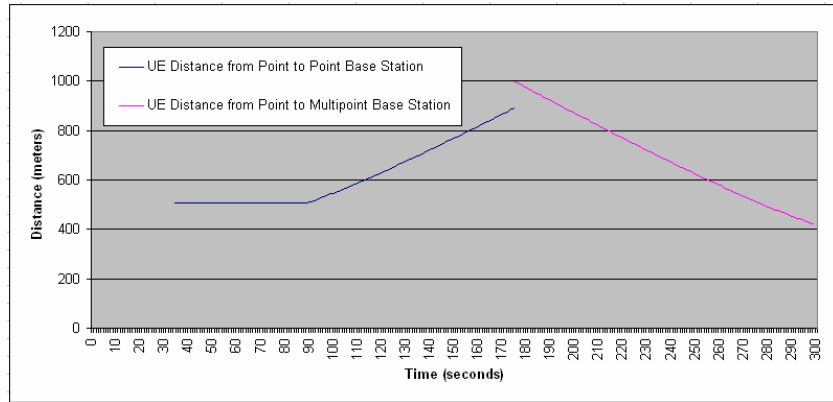


Figure 57. UE Distance from the two Base Station (Scenario 2: Medium Load –Proposed Handover Algorithm)

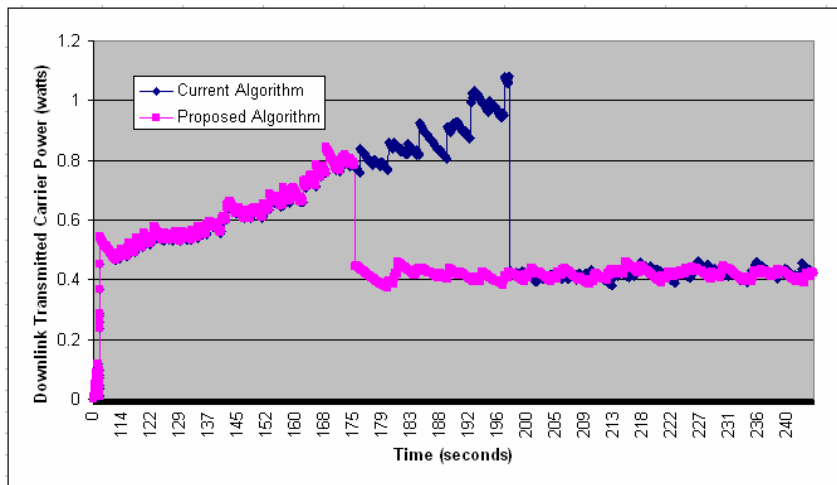


Figure 58. Total Downlink transmitted power used in Point to Point Cell (Scenario 2: Medium Load)

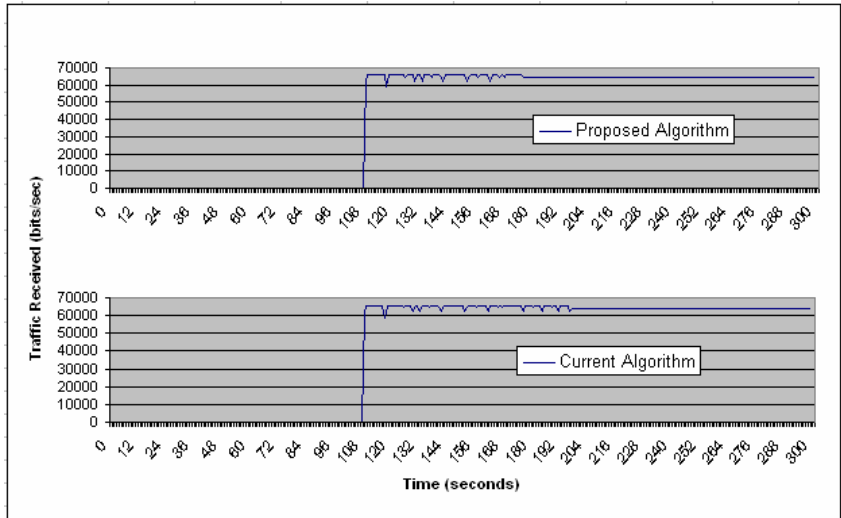


Figure 59. Traffic Received (Scenario 2: Medium Load)

From the results shown above (Figure 56 - Figure 59) the following observations have been made for Instance 1 of Scenario 2:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 1.125 watts
- Proposed MBMS Handover Algorithm: 0.873 watts (23% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 1002 meters from Point to Point Base Station
 - 886 meters from the Point to Multipoint Base Station
 - Proposed MBMS Handover Algorithm:
 - 890 meters from the Point to Point Base Station
 - 998 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 197 second
 - Proposed MBMS Handover Algorithm: 175 second (Releasing Resources 22 seconds sooner)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

Instance 2: High load in the Point to Point Cell (Figure 60 - Figure 63)

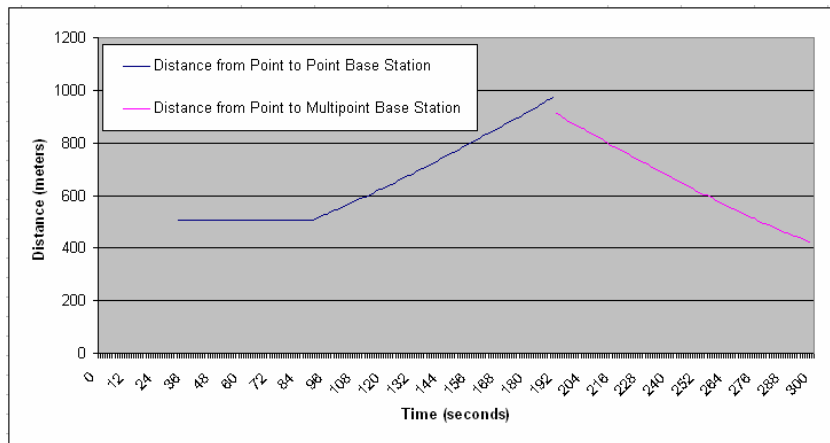


Figure 60. UE Distance from the two Base Stations (Scenario 2: High Load – Current Handover Algorithm)

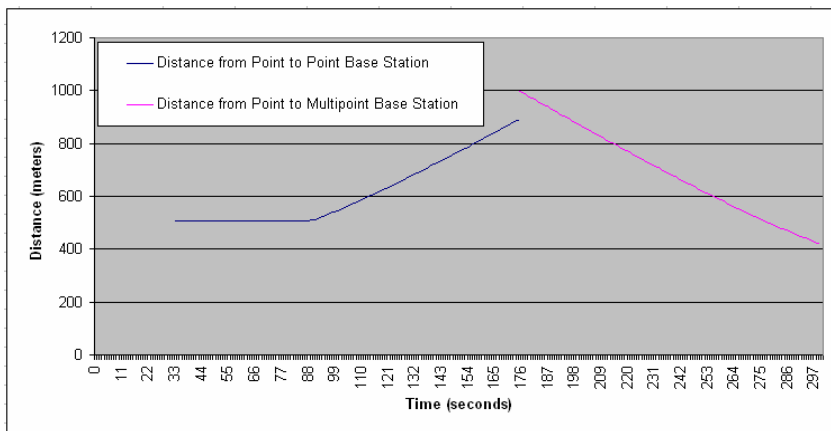


Figure 61. UE Distance from the two Base Stations (Scenario 2: High Load – Proposed Handover Algorithm)

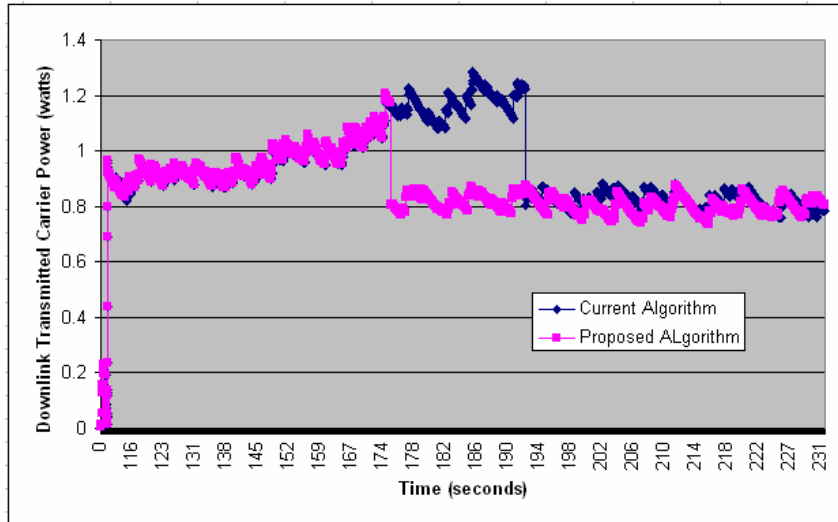


Figure 62. Total Downlink transmitted power used in Point to Point Cell (Scenario 2: High Load)

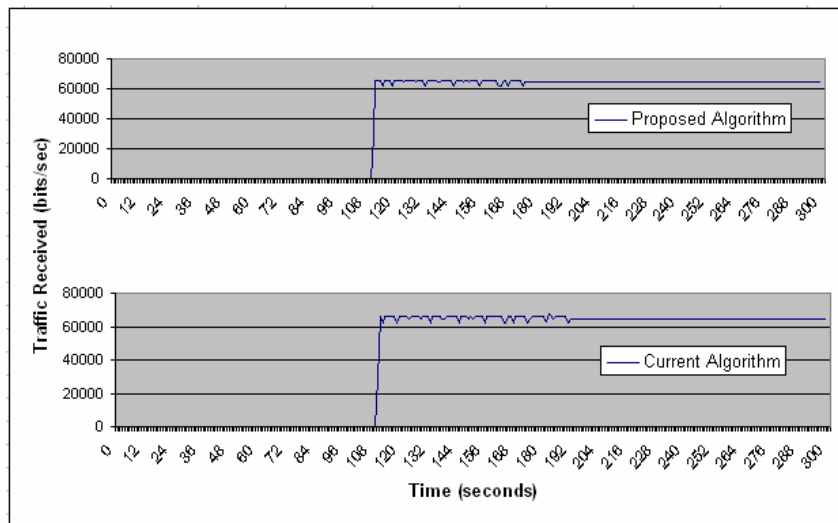


Figure 63. Traffic Received (Scenario 2: High Load)

From the results shown above (Figure 56 - Figure 59) the following observations have been made for Instance 2 of Scenario 2:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 1.29 watts
- Proposed MBMS Handover Algorithm: 1.23 watts (5% decrease)

Handover Execution:

- Distance from Point-to-Point Base Station:
 - Current Handover Algorithm

- 972 meters from Point to Point Base Station
- 916 meters from the Point to Multipoint Base Station
- Proposed MBMS Handover Algorithm:
 - 890 meters from the Point to Point Base Station
 - 998 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 191 second
 - Proposed MBMS Handover Algorithm: 175 second (Releasing Resources 16 seconds sooner)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

5.2.3 Scenario 3: From Common to Dedicated Resources (Angle $\phi \approx 0^\circ$)

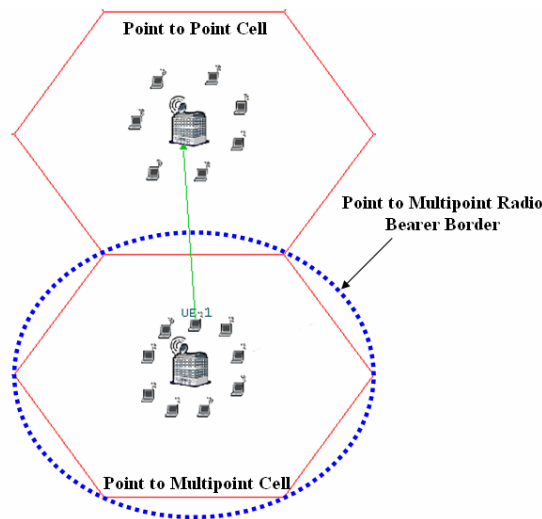


Figure 64. Moving from Common to Dedicated Resources (Angle $\phi \approx 0^\circ$)

Scenario 3 shown in Figure 64, considers the case where UE 1 is moving from a Point-to-Multipoint Cell (Common Resources) towards a Point-to-Point Cell (Dedicated Resources) and the UE is moving on the straight line that connects the Point to Multipoint Base Station with the UE (Angle $\phi = \sim 0^\circ$). In this scenario all the other mobile terminals are static. UE 1 is following a trajectory as shown in the figure above, and receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. The

distance between the two Base Stations is about ~1660 meters. For this scenario three instances have been simulated (Low, Medium & High Load), with different number of users at different positions in the Point to Point Cell. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained from each instance are presented below:

5.2.3.1 Simulation Results: Current Vs Proposed Handover Algorithm

Instance 1: Low load in the Point to Point Cell (Figure 65 - Figure 68)

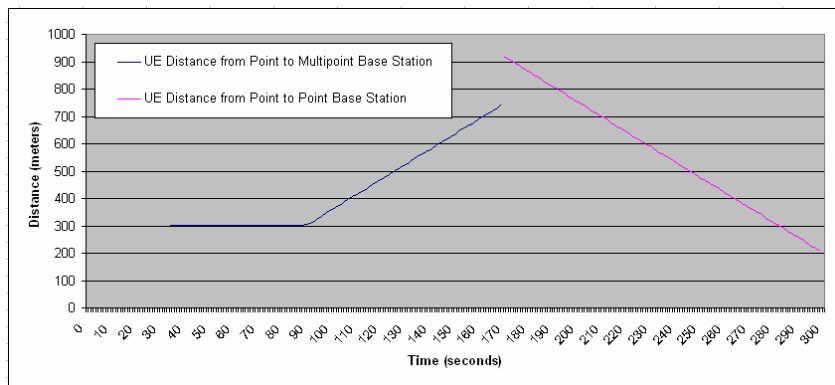


Figure 65. UE Distance from the two Base Stations (Scenario 3: Low Load – Current Handover Algorithm)

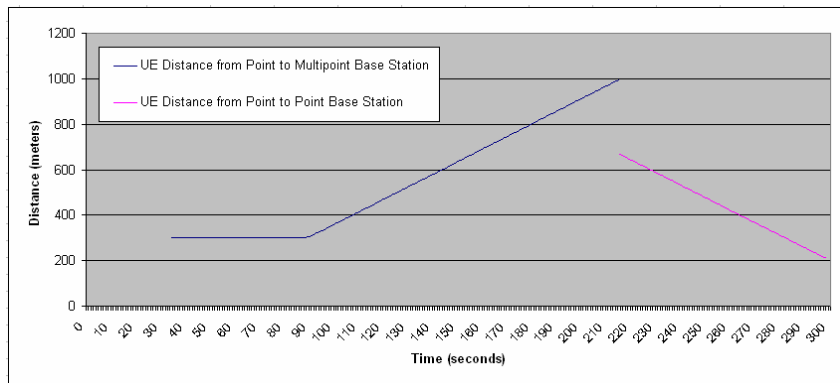


Figure 66. UE Distance from the two Base Stations (Scenario 3: Low Load – Proposed Handover Algorithm)

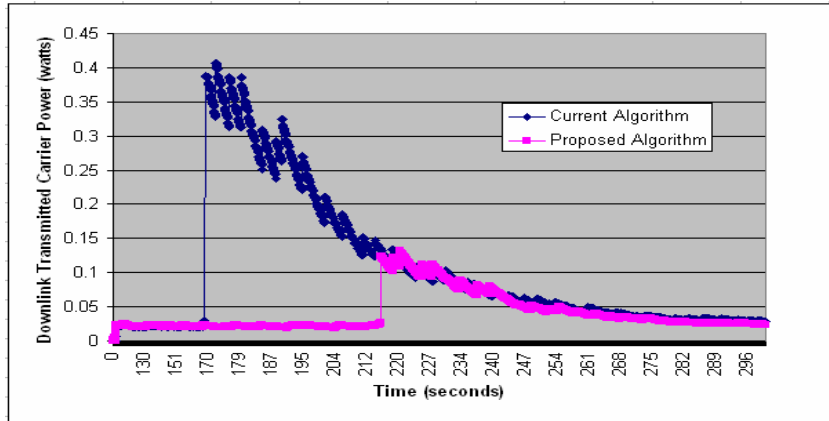


Figure 67. Total Downlink transmitted power used in Point to Point Cell (Scenario 3: Low Load)

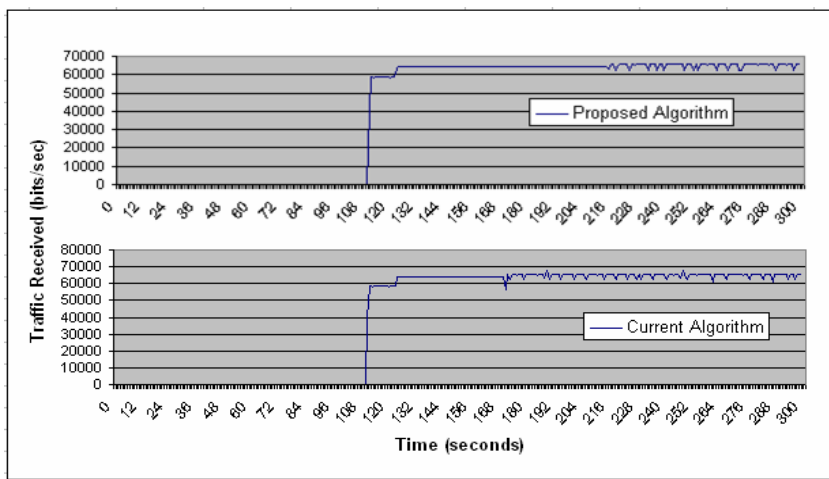


Figure 68. Traffic Received (Scenario 3: Low Load)

From the results shown above (Figure 65 - Figure 68) the following observations have been made for Instance 1 of Scenario 3:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 0.41 watts
- Proposed MBMS Handover Algorithm: 0.13 watts (67% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 918 meters from Point to Point Base Station
 - 745 meters from the Point to Multipoint Base Station

- Proposed MBMS Handover Algorithm:
 - 665 meters from the Point to Point Base Station
 - 998 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 168 second
 - Proposed MBMS Handover Algorithm: 214 second (Allocating Resources 46 seconds later)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

Instance 2: Medium load in the Point to Point Cell (Figure 69 - Figure 72)

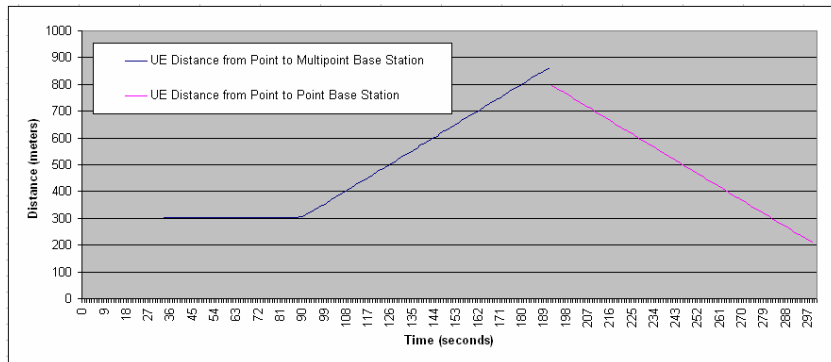


Figure 69. UE Distance from the two Base Stations (Scenario 3: Medium Load – Current Handover Algorithm)

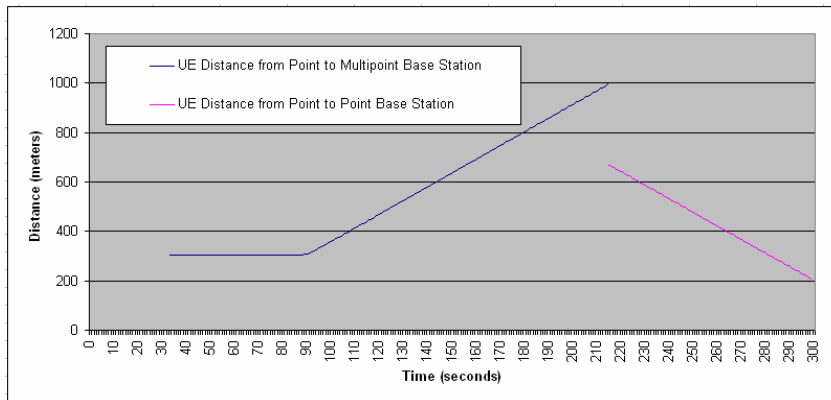


Figure 70. UE Distance from the two Base Stations (Scenario 3: Medium Load – Proposed Handover Algorithm)

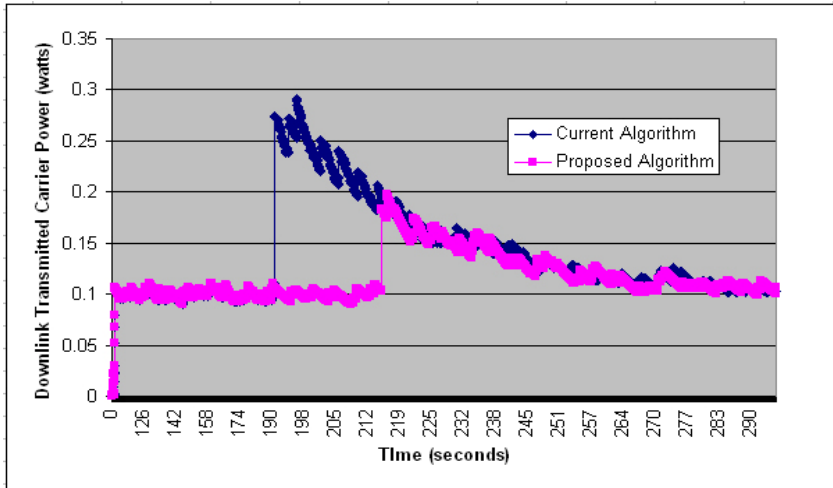


Figure 71. Downlink transmitted power used in Point to Point Cell (Scenario 3: Medium Load)

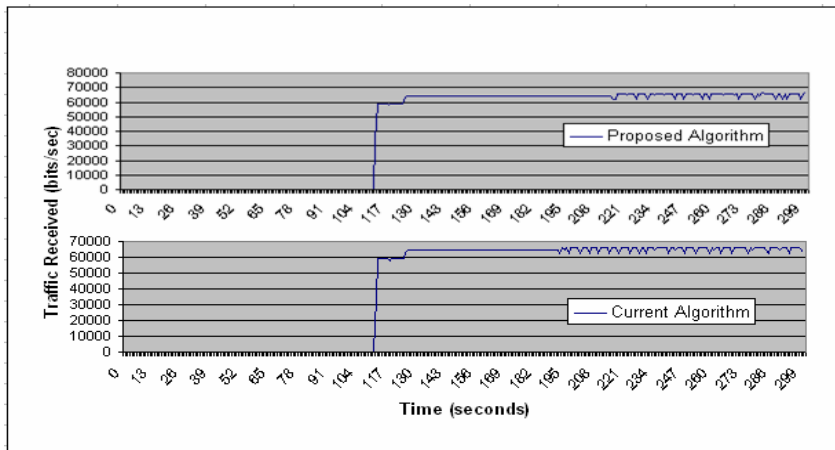


Figure 72. Traffic Received (Scenario 3: Medium Load)

From the results shown above (Figure 69 - Figure 72) the following observations have been made for Instance 2 of Scenario 3:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 0.291 watts
- Proposed MBMS Handover Algorithm: 0.2 watts (32% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 799 meters from Point to Point Base Station
 - 864 meters from the Point to Multipoint Base Station

- Proposed MBMS Handover Algorithm:
 - 666 meters from the Point to Point Base Station
 - 997 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 190 second
 - Proposed MBMS Handover Algorithm: 214 second (Allocating Resources 24 seconds later)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

Instance 3: High load in the Point to Point Cell (Figure 73 - Figure 76)

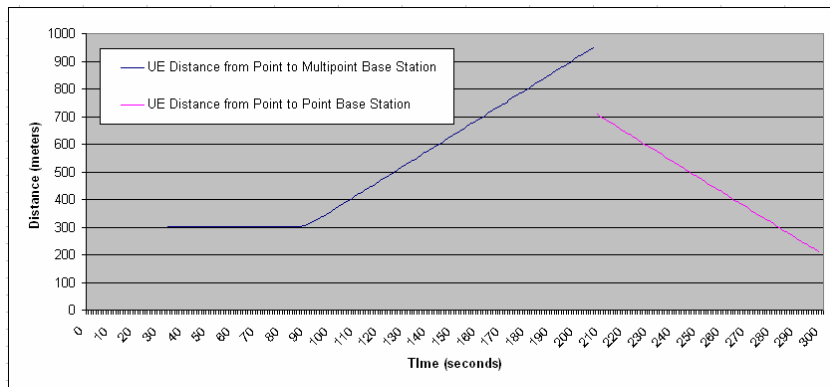


Figure 73. UE Distance from the two Base Stations (Scenario 3: High Load – Current Handover Algorithm)

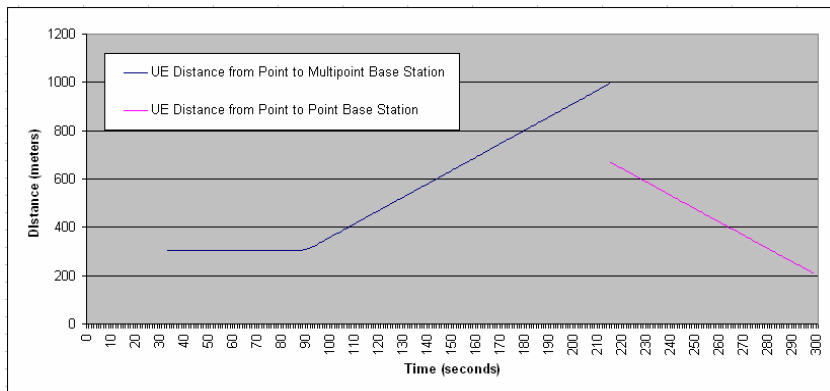


Figure 74. UE Distance from the two Base Stations (Scenario 3: High Load – Proposed Handover Algorithm)

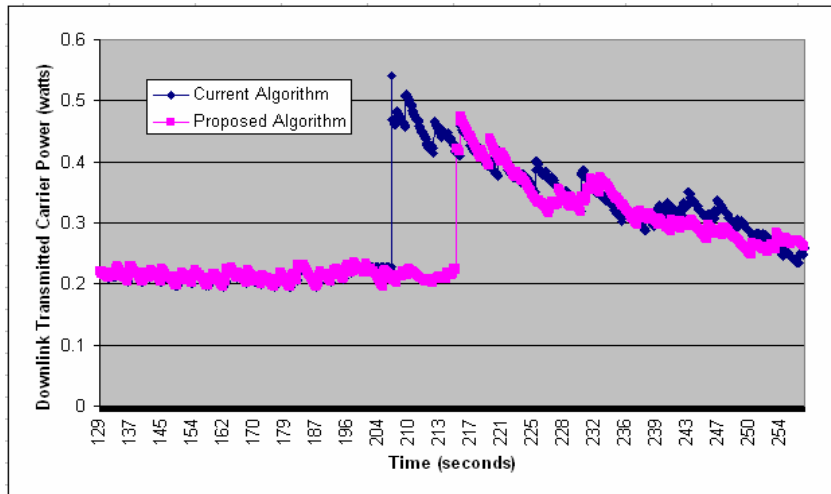


Figure 75. Downlink transmitted power used in Point to Point Cell (Scenario 3: High Load)

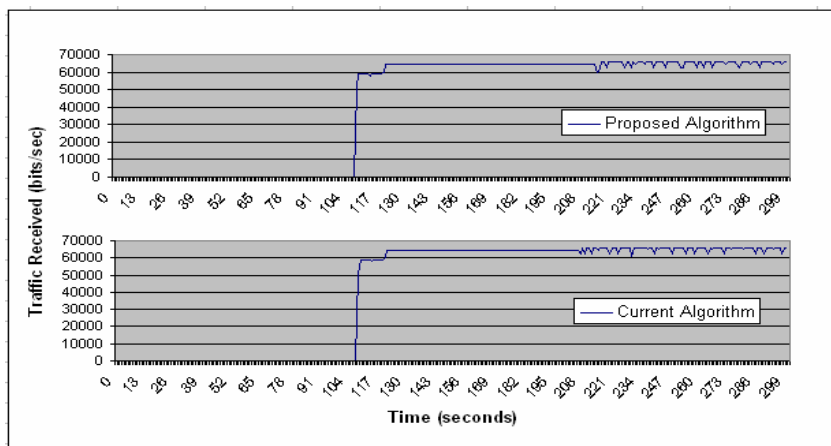


Figure 76. Traffic Received (Scenario 3: High Load)

From the results shown above (Figure 73 - Figure 76) the following observations have been made for Instance 3 of Scenario 2:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 0.56 watts
- Proposed MBMS Handover Algorithm: 0.48 watts (15% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 713 meters from Point to Point Base Station
 - 950 meters from the Point to Multipoint Base Station

- Proposed MBMS Handover Algorithm:
 - 667 meters from the Point to Point Base Station
 - 996 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 208 second
 - Proposed MBMS Handover Algorithm: 214 second (Allocating Resources 6 seconds later)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

5.2.4 Scenario 4: From Common to Dedicated Resources (Angle $\phi > 0^\circ$)

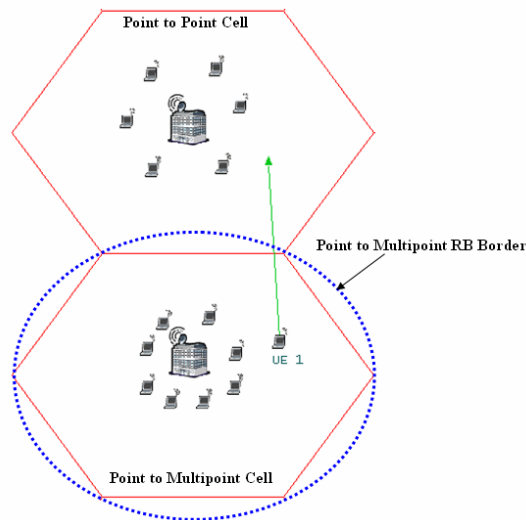


Figure 77. From Point-to-Multipoint To Point-to-Point: Simple Scenario 2

Scenario 4 shown in Figure 77, considers the case where UE 1 is moving from a Point-to-Multipoint Cell (Common Resources) towards a Point-to-Point Cell (Dedicated Resources) and the UE is not moving on the straight line that connects the Point to Multipoint Base Station with it (Angle $\phi > 0^\circ$). In this scenario all the other mobile terminals are static. UE 1 is following a trajectory as shown in the figure above, and receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. The distance between the two Base Stations is about ~1660 meters. For this scenario two instances have been simulated (Low & Medium Load), with different number

of users at different positions in the Point to Point Cell. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained for each instance are presented below:

5.2.4.1 Simulation Results: Current Vs Proposed Handover Algorithm

Instance 1: Low load in the Point to Point Cell (Figure 78 - Figure 81)

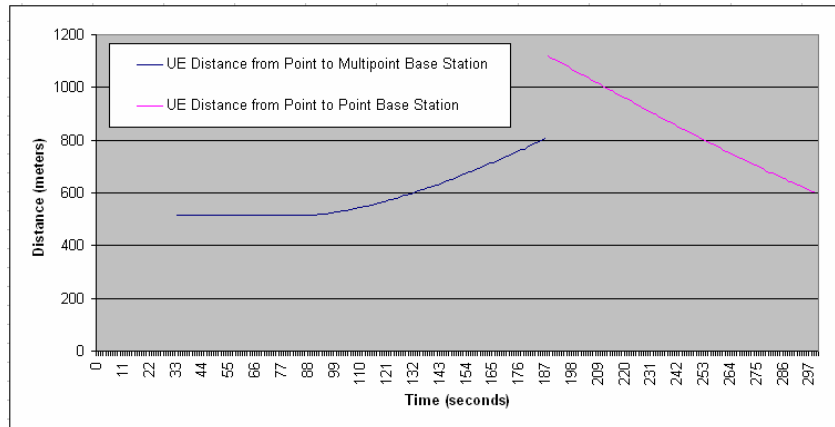


Figure 78. UE Distance from the two Base Stations (Scenario 4: Low Load – Current Handover Algorithm)

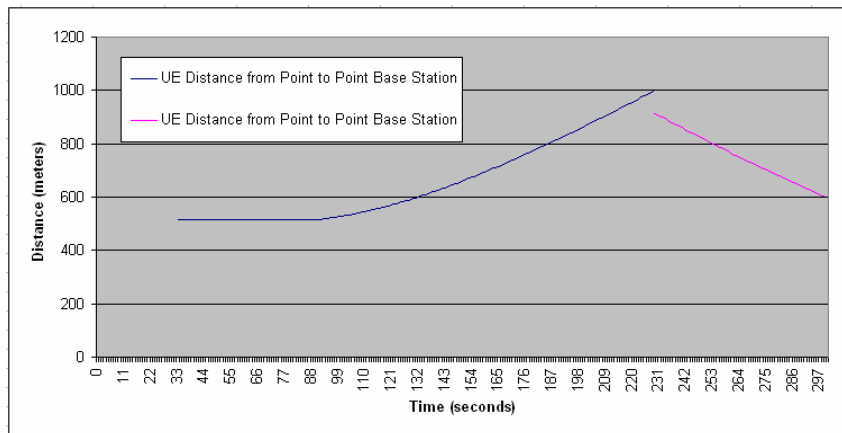


Figure 79. UE Distance from the two Base Station (Scenario 4: Low Load –Proposed Handover Algorithm)

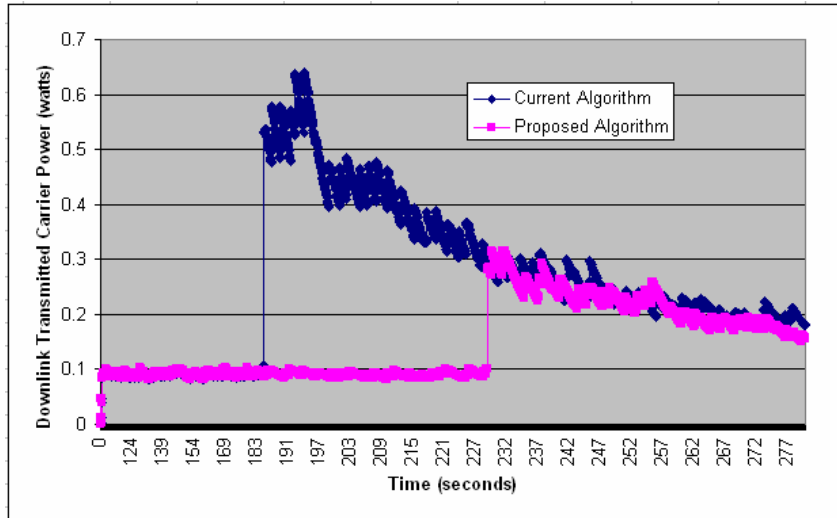


Figure 80. Total Downlink transmitted power used in Point to Point Cell (Scenario 4: Low Load)

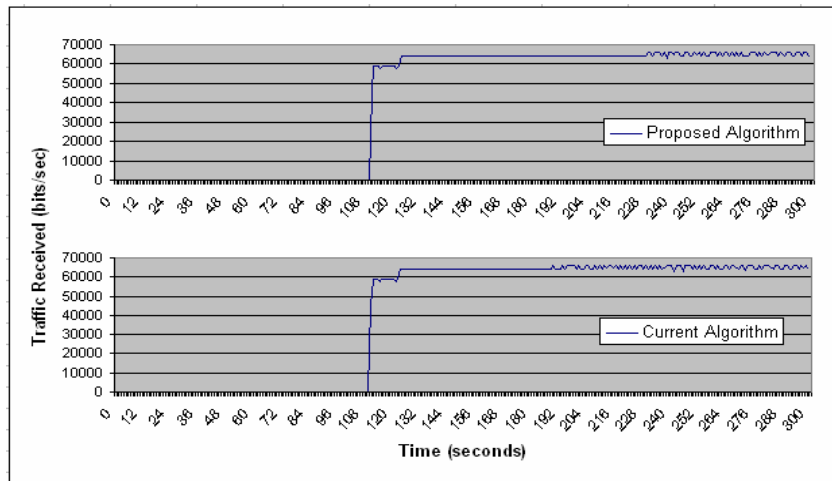


Figure 81. Traffic Received (Scenario 4: Low Load)

From the results shown above (Figure 78 - Figure 81) the following observations have been made for Instance 1 of Scenario 4:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 0.64 watts
- Proposed MBMS Handover Algorithm: 0.316 watts (51% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm

- 1104 meters from Point to Point Base Station
 - 805 meters from the Point to Multipoint Base Station
- Proposed MBMS Handover Algorithm:
 - 911 meters from the Point to Point Base Station
 - 998 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 187 second
 - Proposed MBMS Handover Algorithm: 229 second (Allocating Resources 42 seconds later)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

Instance 2: Medium load in the Point to Point Cell (Figure 82 - Figure 85)

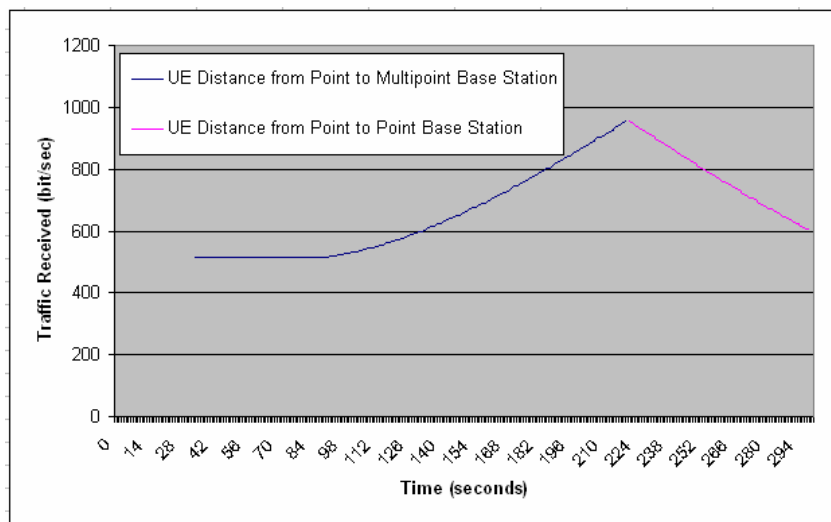


Figure 82. UE Distance from the two Base Stations (Scenario 4: Medium Load – Current Handover Algorithm)

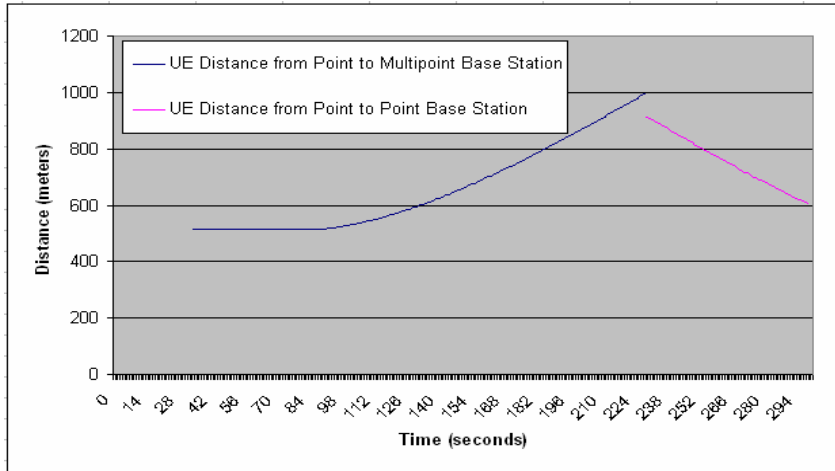


Figure 83. UE Distance from the two Base Station (Scenario 4: Medium Load – Proposed Handover Algorithm)

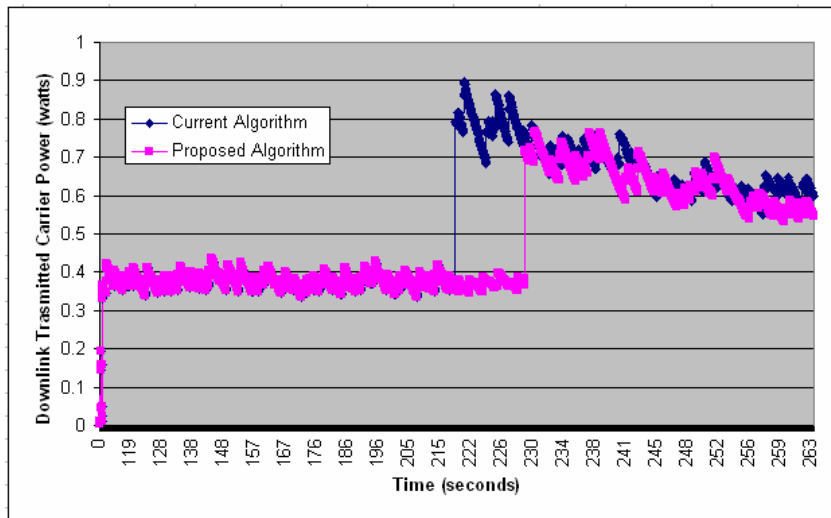


Figure 84. Total Downlink transmitted power used in Point to Point Cell (Scenario 4: Medium Load)

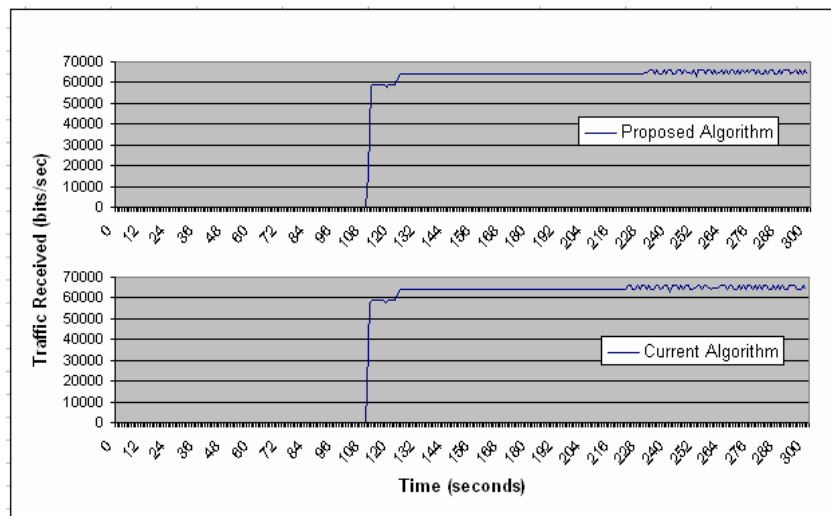


Figure 85. Traffic Received (Scenario 4: Medium Load)

From the results shown above (Figure 82 - Figure 85) the following observations have been made for Instance 2 of Scenario 4:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 0.9 watts
- Proposed MBMS Handover Algorithm: 0.77 watts (14% decrease)

Handover Execution:

- Distance from Point-to-Point Base Station:
 - Current Handover Algorithm
 - 955 meters from Point to Point Base Station
 - 954 meters from the Point to Multipoint Base Station
 - Proposed MBMS Handover Algorithm:
 - 910 meters from the Point to Point Base Station
 - 999 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 220 second
 - Proposed MBMS Handover Algorithm: 229 second (Allocating Resources 9 seconds later)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

5.2.5 Scenario 5: From Dedicated to Common Resources – Adding Mobility

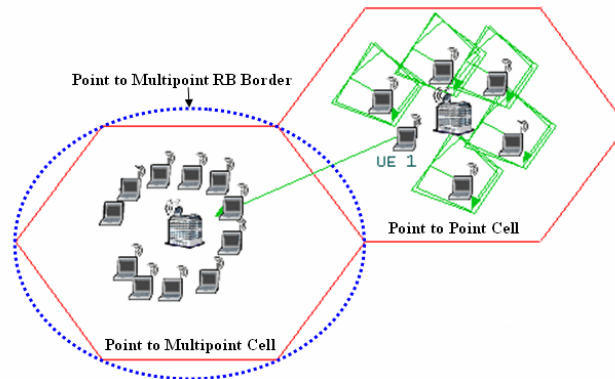


Figure 86. From Point-to-Point To Point-to-Multipoint: Adding Mobility

Scenario 5 shown in Figure 86, considers the case where UE 1 is moving from a Point-to-Point Cell (Dedicated Resources) towards a Point-to-Multipoint Cell (Common Resources) and mobility is added in the Point to Point Cell. All the UEs in the Point to Point Cell are following the same trajectory as shown in the figure above, except UE 1 that is moving from the Point to Point Cell towards the Point to Multipoint Cell. All the UEs are receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. The distance between the two Base Stations is about ~1740 meters. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained and presented below (Figure 87 - Figure 90):

5.2.5.1 Simulation Results: Current Vs Proposed Handover Algorithm

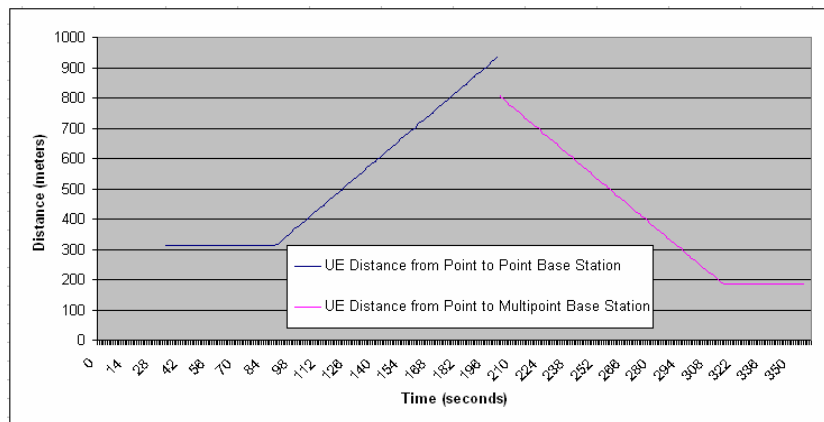


Figure 87. UE Distance from the two Base Stations (Scenario 5 – Current Handover Algorithm)

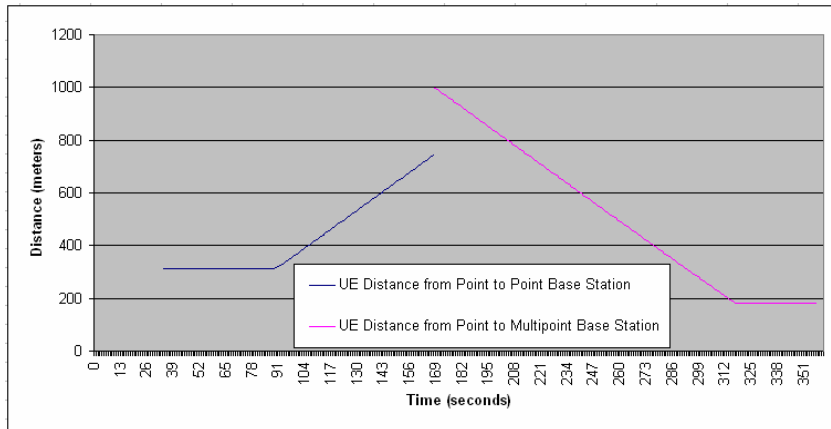


Figure 88. UE Distance from the two Base Stations (Scenario 5 – Proposed Handover Algorithm)

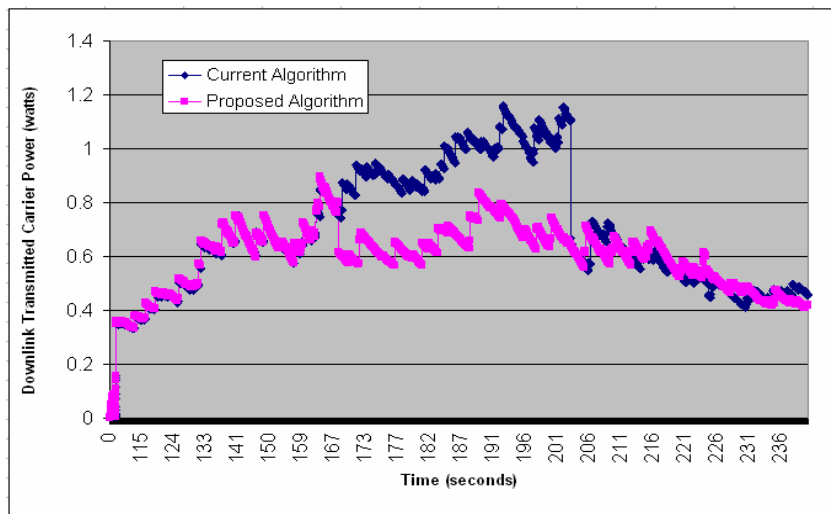


Figure 89. Total Downlink transmitted power used in Point to Point Cell (Scenario 5)

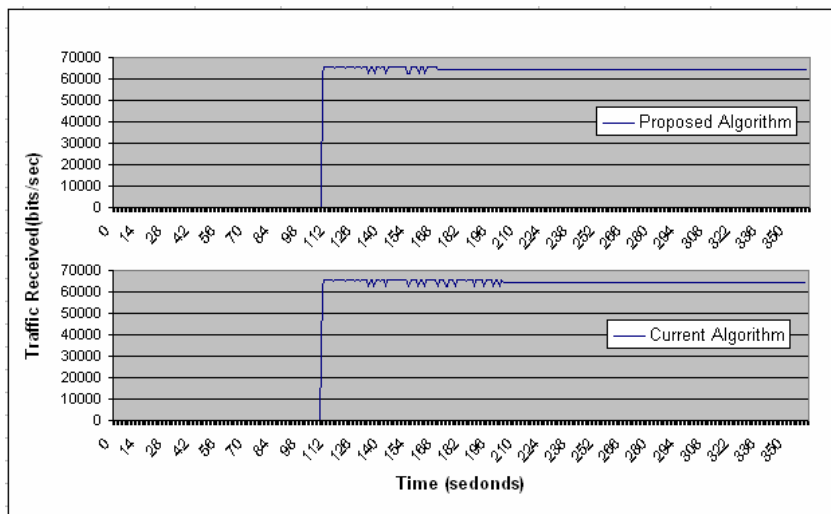


Figure 90. Traffic Received (Scenario 5)

From the results shown above (Figure 87 - Figure 90) the following observations have been made for Scenario 5:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 1.166 watts
- Proposed MBMS Handover Algorithm: 0.9 watts (23% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 935 meters from Point to Point Base Station
 - 808 meters from the Point to Multipoint Base Station
 - Proposed MBMS Handover Algorithm:
 - 745 meters from the Point to Point Base Station
 - 998 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 202 second
 - Proposed MBMS Handover Algorithm: 168 second (Releasing Resources 34 seconds sooner)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

5.2.6 Scenario 6: From Common to Dedicated Resources – Adding Mobility

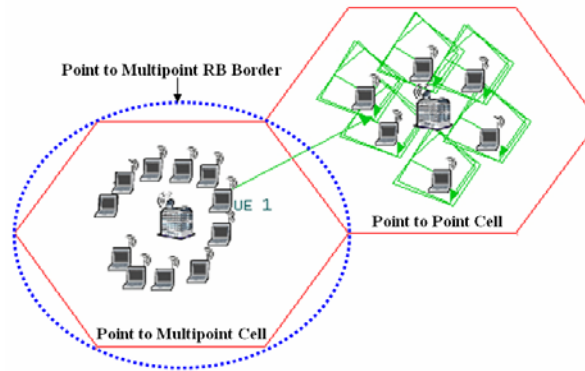


Figure 91. From Point-to-Point To Point-to-Multipoint: Adding Mobility

Scenario 6 shown in Figure 91, considers the case where UE 1 is moving from a Point-to-Multipoint Cell (Common Resources) towards a Point-to-Point Cell (Dedicated Resources) and mobility is added in the Point to Point Cell. All the UEs in the Point to Point Cell are following the same trajectory as shown in the figure above while UE 1 is moving from the Point to Multipoint Cell towards the Point to Point Cell. All the UEs are receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. The distance between the two Base Stations is about ~1740 meters. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained and presented below (Figure 92 - Figure 95):

5.2.6.1 Simulation Results: Current Vs Proposed Handover Algorithm

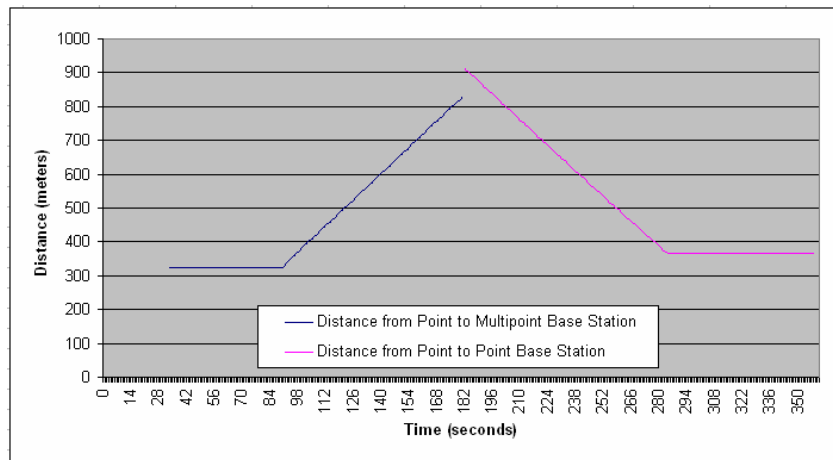


Figure 92. UE Distance from the two Base Stations (Scenario 6 – Current Handover Algorithm)

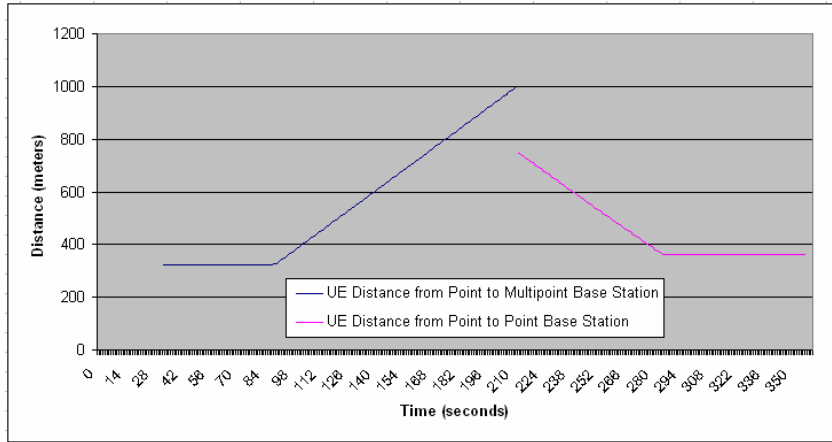


Figure 93. UE Distance from the two Base Stations (Scenario 6 – Proposed Handover Algorithm)

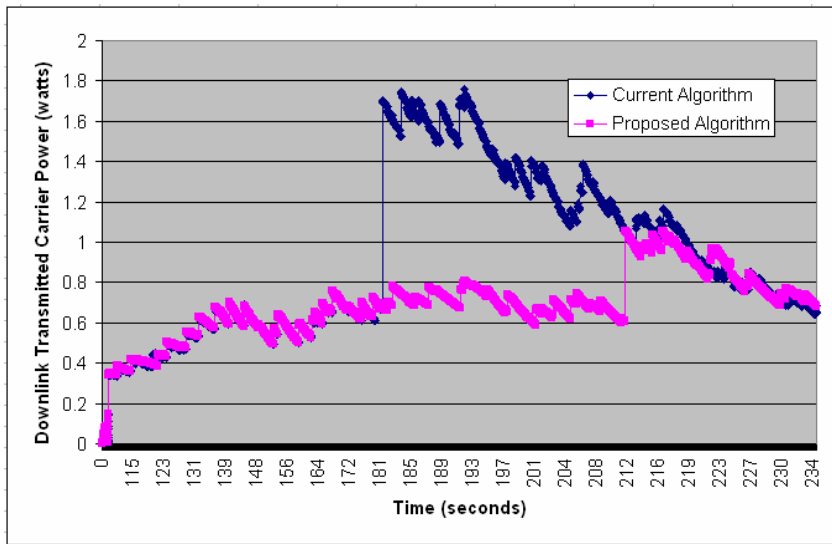


Figure 94. Total Downlink transmitted power used in Point to Point Cell (Scenario 6)

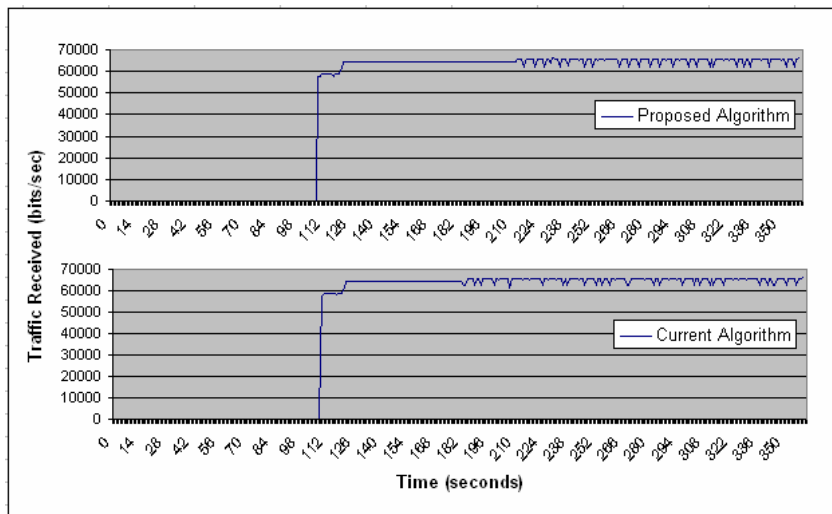


Figure 95. Traffic Received (Scenario 6)

From the results shown above (Figure 92 - Figure 95) the following observations have been made for Scenario 6:

Maximum Power used in the Point to Point Cell:

- Current Handover Algorithm: 1.76 watts
- Proposed MBMS Handover Algorithm: 1.06 watts (40% decrease)

Handover Execution:

- Distance from Point-to-Point and Point to Multipoint Base Station:
 - Current Handover Algorithm
 - 912 meters from Point to Point Base Station
 - 831 meters from the Point to Multipoint Base Station
 - Proposed MBMS Handover Algorithm:
 - 746 meters from the Point to Point Base Station
 - 997 meters from the Point to Multipoint Base Station (On the Border of the Point to Multipoint Cell)
- Time of Handover Execution:
 - Current Handover Algorithm: 181 second
 - Proposed MBMS Handover Algorithm: 211 second (Allocating Resources 30 seconds later)

QoS level requested:

- Current Handover Algorithm: Satisfied
- Proposed MBMS Handover Algorithm: Satisfied

5.2.7 Scenario 7: A Group of UEs moving from FACH to DCH

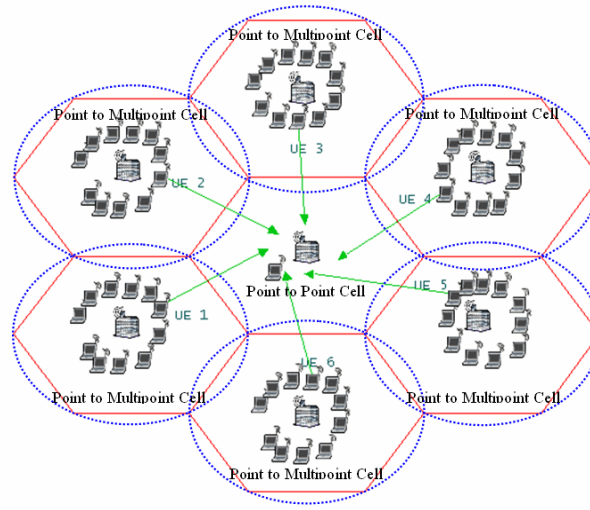


Figure 96. UEs moving from surrounding Point to Multipoint Cells into a Central Point to Point Cell (Scenario 7)

Scenario 7 shown in Figure 96, considers the case where a group of UEs are moving from the surrounding Point-to-Multipoint Cells (Common Resources) towards the Point-to-Point Cell (Dedicated Resources). In this scenario UE 1 – UE 6 are following a trajectory as shown in the figure above. All the UEs are receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained and presented below:

5.2.7.1 Simulation Results: Current Vs Proposed Handover Algorithm

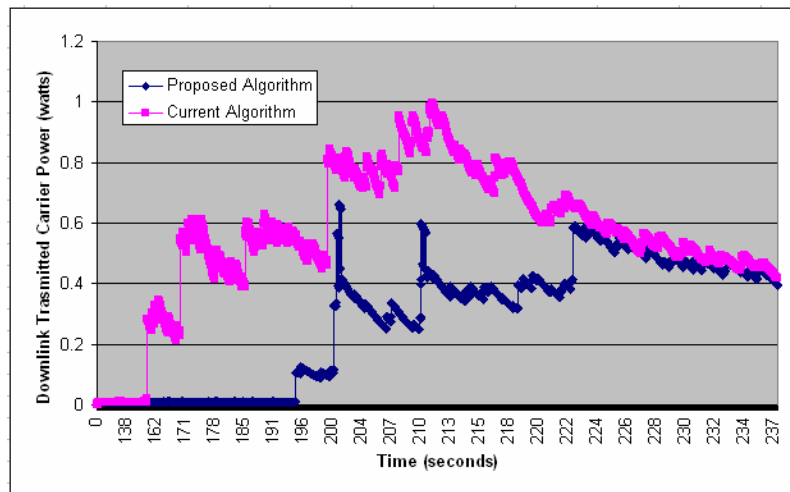


Figure 97. Total Downlink transmitted Carrier power used in Point to Point Cell (Scenario 7)

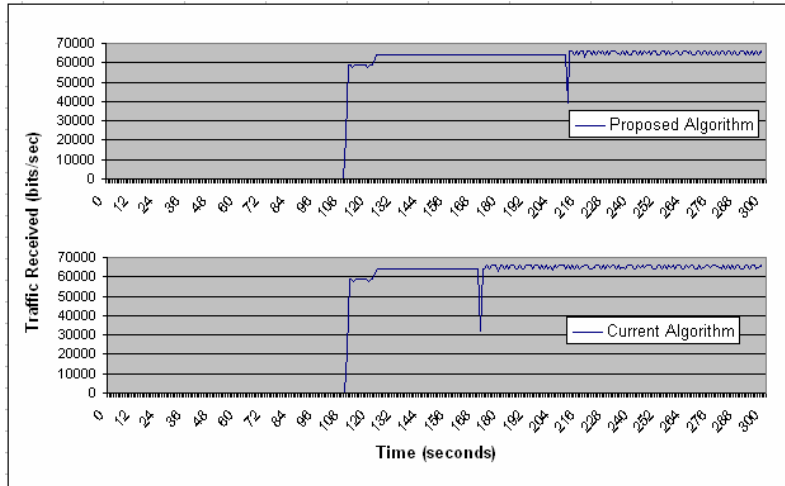


Figure 98. Traffic Received from UE 1 (Scenario 7)

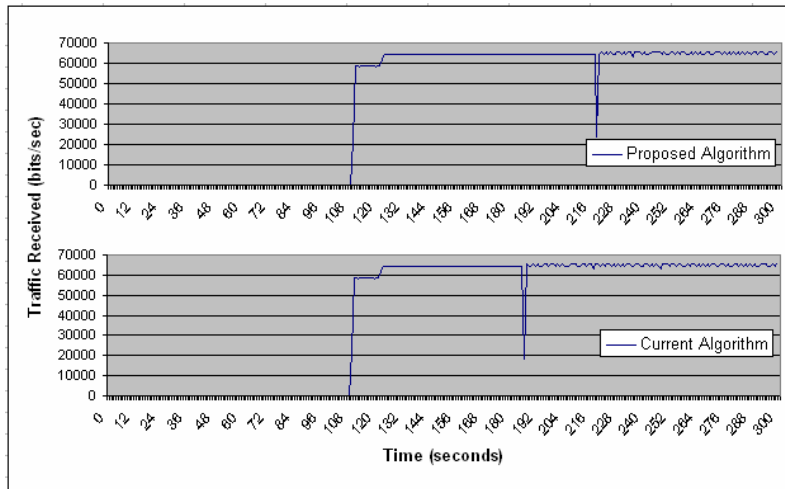


Figure 99. Traffic Received from UE 2 (Scenario 7)

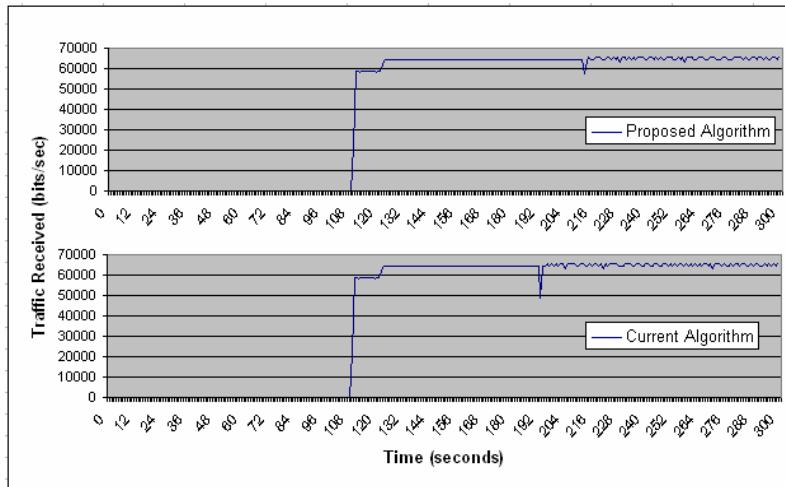


Figure 100. Traffic Received from UE 3 (Scenario 7)

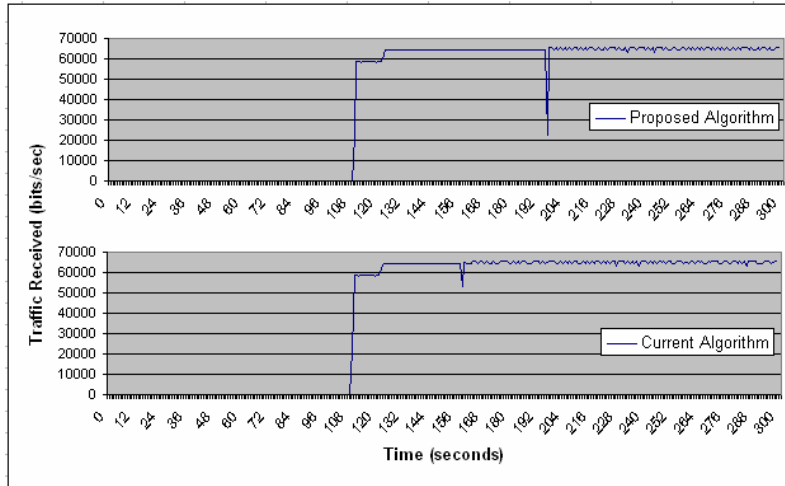


Figure 101. Traffic Received from UE 4 (Scenario 7)

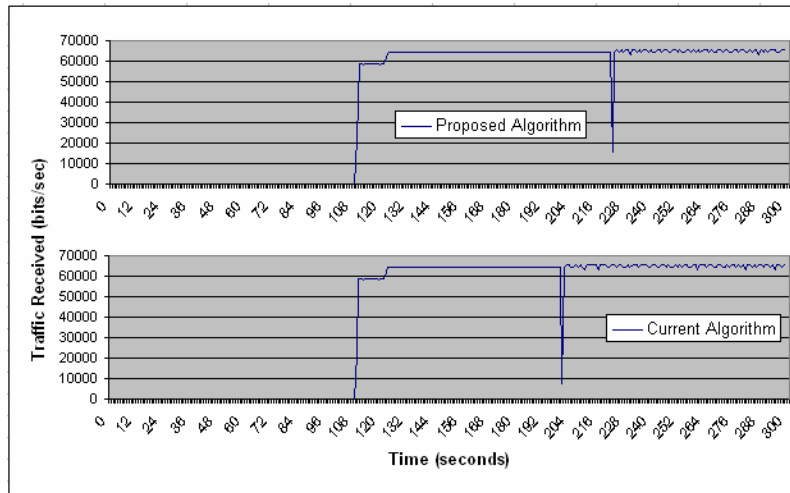


Figure 102. Traffic Received from UE 5 (Scenario 7)

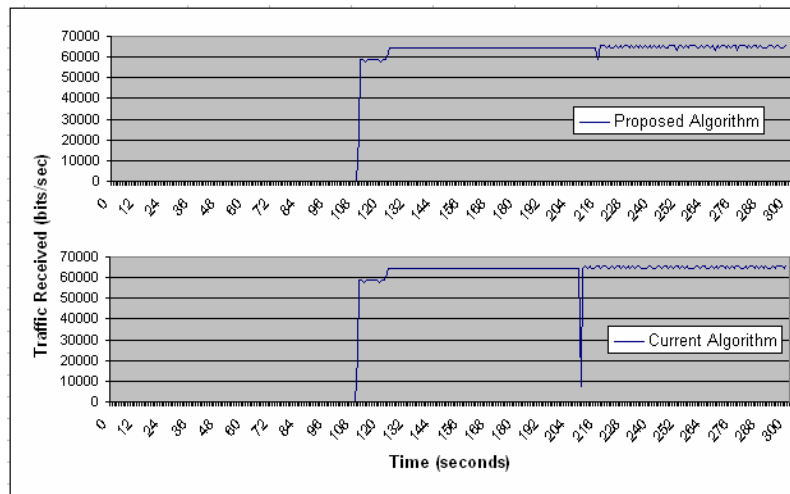


Figure 103. Traffic Received from UE 6 (Scenario 7)

In the scenario described above, the UEs moving from the surrounding Point to Multipoint Cells into the Central Cell area (Point to Point Cell) will increase the demanded capacity (power) in the Point to Point Cell. As more connections are established in the Point to Point Cell due to handover, more power is used, increasing the total amount of noise (interference) in the Cell. Also the greater the distance from the Point to Point Base Station the handover is executed, the more power is used in order to reach the UE and satisfy the QoS requested for the MBMS Service. As it is shown in Figure 97, when the Proposed MBMS Handover Algorithm is used, a great decrease on the total power used is observed. This gain was caused due to ability of the Proposed MBMS Handover Algorithm to execute the handover on the Border of the Point to Multipoint Cell that is as close as possible to the Point to Point Base Station, thus reducing the interference caused in the Point to Point Cell and achieving less power consumption per subscriber. Moreover, as we have seen in section 4.1, as FACH is a Common Channel (FACH) and needs to be received by all Terminals in the Point to Multipoint Cell, also those near the Cell's border, the proportion of the available Downlink Transmission Power allocated for this channel will be adjusted and be at a level aimed to ensure the QoS level requested throughout the *Coverage of the Point to Multipoint Cell* despite the number and the location of the Users in the Cell. Therefore, executing the handover on the border of the Point to Multipoint Cell will also maintain a satisfactory call quality for the UEs (See Figure 98 - Figure 103). The dip curve shown in Figure 98 - Figure 103 is caused due to the packet loss caused when the UE is handover from the Point to Multipoint Cell (FACH) to the Point to Point Cell (DCH).

On the other hand, when the Current Handover Algorithm is used, the handover is triggered and Dedicated resources (power) are allocated in the Point to Point Cell according to the Handover conditions referred in section 3.2.2. Thus, even though the UEs haven't left the coverage of the Point to Multipoint Cell yet, the Handover event is triggered and the Dedicated resources are allocated in the Point to Point Cell just when the Handover Condition is met, resulting in an increase of the interference caused in the Point to Point Cell and as a result more power consumption per subscriber is required.

5.2.8 Scenario 8: A Group of UEs moving from DCH to FACH

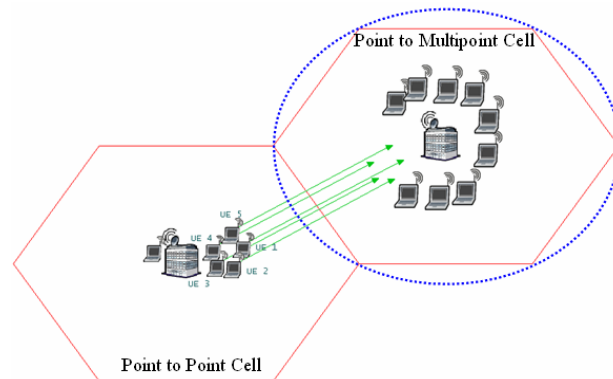


Figure 104. Group of five UEs moving from Dedicated to Common Resources

Scenario 8 shown in Figure 104, considers the case where a group of five UEs are moving from a Point to Point Cell (Dedicated Resources) towards a Point to Multipoint Cell (Common Resources). In this scenario UE 1 – UE 5 are following a trajectory as shown in the figure above. All the UEs are receiving an MBMS Streaming Video of 25 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained and presented below.

5.2.8.1 Simulation Results: Current Vs Proposed Handover Algorithm

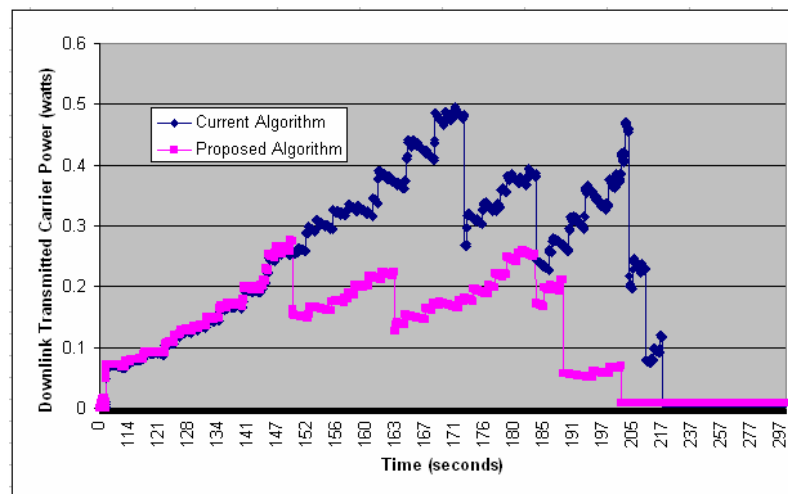


Figure 105. Total Downlink transmitted Carrier power used in Point to Point Cell (Scenario 8)

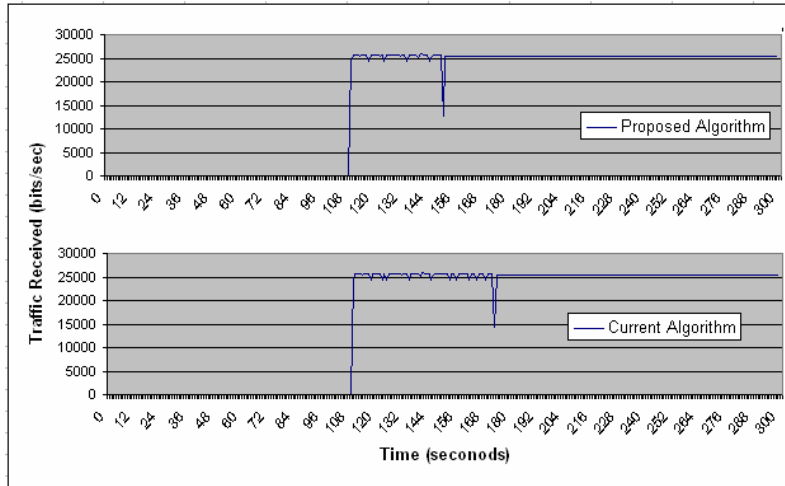


Figure 106. Traffic Received from UE 1 (Scenario 8)

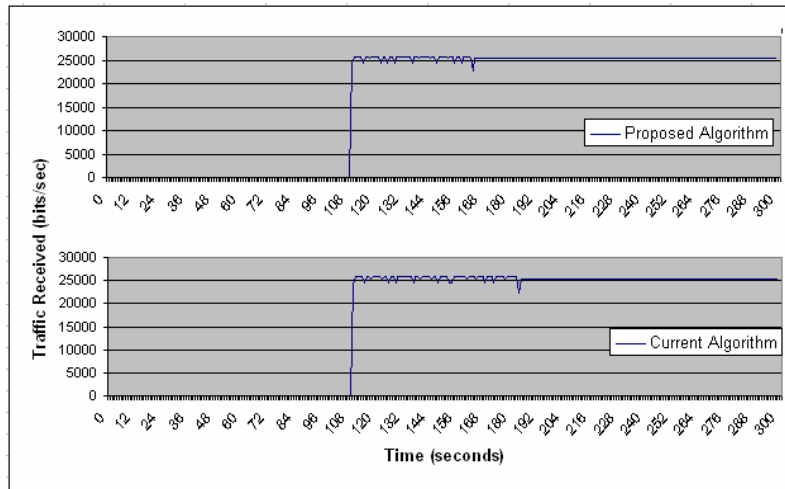


Figure 107. Traffic Received from UE 2 (Scenario 8)

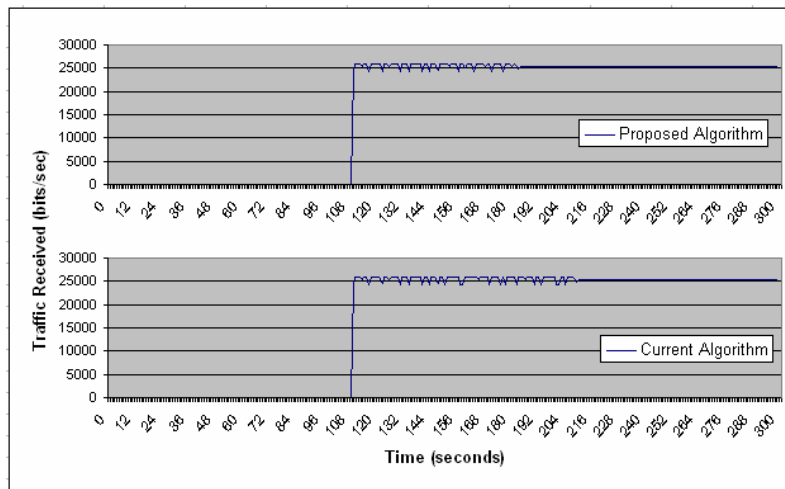


Figure 108. Traffic Received from UE 3 (Scenario 8)

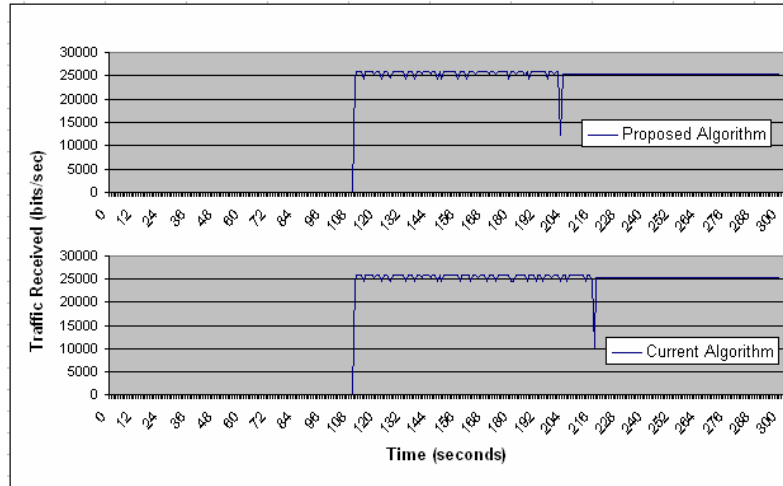


Figure 109. Traffic Received from UE 4 (Scenario 8)

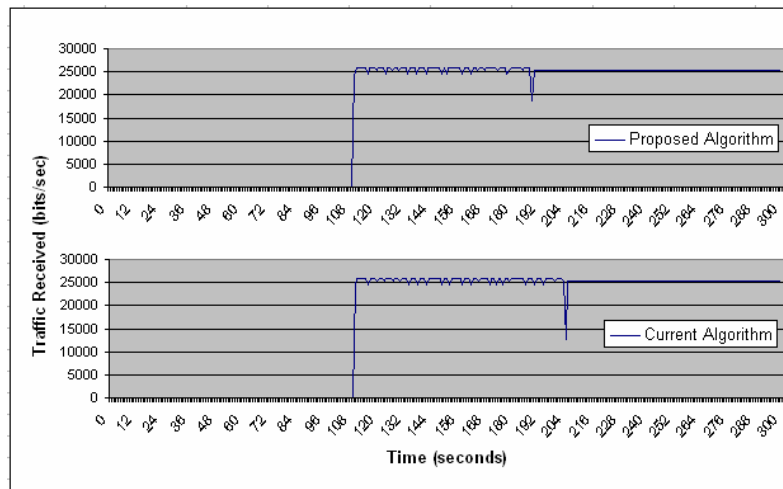


Figure 110. Traffic Received from UE 5 (Scenario 8)

As we have seen in section 4.1, the Downlink Transmission Power allocated for Dedicated Resources (DCH) is variable and increasing exponentially while the UE distance from its attached Point to Point Base Station is increasing. As it is shown in Figure 105, by using the Proposed MBMS Handover Algorithm, a great decrease on the total power used in the Point to Point Cell was observed. This gain was caused due to ability of the Proposed MBMS Handover Algorithm to execute the handover on the Border of the Point to Multipoint Cell and release the Dedicated Resources allocated by the UE as close as possible to the Point to Point Base Station, thus reducing the interference caused in the Point to Point Cell and achieving less power consumption per subscriber. Moreover, as we have seen in section 4.1, as FACH is a Common Channel (FACH) and needs to be received by all Terminals in the Point to Multipoint Cell, also those near the Cell's border, the

proportion of the available Downlink Transmission Power allocated for this channel will be adjusted and be at a level aimed to ensure the QoS level requested throughout the *Coverage of the Point to Multipoint Cell* despite the number and the location of the Users in the Cell. Therefore, executing the handover on the border of the Point to Multipoint Cell will release the Base Station power for servicing more users as soon as possible, resulting in the enhancement of the overall system capacity by also maintaining a satisfactory call quality (See Figure 106 - Figure 110). The dip curve shown in Figure 106 - Figure 110 is caused due to the packet loss caused when the UE is handover from the Point to Point Cell (DCH) to the Point to Multipoint Cell (FACH).

On the other hand, when the Current Handover Algorithm is used, the handover is triggered and resources (power) are released from the Point to Point Cell according to the Handover conditions referred in section 3.2.2. Thus, even though the UEs are entering the Point to Multipoint Cell Coverage the Handover event is not triggered and the resources allocated in the Point to Point Cell are not released until the Handover Condition is met, resulting in an increase of the interference caused in the Point to Point Cell and as a result more power consumption per subscriber is required.

5.2.9 Scenario 9: From Common to Dedicated Resources & vice versa

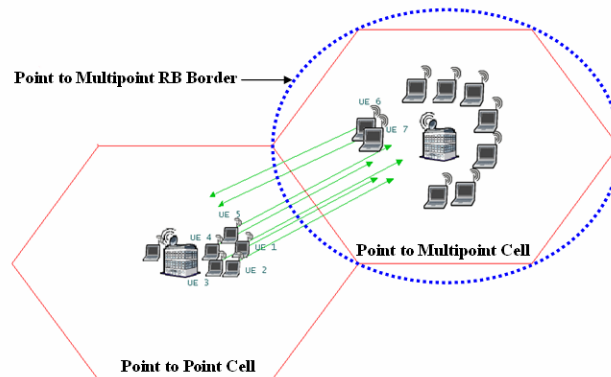


Figure 111. Moving from a Point to Point towards a Point to Multipoint Cell and vice versa

Scenario 9 shown in Figure 111, considers the case where a group of five UEs (UE 1 – UE 5) are moving from the Point to Point Cell (Dedicated Resources) towards the Point to Multipoint Cell (Common Resources) while at the same time a group of two UEs (UE 6 & UE 7) are moving from the Point to Multipoint Cell towards the Point to Point Cell. UE 1 – UE 7 are following a trajectory as shown in the figure above. All the UEs are receiving an

MBMS Streaming Video of 25 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained and presented below:

5.2.9.1 Simulation Results: Current Vs Proposed Handover Algorithm

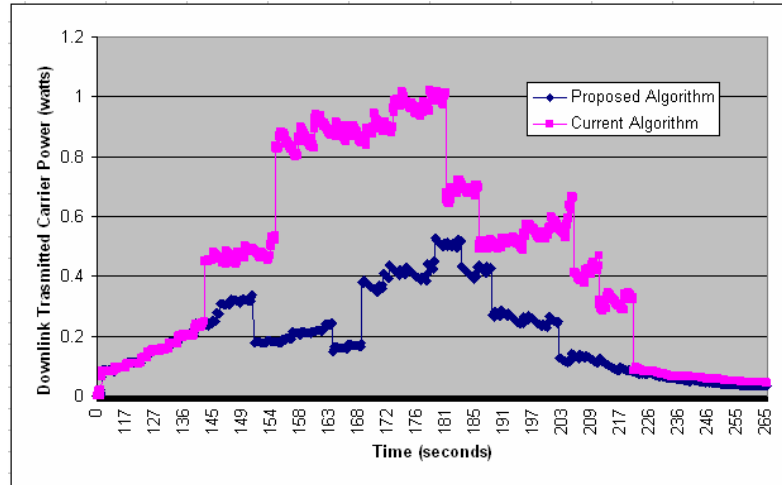


Figure 112. Total Downlink transmitted Carrier power used in Point to Point Cell (Scenario 9)

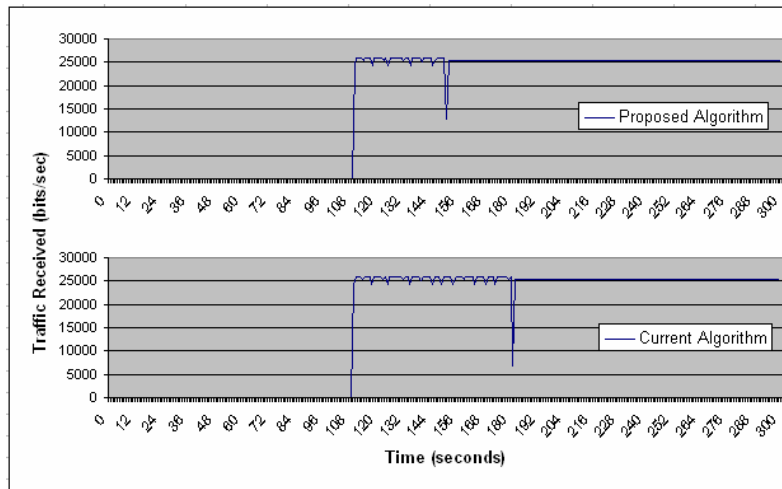


Figure 113. Traffic Received from UE 1 (Scenario 9)

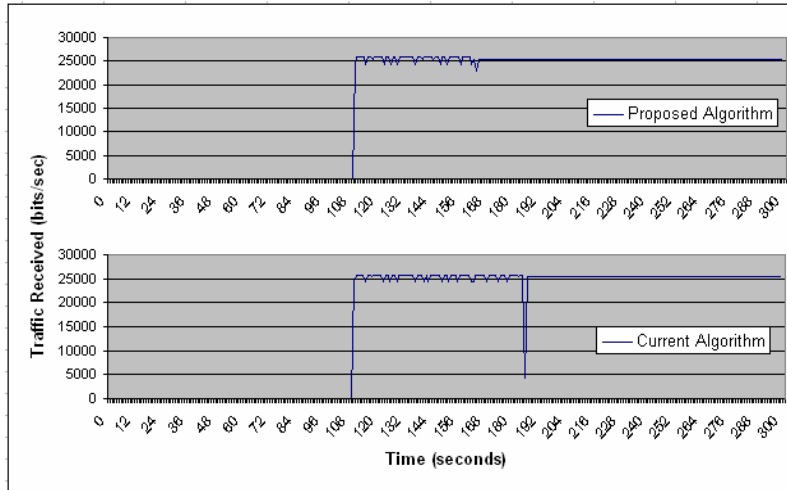


Figure 114. Traffic Received from UE 2 (Scenario 9)

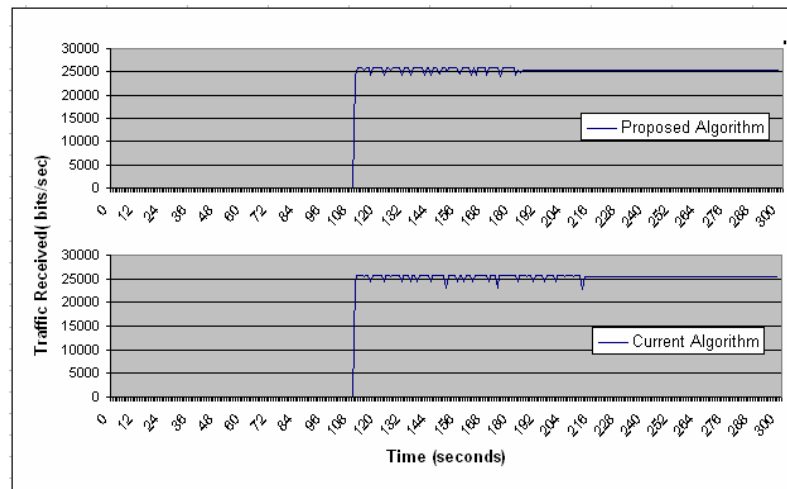


Figure 115. Traffic Received from UE 3 (Scenario 9)

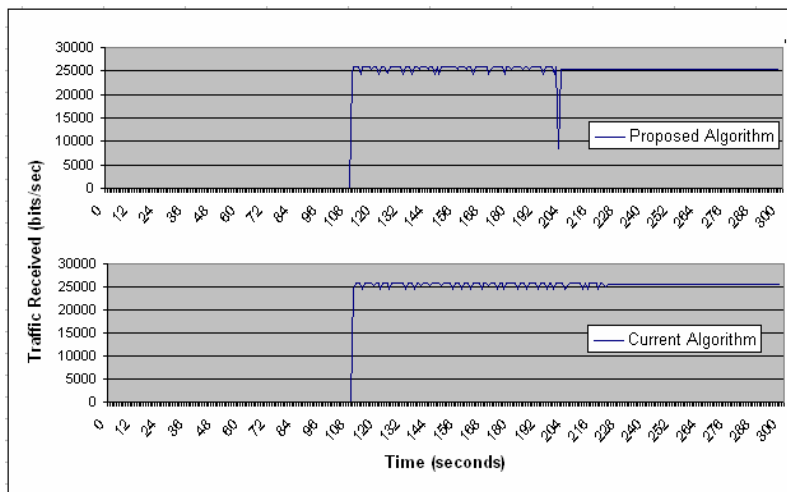


Figure 116. Traffic Received from UE 4 (Scenario 9)

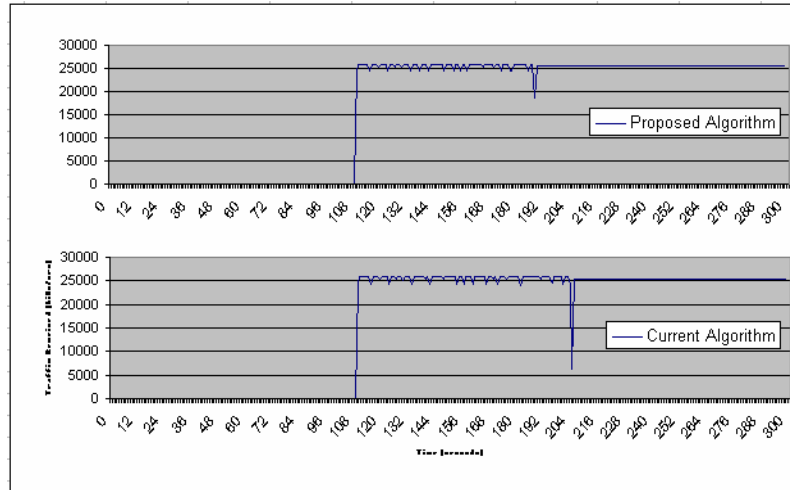


Figure 117. Traffic Received from UE 5 (Scenario 9)

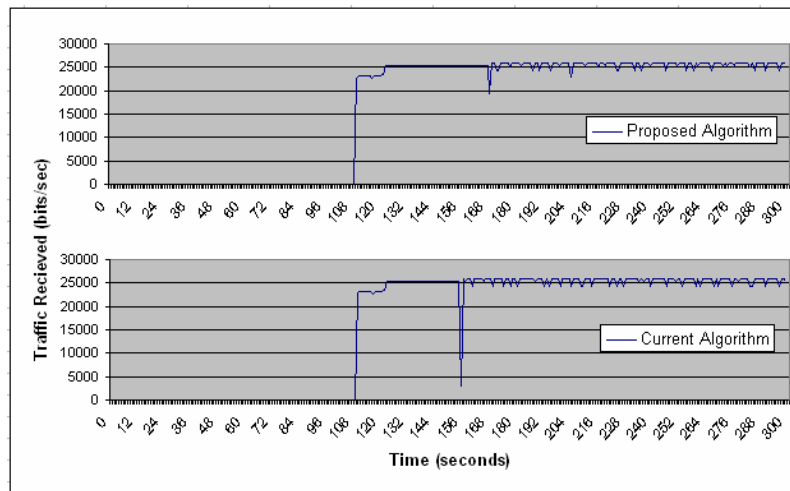


Figure 118. Traffic Received from UE 6 (Scenario 9)

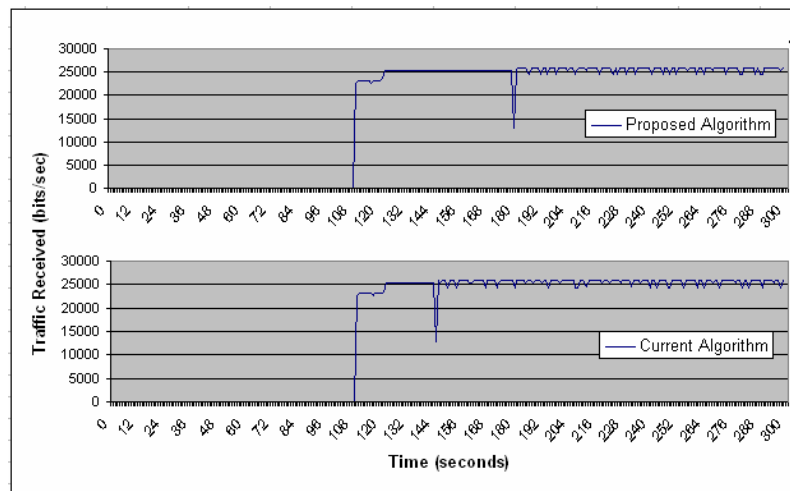


Figure 119. Traffic Received from UE 7 (Scenario 9)

In the scenario described above, the UEs moving from the Point to Multipoint Cell into the Point to Point Cell will increase the demanded capacity (power) in the Point to Point Cell. As more connections are established in the Point to Point Cell due to handover, more power is used, increasing the total amount of noise (interference) in the Point to Point Cell. On the other hand, the UEs moving from the Point to Point Cell towards the Point to Multipoint Cell will decrease the demanded capacity (power) in the Point to Point Cell after the UEs stop listening to the Dedicated Resources (DCH) and start listening to the Common Resources (FACH). As it is shown in Figure 112, by using the Proposed MBMS Handover Algorithm, a great decrease on the total power used was observed. This gain was caused due to ability of the Proposed MBMS Handover Algorithm to execute the handover on the Border of the Point to Multipoint Cell that is as close as possible to the Point to Point Base Station, thus reducing the interference caused in the Point to Point Cell and achieving less power consumption per subscriber. For the case where UE 1 – UE 5 are moving from the Point to Point Cell towards the Point to Multipoint Cell by executing the handover on the Border of the Point to Multipoint Cell thus releasing the Dedicated Resources allocated by the UE as soon as possible and as close as possible to the Point to Point Base Station, the interference caused in the Point to Point Cell will be reduced and less power consumption will be required for UE 1 – UE 5. For the case where UE 6 and UE 7 are moving from the Point to Multipoint Cell towards the Point to Point Cell the Dedicated Resources in the Point to Point Cell are not allocated until the UE reaches the Point to Multipoint Cell Border therefore the interference in the Point to Point Cell is also decreased, in comparison with the current Handover algorithm, and less power consumption will be required for UE 6 and UE 7 after the execution of the handover. Therefore, for both cases, executing the handover on the border of the Point to Multipoint Cell will decrease the interference caused in the Point to Point Cell, releasing the Base Station power for servicing more users, resulting in the enhancement of the overall system capacity by also maintaining a satisfactory call quality (See Figure 113 - Figure 119).

On the other hand, when the Current Handover Algorithm is used, the handover is triggered and resources (power) are allocated or released from the Point to Point Cell according to the Handover conditions referred in section 3.2.2. Thus, even though the UEs are in greater distance from the Point to Point Base Station the MBMS Handover will be triggered resulting in an increase of the interference caused in the Point to Point Cell and as a result more power consumption per subscriber will be required.

5.2.10 Scenario 10: Not leaving from the Point to Multipoint Cell Coverage

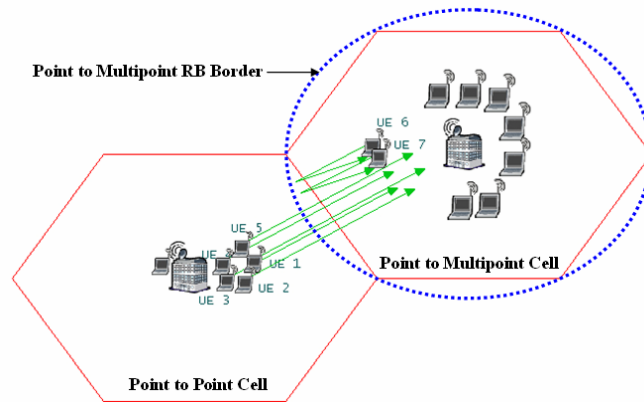


Figure 120. UEs changing direction before leaving the Point to Multipoint Cell Coverage

Scenario 10 shown in Figure 120, is exactly the same as Scenario 9, but in this scenario, UE 6 & UE 7 before they leave the Coverage of the Point to Multipoint Cell, at about 980 meters from the Point to Multipoint Base Station change their direction starting moving towards the Point to Multipoint Base Station. The Point to Multipoint Cell Coverage is 1000 meters. UE 6 and UE 7 are following a trajectory as shown in the figure above. Results concerning the QoS level of the received signal and the Total downlink Transmitted Carrier Power used have been obtained and presented below:

5.2.10.1 Simulation Results: Current Vs Proposed Handover Algorithm

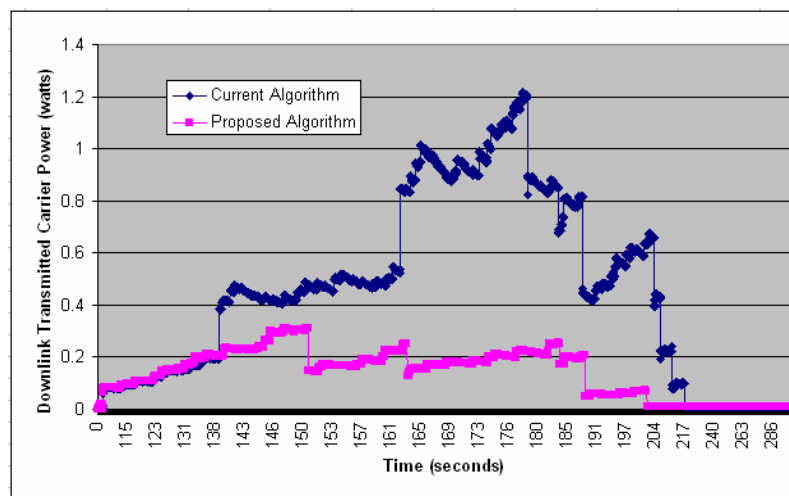


Figure 121. Total Downlink transmitted Carrier power used in Point to Point Cell (Scenario 10)

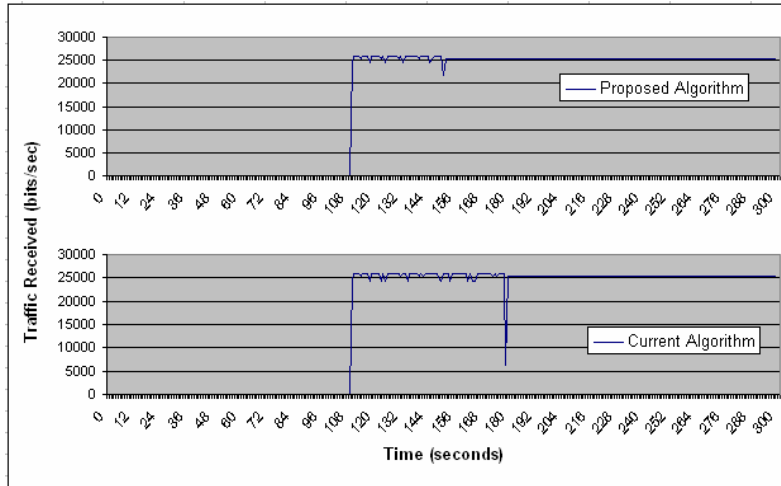


Figure 122. Traffic Received from UE 1 (Scenario 10)

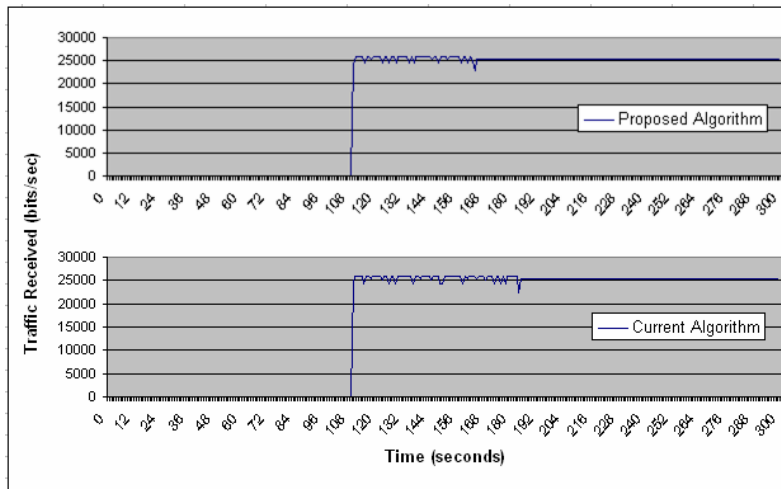


Figure 123. Traffic Received from UE 2 (Scenario 10)

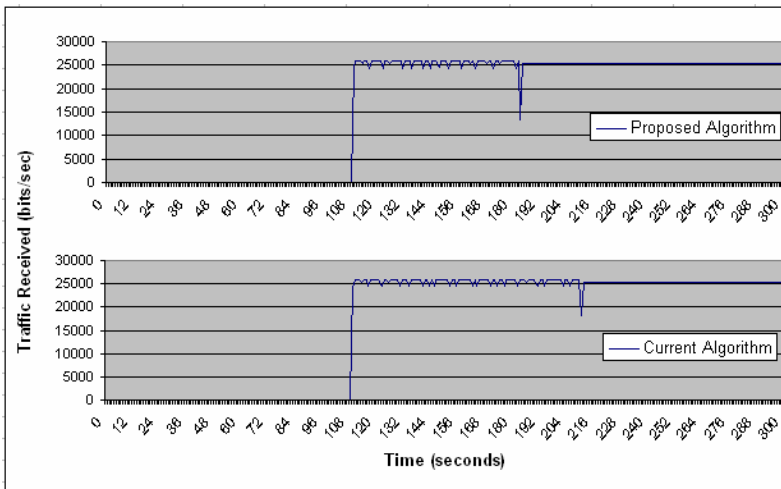


Figure 124. Traffic Received from UE 3 (Scenario 10)

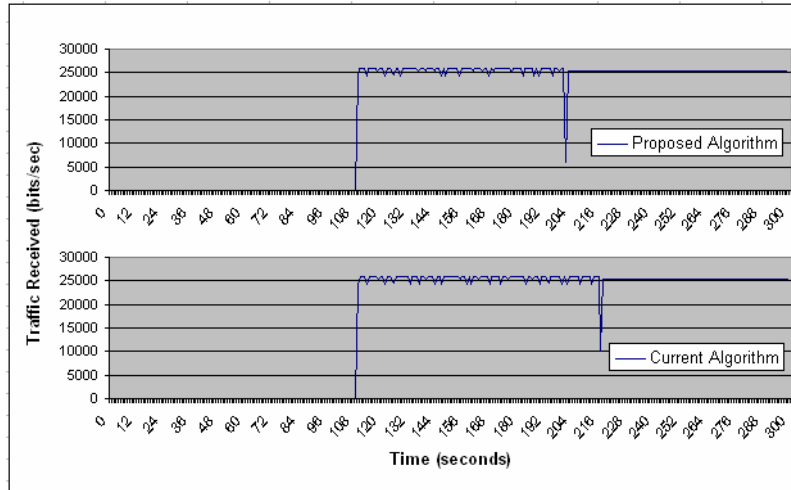


Figure 125. Traffic Received from UE 4 (Scenario 10)

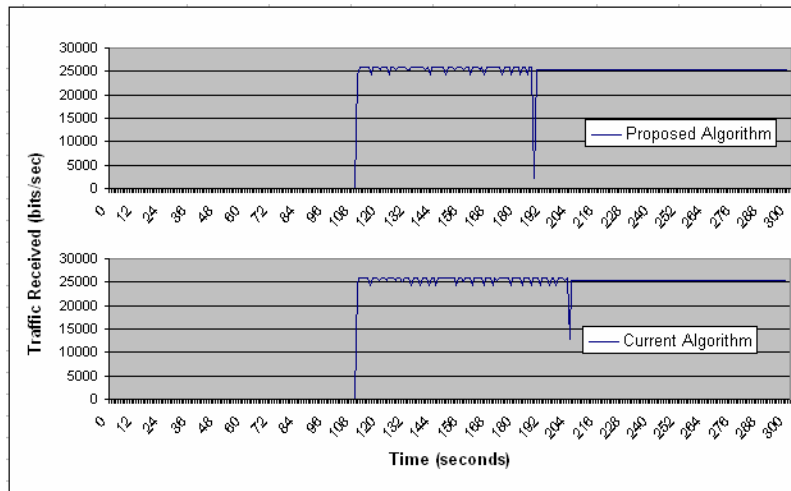


Figure 126. Traffic Received from UE 5 (Scenario 10)

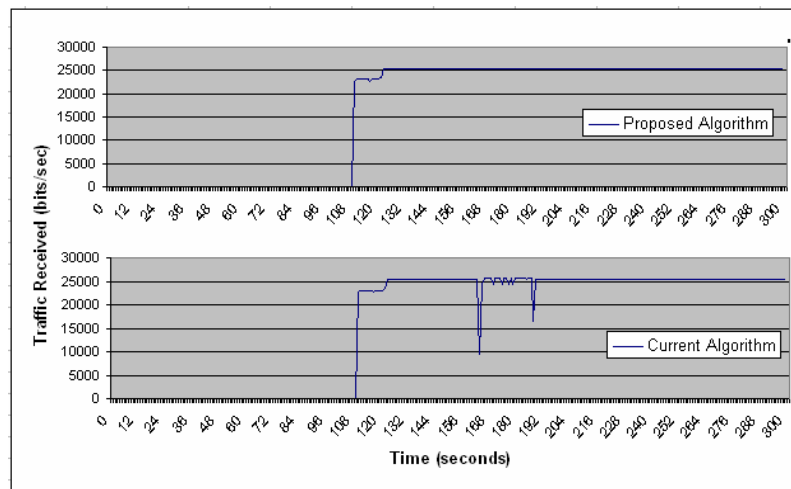


Figure 127. Traffic Received from UE 6 (Scenario 10)

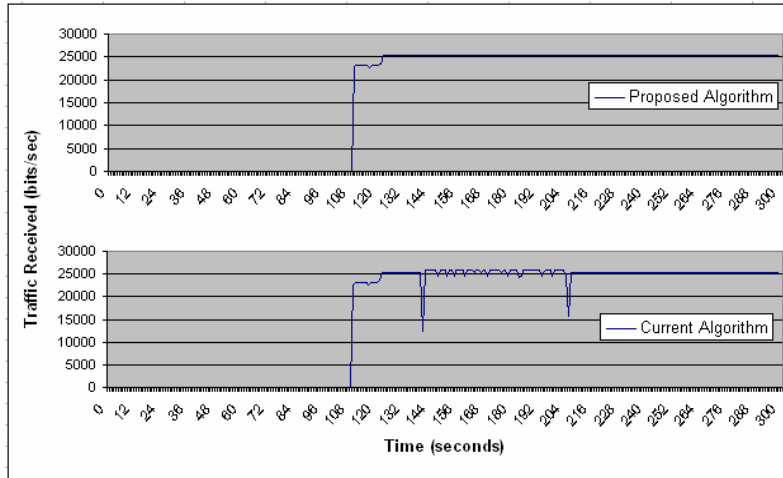


Figure 128. Traffic Received from UE 7 (Scenario 10)

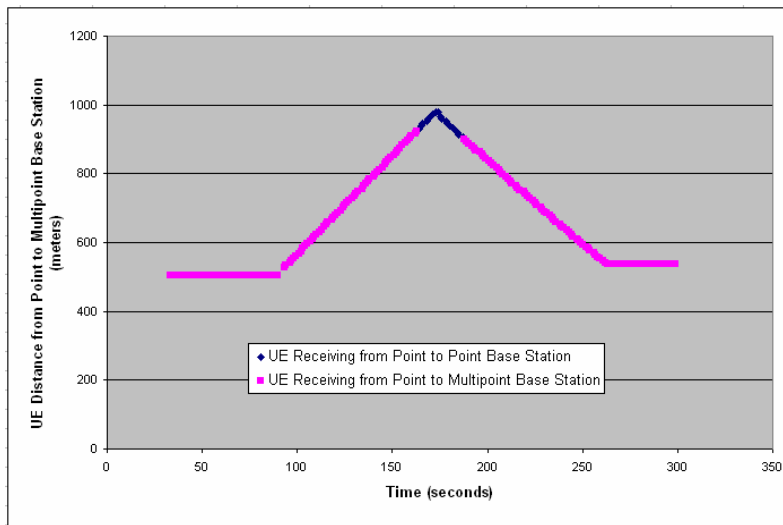


Figure 129. UE 6 distance from PtM Base Station & Base Station of attachment (Current Handover Algorithm)

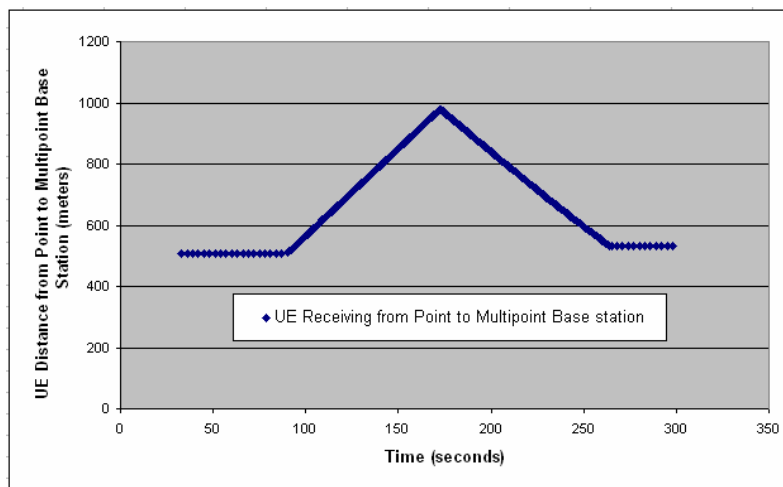


Figure 130. UE 6 distance from PtM Base Station & Base Station of attachment (Proposed Handover Algorithm)

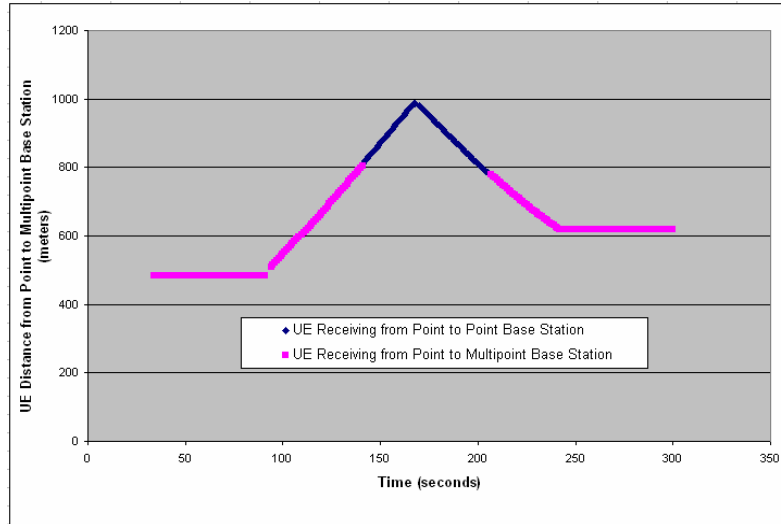


Figure 131. UE 7 distance from PtM Base Station & Base Station of attachment (Current Handover Algorithm)

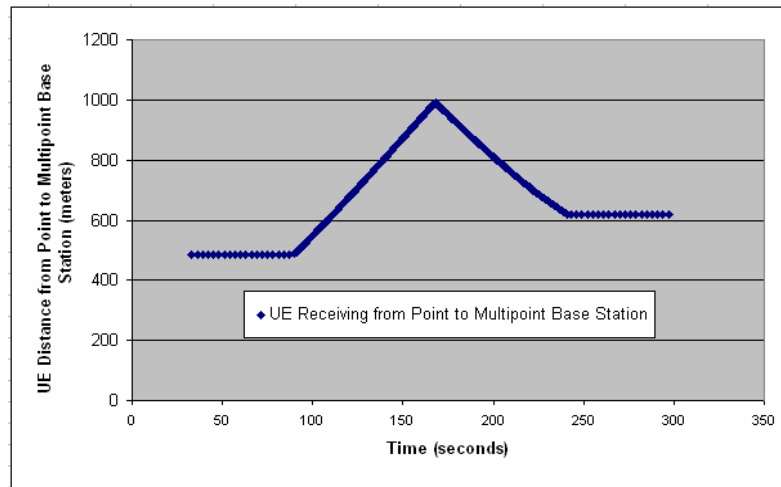


Figure 132. UE 7 distance from PtM Base Station & Base Station of attachment (Proposed Handover Algorithm)

In the scenario described above, the two UEs (UE 6 & UE 7) are moving from the Point to Multipoint Cell into the Point to Point Cell but instead of leaving from the Point to Multipoint Cell Coverage (1000 meters) the two UEs decide to change their direction near the border of the Point to Multipoint Cell (at about 980 meters from the Point to Multipoint Base Station) and move again towards the Point to Multipoint Base Station. Since the proportion of the available Downlink Transmission Power allocated for FACH channel ensures the QoS level requested for the MBMS Service throughout the *Coverage of the Point to Multipoint Cell* it will be unnecessary for these two UEs to handover into the Point to Point Cell. As we have said, as more connections are established in the Point to Point Cell due to handover, more power is used from the Point to Point Base Station, increasing

the total amount of noise (interference) in the Cell thus requiring more power consumption per subscriber.

As it is shown in Figure 121, by using the Proposed MBMS Handover Algorithm, a great decrease on the total power used was observed (up to 78% decrease on the Downlink Power used for the presented scenario) in comparison with the case where the Current Algorithm is used while at the same time also satisfying the requested QoS level of the MBMS Service (See Figure 122 - Figure 128). This gain was caused for two reasons:

- The ability of the Proposed MBMS Handover Algorithm to prevent unnecessary handovers from happening (For UE 6 and UE 7)
- The ability of the Proposed MBMS Handover Algorithm to execute the handover as close as possible to the Point to Point Base Station but without disturbing the QoS of the received signal, thus reducing as much as possible the total downlink transmitted power used in the Point to Point Cell (For UE 1 – UE 5).

For example, when the Proposed Handover Algorithm is used, UE 6 (See Figure 130) and UE 7 (See Figure 132) are not handover into the Point to Point Cell even though the UEs are near the Border of the Point to Multipoint Cell, since the UEs can still receive the MBMS Service with the requested QoS from the FACH transmitted from the Point to Multipoint Base Station (See Figure 127 and Figure 128). Therefore the demanded capacity in the Point to Point Cell will not be increased since the UE instead of handover into the Point to Point Cell will continue receiving the MBMS service using the FACH Channel transmitted from the Point to Multipoint Base Station. On the other hand, by using the Current Handover Algorithm two handovers are performing for UE 6 (See Figure 129), one when the UE is at distance 924 meters from the Point to Multipoint Base Station and moving towards the Point to Point Cell and one when the UE is at distance 902 meters from the Point to Multipoint Base Station and moving towards the Point to Multipoint Cell. Also the same happens with UE 7 (See Figure 131). The first handover is executed when the UE 7 is at distance 805 meters from the Point to Multipoint Base Station and moving towards the Point to Point Cell and one when the UE is at distance 779 meters from the Point to Multipoint Base Station and entering the Point to Multipoint Cell. The two UEs moving from the Point to Multipoint Cell into the Point to Point Cell will increase the demanded

capacity (power) in the Point to Point Cell and more power will be used in the Point to Point Cell increasing the total amount of noise (interference) in the Cell (See Figure 121).

Moreover, by using the Proposed MBMS Handover Algorithm, the UEs (UE 1 – UE 5) moving from the Point to Point Cell towards the Point to Multipoint Cell will execute the handover and release the Dedicated Resources allocated by them as close as possible to the Point to Point Base Station (on the Border of the Point to Multipoint Cell) just when the UEs are ready to enter the Point to Multipoint Cell Coverage. By doing this less interference is caused in the Point to Point Cell and less power is used per subscriber. On the other hand, when the Current Handover Algorithm is used, the handover is triggered and resources (power) are released from the Point to Point Cell according to the Handover conditions referred in section 3.2.2. Thus, even though the UEs are entering the Point to Multipoint Cell Coverage the Handover event is not triggered and the resources allocated in the Point to Point Cell are not released until the Handover Condition is met, resulting in an increase of the interference caused in the Point to Point Cell and in an increased on the required power consumption per subscriber.

5.2.11 Scenario 11: Testing Scalability and Capacity Achievement

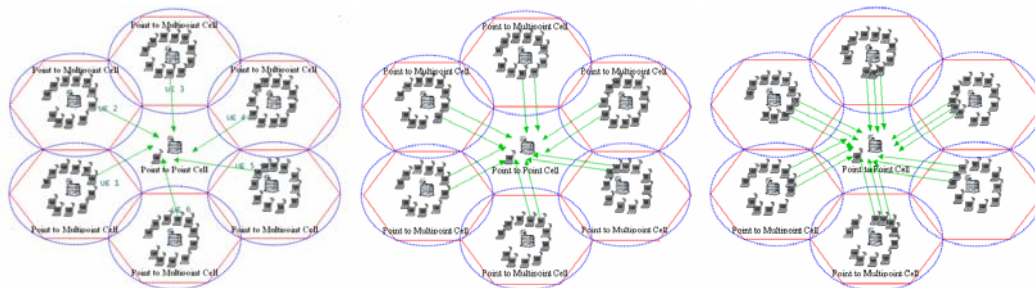


Figure 133. Testing Scalability and Capacity Achievement (Scenario 11 – Instance 1,2,3)

Scenario 11 shown in Figure 133 is used in order to see the scalability of the Proposed MBMS Handover Algorithm and also the capacity achievement of the proposed scheme. This scenario is an enhancement of scenario 7. In this scenario three instances have been used, increasing the number of the UEs that handover from the surrounding Point to Multipoint Cells to the central Point to Point Cell:

- Instance 1: 6 users
- Instance 2: 12 users
- Instance 3: 18 users

All the UEs are receiving an MBMS Streaming Video of 64 Kbits/second. The Cell path-loss model used is “Pedestrian Outdoor”. Results concerning the Total downlink Transmitted Carrier Power required and the Total Downlink Throughput transmitted from the Point to Point Base Station for each instance, when the current and the proposed handover algorithms are used have been obtained, compared and presented below.

5.2.11.1 Simulation Results: Current Vs Proposed Handover Algorithm

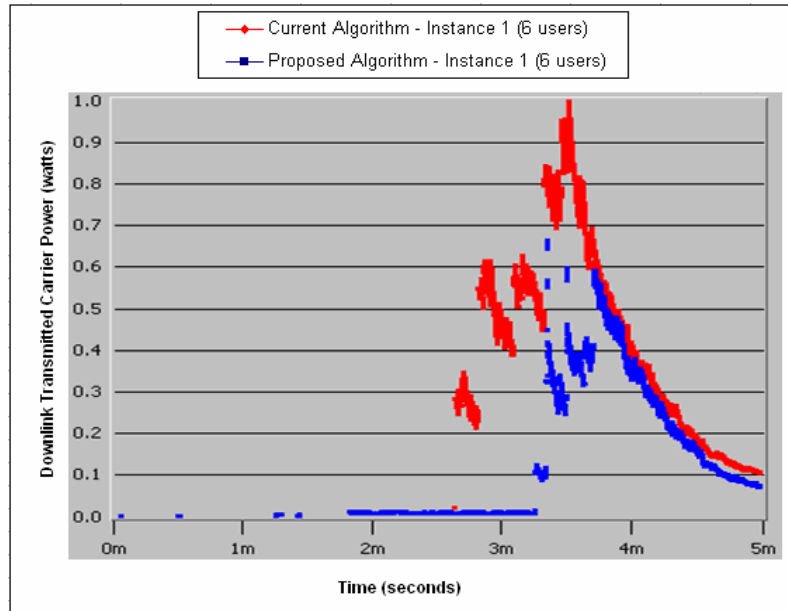


Figure 134. Total Downlink Transmitted Carrier Power used in Point to Point Cell (Scenario 11 – Instance 1)

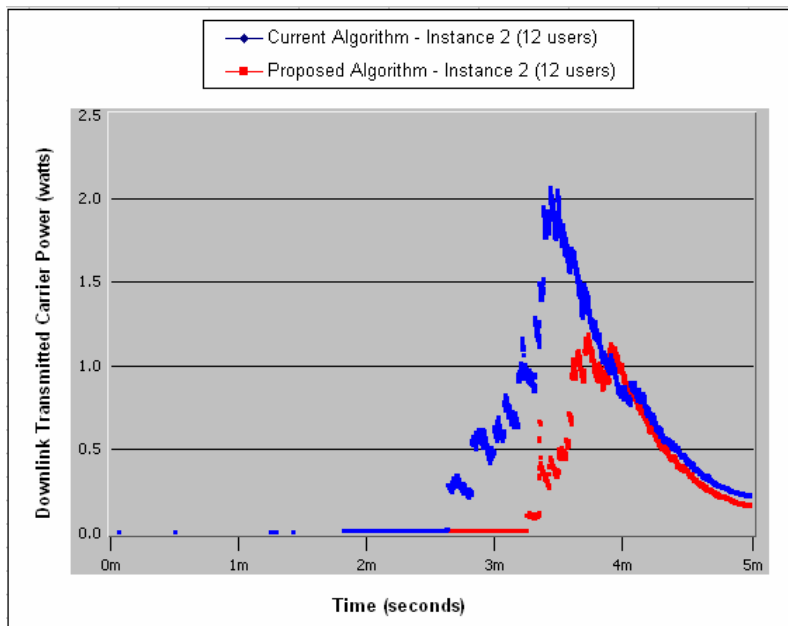


Figure 135. Total Downlink Transmitted Carrier Power used in Point to Point Cell (Scenario 11 – Instance 2)

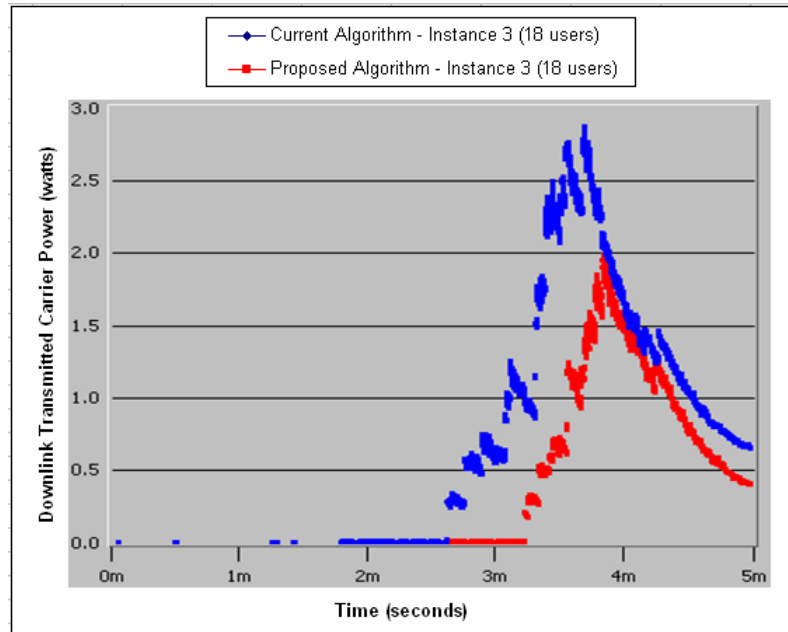


Figure 136. Total Downlink Transmitted Carrier Power used in Point to Point Cell (Scenario 11 – Instance 3)

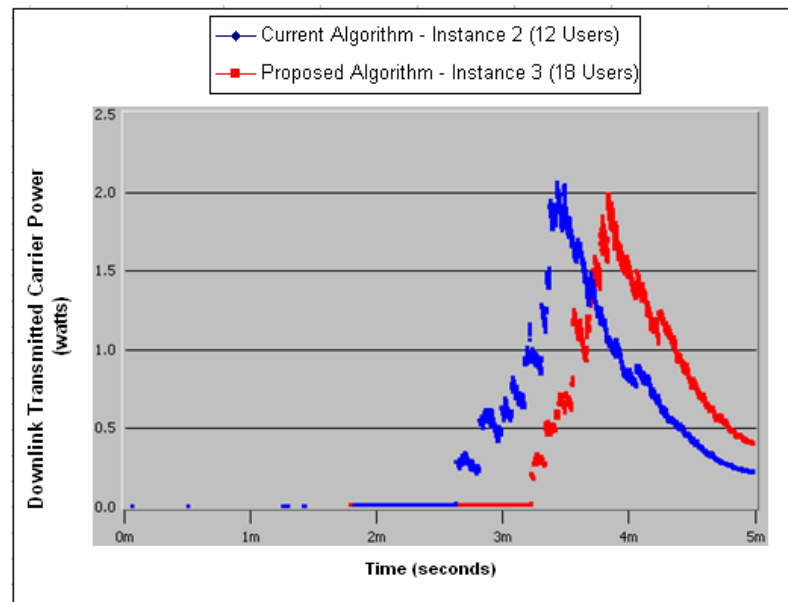


Figure 137. Total Downlink Trasmitted Carrier Power (Instance 2 Vs Instance 3)

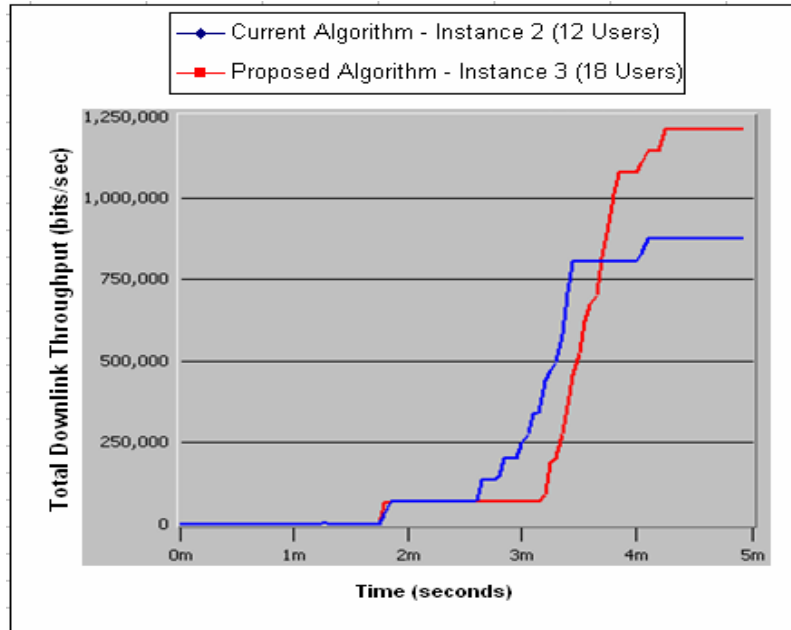


Figure 138. Total Downlink Throughput in Point to Point Cell (Instance 2 Vs Instance 3)

In all Instances simulated above a great decrease on the Total Downlink Transmitted Carrier Power have been observed when the Proposed MBMS Handover Algorithm is used. For Instance 1 (6 users entering the Point to Point Cells) the maximum power used was minimized from 1.0 to 0.64 watts (0.36 watts decrease), for Instance 2 (12 users entering the Point to Point Cell) it was minimized from 2.07 to 1.19 (0.88 watts decrease) and for Instance 3 it was minimized from 2.88 to 2.0 watts (0.88 watts decrease) (See Figure 134 - Figure 136).

By comparing Instance 2 with Instance 3 the results shown in Figure 137 and Figure 138 have been observed. Figure 137 compares the total downlink power used from the Point to Point Base Station for Instance 3 (when the Proposed Handover Algorithm is used) and Instance 2 (when the current Handover Algorithm is used). As it is shown in the figure for both cases the same capacity (power) is used (~2 watts). The difference here is that for Instance 2 (when the current handover algorithm is used) 12 users are entering the Point to Point Cell and for Instance 3 (when the proposed handover algorithm is used) 18 users are entering the Cell. Thus when the Proposed Algorithm is used, by using the same capacity (power) results in an increase of the total number of users that can be served (from 12 users to 18 users), without requesting more power from the Point to Point Cell. On the other hand, Figure 138 compares the Total Downlink Throughput (bits/sec) transmitted from the Point to Point Base Station for Instance 3 (when the Proposed Handover Algorithm is used)

and Instance 2 (when the current Handover Algorithm is used). As we can see here the throughput have been increased from ~861,000 (bits/sec) to ~1,234,000 (bits/sec), that is ~383,000 (bits/sec) more, without requesting more capacity (power).

5.3 Remarks

In all the Scenarios presented, the Proposed MBMS Handover algorithm achieved significant enhancement on the downlink performance by reducing the interference caused in the Point-to-Point Cells and achieving less power consumption per subscriber. This gain was caused due to ability of the proposed Handover Algorithm to execute the handover on the Border of the Point to Multipoint Cell, thus releasing or allocating the Dedicated Resources as close as possible to the Point to Point Base Station reducing the interference caused in the Point to Point Cell and resulting in a less power consumption per subscriber. Also the algorithm is able to prevent unnecessary handovers from happening.

Moreover, by using the Proposed Handover Algorithm when the UE was moving from a Point to Point Cell towards a Point to Multipoint Cell, the dedicated radio resources allocated in the Point to Point Cell were released as soon as possible thus making space for new admissions in the Point to Point Cell. On the other hand, by using the Proposed Handover Algorithm when the UE was moving from a Point to Multipoint Cell towards a Point to Point Cell, the dedicated radio resources in the Point to Point Cell were allocated only when and if necessary thus not causing additional interference in the Point to Point Cell.

By using less power means that less interference is caused in the Point to Point Cells. As we have seen in the results presented, using the Proposed MBMS Handover Algorithm instead of the Current Handover algorithm when the mobile users have to deal with MBMS Handovers can yield to considerable benefits. Since WCDMA is interference-limited this will reflect to an increase on the overall system capacity by also maintain a satisfactory call quality.

Chapter 6

6 Conclusions

With the introduction of MBMS Services in UMTS Networks, the Radio Network Controller (RNC), for radio efficiency reasons can use either Common (Forward Access Channel – FACH) or Dedicated (Dedicated Channel – DCH) resources to distribute the same content in a Cell. Thus the mobile MBMS users that are on the move may have to deal with dynamic changes of network resources when crossing the cell edge (from Common to Dedicated resources and vice versa). This introduces new mobility issues regarding the handover procedure (MBMS Handovers), since until now, handover in UMTS Network have been considered only between Cells supporting the Service on Dedicated Resources. As we have shown in Section 5.2 using the Current Handover Algorithm when an MBMS handover is executing results in inefficient use of resources.

In this thesis, a new Handover Algorithm is proposed that deals with the new aspects of handover introduced with MBMS. The main idea of the proposed scheme is to minimize the interference caused in the Point-to-Point Cells, by taking full advantage of the Point-to-Multipoint Radio Bearers (Common Resources) benefits. This is accomplished by following a different approach than the Current Handover Algorithm. The new MBMS Handover Algorithm, instead of using a predefined threshold for the handover decision as the Current Handover Algorithm does, uses a dynamic estimation scheme and estimates this threshold value using a number of dynamic parameters, which are influenced by the UE movement. In order to estimate this threshold value the UE during its mobility takes into consideration the following parameters:

- The Coverage of the Point-to-Multipoint Cell
- The Speed and its Direction
- The Handover delay
- The path-loss between the Point to Multipoint Base Station and the UE
- The initial CPICH Transmission Power of the Point to Multipoint Base Station
- The shadow fading value
- The band overlap value
- The Antenna Transmit and Receive gain values

- The total downlink interference caused by other Node_Bs
- The in-band noise caused from background and thermal sources

Since the *Coverage of the Point-to-Multipoint Cell* can be influenced by factors such as obstacles, environmental conditions, and noise and the *Handover Delay* can be influenced by the total load in the Network we also proposed that the task of evaluating these parameters should be given to the RNC and then periodically broadcast them to the UEs in the Cell through the MBMS Point to Multipoint Control Channel (MCCH). Due to the fact that the MCCH currently does not include these fields, we recommend it be enhanced by adding two more fields for the accommodation of these two new parameters.

As it is shown in chapter 5, in all the Scenarios presented, the Proposed MBMS Handover algorithm succeeded significant enhancements on the downlink performance by reducing the interference caused in the Point-to-Point Cells and achieving less power consumption per subscriber. This gain was caused due to ability the of the proposed Handover Algorithm to execute the handover as close as possible to the Point to Point Cell, thus minimizing the maximum downlink power required, at a position where the requested QoS level of the MBMS Service could also be satisfied (On the border of the Point to Multipoint Cell) and also its ability to prevent unnecessary handovers from happening. This capacity enhancement occurs only when the UE has to deal with dynamic changes of resources, i.e. when the UE moves from Dedicated to Common Resources and vice versa, without affecting the Point-to-Multipoint Cells. In wireless/mobile environments where the radio resources are limited, any capacity increase is of major importance therefore we believe that the proposed MBMS handover algorithm is crucial for the MBMS system.

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Appendix A - WCDMA Radio Channels

Logical channels

Logical channels are not actually channels. They can be understood as different tasks the network and the terminal should perform in different moments of time. For the current project, only the Logical channels used in the present study of “Intra-RNC Handover in the MBMS System” are going to be described. The tasks and the Logical channels that are used to perform these tasks are the following:

Dedicated Control Channel (DCCH): When there is a dedicated, active connection the network sends Control information concerning this connection.

Dedicated Traffic Channel (DTCH): The dedicated user traffic for one user service in the downlink direction is sent through this logical channel.

MBMS point-to-multipoint Control Channel (MCCH): This logical channel is used for a p-t-m downlink transmission of control plane information between network and UEs in RRC Connected or Idle Mode. The control plane information on MCCH is MBMS specific and is sent to UEs in a cell with an activated (joined) MBMS service. MCCH can be sent in S-CCPCH carrying the DCCH of the UEs in CELL_FACH state, or in standalone S-CCPCH, or in same S-CCPCH with MTCH. Short indication is always given to UE to when to read MCCH. UTRAN may use in-band notification instead of the MICH to notify users receiving MTCH. Reception of paging has priority over reception of MCCH for Idle mode and URA/CELL_PCH UEs.

MBMS point-to-multipoint Traffic Channel (MTCH): This logical channel is used for p-t-m downlink transmission of user plane information between network and UEs in RRC Connected or Idle Mode. The user plane information on MTCH is MBMS Service specific and is sent to UEs in a cell with an activated MBMS service.

Transport Channels

There are two types of Transport channels. These are the **Common** channels and the **Dedicated** channels:

Dedicated Channel (DCH): The DCH carry dedicated traffic (DTCH) and control information (DCCH). It should be noted that one DCH might carry several DTCH depending on the case. For example, a user may have a simultaneous voice call and video call active. The voice call uses one logical DTCH and the video call requires another logical DTCH. Both of these, however, use the same DCH.

Broadcast Channel (BCH): This channel (carries the content of BCCH), broadcasted from the Base Station (BS), carries information intended for the whole cell and is hence sent out at fairly high power levels because every terminal in the indented cell coverage area must able to “hear” it. The UE must be able to decode the BCH in order to register to the network.

Random Access Channel (RACH): A contention based uplink channel used for transmission of relatively small amount of data, e.g. for initial access or non-real time dedicated control or traffic data.

Forward Access Channel (FACH): Common downlink channel **without Closed-loop power control** used for transmission of relatively small amount of data. This channel carries control information to the UE known to be in the cell. For example, when the RNC receives a random access message (through the RACH) from the terminal, the response is delivered through FACH. In addition to this, the **FACH may carry packet traffic in the downlink direction**. One cell may contain numerous FACH. Also this channel carries the content of MCCH and MTCH Logical channels.

Physical Channels

When the information is collected from the Logical channels and organized to the Transport channels it is in ready-to-transfer format. Before transmitting, the Transport

Channels are arranged to the Physical Channels. The physical channels are used between the Terminal and the Base Station. The physical channels are:

Primary Common Control Physical Channel (P-CCPCH): Carries the BCH in the downlink direction. The P-CCPCH is available in a way that all the terminals populated within the cell coverage are able to demodulate its contents. It uses a fixed channelisation code and thus its spreading code is fixed too. This is a must because otherwise the terminals are not able to “see” and demodulate the P-CCPCH.

Secondary Common Control Physical Channel (S-CCPCH): Carries two transport channels in it: Paging Channel (PCH) and Forward Access Channel (**FACH**). These transport channels may use the same or separate S-CCPCH, thus a cell always contains at least one S-CCPCH.

Dedicated Physical Data Channel (DPDCH): Carries dedicated user traffic. The size of the DPDCH is variable and it may carry several calls/connection in it. As the name says, it is a dedicated channel, which means that it is used between the network and one user.

Dedicated Physical Control Channel (DPCCH): The Dedicated Physical Channels are always allocated as pairs for one connection. The one channel is used for control information transfer and the other for actual traffic. The DPCCH transfers the control information (for example power control information) during the dedicated connection.

Together
carry the
contents
of DCH

Common Pilot Channel (CPICH): is an unmodulated code channel, which is scrambled with the cell-specific scrambling code. It is used for dedicated channel estimation (by the terminal) and to provide channel estimation reference when common channels are concerned. The terminals listen to the pilot signal continuously and this is why it is used for some “vital” purposes in the system, e.g. handover measurements (the UE always searches the most attractive cells and by decreasing the CPICH power level, the cell is less attractive) and cell load balancing (the CPICH power level adjustment balances the load between cells).

Paging Indication Channel (PICH): This channel is used to alert the UE of a forthcoming page message.

MBMS Notification Indicator Channel (MICH): MBMS notification utilizes a new MBMS specific PICH called MBMS Notification Indicator Channel (MICH) in cell. The MBMS notification mechanism is used to inform UEs of an upcoming change in critical MCCH information. The MBMS notification indicators will be sent on an MBMS specific PICH, called the MICH.

Appendix B - MBMS Specific WCDMA Logical Channels

MBMS Point-to-Multipoint Control Channel (MCCH)

This **logical** channel is used for P-t-M downlink transmission of **Control Plane** information between network and the UEs in RRC Connected or Idle mode. The control plane information on MCCH is MBMS specific and is sent to UEs in a Cell with activated an MBMS Service. Short indications are always given to the UE to when to read the MCCH.

The MCCH is always mapped to one specific FACH in the S-CCPCH as indicated on the BCCH. The BCCH is broadcasting the **MBMS System Information** to UEs in order to provide them with information considering the MCCH like:

- MCCH schedule information (Access Info, Repetition Period, Modification Period).
- Configuration of the Radio Bearer carrying the MCCH (e.g. Scrambling Code)

So upon receiving the MBMS System Information the UE shall establish the Radio Bearer Carrying the MCCH channel in the Cell.

MCCH information is split into critical and non-critical information. The **critical** information is transmitted every “Repetition Period” and is made up of the:

- MBMS Service Information
- MBMS Radio Bearer Information
- MBMS Neighbouring Cell Information

The **non-critical** information corresponds to the MBMS Access Information.

MBMS Service Information

The purpose of this signalling flow is for RNC to inform UEs of all the MBMS services available in the Cell. The MBMS Service Information shall be transmitted periodically to **support mobility** in the MBMS service.

For each MBMS Service listed in the MBMS Service Information contains at least the Following information:

- MBMS Service ID,
- Indication if a P-t-M Bearer is established for the Service in the Cell.

The **MBMS service IDs** indicates the MBMS services which are being served in the cell or the MBMS services which can be served if the UE requests it. **P-t-M indication** indicates if the MBMS Service is transmitted on P-t-M or P-t-P channel type in the cell. If the MBMS Service is transmitted on a P-t-M channel type, it informs the UE of the need of reception of the **MBMS Radio Bearer Information**.

MBMS Radio Bearer Information

The purpose of this signalling flow is for the RNC to inform UEs regarding the MTCH radio Bearer Information. The MBMS Radio Bearer Information is only available for P-t-M transmission. For each Service Listed in the MBMS Service Information and indicated that it's transmitted in a P-t-M channel type, contains at least the following information:

- MBMS Service ID
- MBMS UTRAN Cell Group Identifier (MBMS UCG-Id),
- Logical Channel Information
- Transport Channel Information
- Physical Channel Information

An MBMS UTRAN Cell Group Identifier is used to indicate to UEs which MBMS Cell Group the cell pertains to.

MBMS Neighbouring Cell Information

The purpose of the MBMS Neighbouring Cell Information signalling flow is for the UTRAN to inform the UEs of the **MTCH configuration** in the Neighbouring Cells which are available for Selective Combining. Cells that are available for Selective Combining are only Cells that belongs to the same **MBMS Cell Group**. The MBMS Neighbouring Cell Information contains information describing the P-t-M Radio Bearer to which the MBMS Service it is mapped in the Neighbour Cell. For each MBMS Service (MBMS Service ID) that Selective Combining with one or more Neighbouring Cells is possible, the MBMS Neighbouring Cell Information includes for each Neighbouring Cell that Selective Combining is Possible:

- Cell ID,

- Transport channel information in the Cell,
- Physical channel information in the Cell,
- Radio Bearer information in the Cell,
- Selective combining information in the Cell.

With MBMS Neighbouring Cell Information the UE is able to receive MTCH transmission from neighbouring cell without reception of the MCCH of that cell.

MBMS Access Information

The purpose of this signalling flow is for the RNC to inform UE(s) interested in a particular service of the potential need to establish an RRC connection. The MBMS ACCESS INFORMATION is transmitted during counting and re-counting on MCCH and it includes MBMS Service Id for each service for which counting is required and the associated access "probability factor".

MBMS Point-to-Multipoint Traffic Channel (MTCH)

This **logical** channel is used for P-t-M downlink transmission of **user plane** information between network and the UEs in RRC Connected or Idle mode. The user plane information on MTCH is MBMS specific and is sent to UEs in a cell with activated MBMS Service.

The MTCH is always mapped to one specific FACH in the S-CCPCH as indicated on the MCCH.