MBMS Handover Control: A New Approach for Efficient Handover in MBMS Enabled 3G Cellular Networks

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Abstract – Multimedia Broadcast Multicast Service (MBMS) is a new unidirectional (downlink only) Point-to-Multipoint bearer service introduced in Universal Mobile Telecommunication System (UMTS) Release 6 specifications. The advantage of this kind of bearer service compared to legacy UMTS bearer services is that it enables the efficient usage of radio-network and core-network resources (by allowing the resources to be shared), with an emphasis on radio interface efficiency. Due to the new aspects introduced with MBMS, enhanced Radio Resource Management algorithms have to be considered in order to guarantee Quality of Service (QoS), to maintain the planned coverage area, and to offer high capacity during a MBMS session. In this paper we focus our research on Handover Control. We investigate and highlight the inefficiencies caused when a mobile user is receiving an MBMS service and performs a handover adopting the existing Handover approach described in 3GPP TR 25.922 specifications. We therefore propose and evaluate a specific MBMS Handover approach to address the issues highlighted in our analysis.

1 Introduction

The need for efficient data distribution when a large number of users want to receive the same data has led to the definition of Multimedia Broadcast Multicast Service (MBMS) System [1], an enhancement on UMTS Release-6 architecture [2]. The advantage of this kind of bearer service compared to legacy UMTS bearer services is that it enables the efficient usage of core-network and radio-network resources (by allowing the network resources to be shared), with main focus on the radio resource efficiency. In the radio interface Wideband Code Division Multiple Access (WCDMA) [3] is used for the radio resource allocation. A consequence of using WCDMA is that capacity of 3G systems is not hard limited. This means that an additional user entering the system will not be blocked due to exceeding the limited amount of available channels. If a sufficient number of spreading codes is available, the noise rise (Intra- and Inter- Cell interference) due to the increased load introduced by the new user becomes the main capacity-limiting factor in the network.

MBMS is a unidirectional (downlink only) bearer service in which the same stream of data is transmitted from a single source entity to multiple recipients adopting the “Sending data once - Receive multiple copies everywhere” concept (see Figure 1).
With MBMS bearer services, the Core Network will send only one stream of data to the Radio Network Controller (RNC), irrespective of the number of Base Stations (BSs) or User Equipments (UEs) that want to receive it. It is the RNC’s job to replicate and distribute the MBMS content to the UEs in the Cells as efficiently as possible. According to the MBMS specifications defined by the 3GPP [1], MBMS services can be provided in each cell by either Point-to-Multipoint (P-t-M) or by Point-to-Point (P-t-P) transmission, but a dynamic decision should be made as to which approach to adopt, in order to use the scarce resources efficiently (e.g. it is more efficient to use P-t-M for many users and P-t-P for a few users in a cell). This decision is made by the RNC. With the P-t-M transmission one Forward Access Channel (FACH) is established and shared by all the UEs in the Cell (including those near the Cell edge) while with the P-t-P transmission one Dedicated Channel (DCH) is established for each UE in the Cell. The fundamental selection criterion of transmission mode is the amount of Base Station (BS) power required to transmit to the group of MBMS users in the Cell. As a P-t-M transmission (FACH) needs to cover the cell perimeter and be received by all the UEs in the Cell, also those near the Cell’s border, it requires more radio resources (power) than a DCH. Therefore, few DCHs might outperform one FACH in terms of radio resource efficiency. Thus, in some cases where there are few MBMS users in the Cell (e.g. Cell 2) it may be preferable to transmit the required service adopting P-t-P transmission using DCH’s. However if we have a Cell with a considerable number of MBMS users requesting the same MBMS service content (e.g. Cell 1), establishing a common FACH for all users may be the best solution, since it requires less cell resources and decreases the transmit complexity in a way that the service is transmitted for all users in the cell in a unique common channel avoiding multiple transmissions of the same content. This decision requires information on the number of UEs in a Cell that are interested in a given MBMS Service. 3GPP proposes “MBMS Counting” [1], which can be used to determine the optimum transmission mechanism within a Cell for a given service.

![Figure 1 Core and Radio Network use of resources with MBMS](image)

With the aforementioned aspects introduced two different type of MBMS cells will exist: P-t-P and P-t-M transmission mode cells. The mobile users that are on the move and receive an MBMS Service may have to deal with the following four types of handovers when crossing the Cell edge:

1. From P-t-P (DCH) to P-t-P (DCH) transmission mode Cell
2. From P-t-M (FACH) to P-t-M (FACH) transmission mode Cell
3. From P-t-M (FACH) to P-t-P (DCH) transmission mode Cell
4. From P-t-P (DCH) to P-t-M (FACH) transmission mode Cell

The first type (1) of handover can be efficiently executed using the Soft Handover algorithm [4][5][6][7], while the second type (2) of handover can be efficiently executed using the Selective or Soft Combining approach as described in [7]. The last two types of handovers, (3) and (4) have to do with dynamic changes of network resources (from FACH to DCH and vice versa), an issue not yet considered. This dynamic change may efficiently be triggered either within a cell, or when crossing the cell edge. Within a cell a UE counting threshold [8][9] can be used. This is beyond the scope of this paper. In this paper we only address the case when users are crossing a cell edge and handover between cells supporting the same MBMS Service using different types of transmission mode. Throughout this paper we will refer to these types of handovers (3) & (4) as MBMS Handovers.

Since Soft Handover [7] cannot be utilized between different kinds of resources, the new types of MBMS Handovers will be dealt as Hard Handover cases. Adopting the existing Hard Handover algorithm [7] when the mobile users have to deal with the new types of MBMS Handovers will result in inefficiencies, due to the approach used. In this paper we investigate and highlight the inefficiencies caused and propose and evaluate a specific MBMS Handover algorithm to address the issues highlighted in our analysis. The main concept of the proposed scheme is to guarantee Quality of Service (QoS) and achieve increased system capacity during an MBMS Handover, taking into consideration the new aspects introduced. The key in accomplishing this lies in a fuller utilization of the broadcast nature (capacity and coverage characteristics) of Common resources (FACH).

The paper is organized as follows: Section 2 analyses the inefficiencies caused when a UE is performing an MBMS Handover using the existing Hard Handover approach, highlighting the need for a new MBMS Handover Control approach. In Section 3 the proposed MBMS Handover Control approach is described while the Performance Evaluation is presented in Section 4. Section 5 analyses the sensitivity of the proposed scheme. Finally in Section 6 we provide our conclusions and future directions.

2 Motivation for a New MBMS Handover Approach

In this section the inefficiencies caused when the existing Hard Handover approach is employed during an MBMS Handover are analysed and illustrated. Before going into that analysis, a brief description of the channels characteristics that take part in these types of handover (DCH and FACH) and the existing Hard Handover approach is provided.

The FACH channel can be shared by several UEs. Power control is not used on FACH. The amount of transmission power is fixed and allocated to FACH so that it achieves coverage right at the cell edge, with the requested QoS, irrespective of the number and the location of the users that are receiving it at any particular point in time. Since FACH ‘guarantees’ the required QoS only throughout the coverage of the cell, leaving its coverage area will result in progressive signal strength degradation and finally ‘collapse’ of the throughput of the connection.
The DCH channel is dedicated only to one UE and allows the use of fast power control. Fast power control is a crucial aspect of WCDMA because it improves link performance and enhances downlink capacity by reducing the average required transmission power. The transmission power allocated for this channel is variable and increasing exponentially while the UE distance from the BS is increasing in order to compensate for the pathloss, shadowing, fading and interference. In this case, the cell border is ‘soft’, and can be increased, but at the expense of more power.

Taking into consideration the FACH and DCH characteristics described above, it is obvious that in order to guarantee the MBMS Service QoS throughout the handover process and reduce the total downlink power in the P-t-P Cells to the minimum required, the handover should be executed as close as possible to the BS in the P-t-P Cell (P-t-P BS) but not outside of the P-t-M Cell Coverage (switching channels outside of the P-t-M Cell Coverage would degrade the quality of the received signal, and may even result in the total collapse of throughput). Thus the proper place to switch channels is on the Coverage limit of the P-t-M Cell. By doing this, the UE will still be inside the FACH Guaranteed Coverage (thus the MBMS service will be received with the requested QoS) and as close as possible to the P-t-P BS (thus the power used will be the minimum required by the P-t-P BS in order to reach the UE, reducing also the Intra- and Inter- Cell interference caused). Executing the handover anywhere else will mean either underutilization of Common resources (FACH) or degradation on the MBMS service QoS.

According to the existing Hard Handover approach [7], the mobile station performs a handover when the Common Pilot Channel (CPICH) signal strength (Ec/No) of a Neighbouring cell exceeds the CPICH signal strength of the Current cell within a predefined threshold (\(AS_{Rep} _{Hyst}\) - Replacement Hysteresis Threshold) (See Figure 2 - Figure 4). The existing Hard Handover approach only considers the DCH characteristics and it is based on a comparison between the CPICH signal strength transmitted from the BSs taking part in the handover procedure. Adopting this approach to execute an MBMS Handover will result in inefficiencies since it does not guarantee the MBMS handover execution on the Coverage limit of the P-t-M Cell. The aforesaid inefficiencies are illustrated using the Scenario depicted in Figure 2.

In this scenario a UE is moving with a speed of 5 Km/h from a P-t-M Cell (FACH) towards a P-t-P Cell (DCH) receiving an MBMS streaming video of ~60 Kbits/sec and performing a handover adopting the existing handover approach using a \(AS_{Rep} _{Hyst}\) of +3dB. A variety of other threshold values (from -3dB to +3dB) have been tested with different scenarios resulting also in similar inefficiencies. The MBMS session starts at the 120th second of the simulation, so we have also set the UE to start its mobility at that time. The simulation environment used is “Pedestrian Outdoor”. The coverage of both cells is 1000 meters while the distance between the two BSs is ~1800 meters (giving a space of 200 meters overlap). Two instances of the same scenario have been simulated. In the first instance the P-t-P Cell has been configured to be high loaded (High Noise (No)) while in the second instance to be low loaded (Low Noise (No)). The measured CPICH signal strength (Ec/No) received from the attached and monitored BS during UE mobility is illustrated in Figure 3 for Instance 1 and in Figure 4 for Instance 2. The Ec/No denotes the Energy per Chip (Ec) to Noise Spectral Density (No) ratio for one user. Simulation results concerning these two instances have been collected, illustrated and described below.
Adopting the existing Hard Handover approach in Instance 1, where the noise in the P-t-P Cell is high results, as illustrated in Figure 2 & Figure 3, in the execution of handover close to the P-t-P BS at a point outside of the P-t-M cell coverage (Handover Point 1). This is caused due to the high degradation that the high noise (No) in the P-t-P Cell causes on the received P-t-P BS CPICH signal strength (Ec/No) (Monitored Cell), forcing the UE to get closer to the P-t-P BS before the handover condition is met (See Figure 3). Since the transmission power allocated for FACH is
at a level aimed to ensure the requested QoS only throughout the coverage of the P-t-M Cell, once outside the coverage area (at the 750th second of the simulation where the UE is at distance ~1004 meters from P-t-M BS and ~774 meters from the P-t-P BS, as indicated in Figure 5) the signal strength of the FACH will start degrading, resulting in the loss of packets, and even total collapse of the throughput, until the handover’s condition is met and the UE is handed over to the P-t-P Cell (at 776th second of the simulation where the UE is at a distance ~1044 meters from P-t-M BS and ~734 meters from the P-t-P BS as indicated in Figure 5).

On the other hand, adopting the existing Hard Handover approach in Instance 2, where the noise in the P-t-P Cell is low results, as illustrated in Figure 2 & Figure 4, in the execution of the handover before the UE leaves the Coverage limit of the P-t-M Cell (Handover Point 2). In this case we will not have any degradation on the QoS of the received traffic, since the UE is still inside the FACH Guaranteed Coverage. But, considering that the requested QoS can be supported up to the coverage limit of the cell (that is ~1000 meters from the P-t-M BS) this results in inefficient use of common (FACH) resources since the UE could continue receiving the MBMS Service, without QoS deterioration, up until the coverage limit, and thus execute the handover closer to the P-t-P BS. This would result in less power consumption and thus less interference in the P-t-P cell. This inefficiency is highlighted in Figure 6. The black thin discontinued line shown in Figure 6 indicates the point in time (at 615th second of the simulation where the UE is at distance ~822 meters from the P-t-M BS and ~956 meters from the P-t-P BS) where the handover was actually executed. As it is shown, after handover execution, the total downlink power required in the P-t-P Cell increased from 0.07 watts to 0.43 watts. Note that the black thick discontinued line shown in the same figure, indicates the point in time where the handover should be executed (at 755th second of the simulation where the UE is at distance ~1000 meters from the P-t-M BS and ~778 meters from the P-t-P BS), considering that FACH can be utilized up to the Coverage limit of the P-t-M cell. This would result in a much lower power consumption (0.22 watts instead of 0.43 watts) in the P-t-P Cell since the handover will be triggered closer to the P-t-P BS, providing a gain of about 2.9 dB for the presented case.

Figure 5 Traffic Received (bits/sec) when the existing handover approach is applied
The results illustrated above (QoS degradation and inefficient use of Common Resources) highlight the reason why a specific handover control approach is essential for mobile users receiving an MBMS service and performing an MBMS Handover. A vital aspect for the efficient execution of these types of handover is the consideration of the FACH capacity and coverage characteristics, a feature not considered in the existing Handover Control approach.

3 Proposed MBMS Handover Control Algorithm

The aim of the proposed MBMS Handover Control algorithm is to compensate for the inefficiencies described in Section 2, guarantee Quality of Service (QoS), and achieve increased system capacity during an MBMS handover. The key in accomplishing this lies in a fuller utilization of the broadcast nature (capacity and coverage characteristics) of Common resources (FACH) by executing the MBMS handover (Switch channels) on the Coverage limit of the P-t-M Cell (See Figure 7 & Figure 8).

Since some signalling delay is caused from the time the handover is triggered until the UE switches channels (Handover Delay time ($\Delta t$)), in order to switch channels on the Coverage limit of the P-t-M Cell the MBMS handover should be triggered at some distance (Handover Delay Distance (HDD)) before the UE reaches this point, anticipating the Handover Delay time ($\Delta t$). Therefore, if the UE is moving from a P-t-P towards a P-t-M Cell, the MBMS Handover should be triggered before the UE enters the Coverage of the P-t-M Cell, at distance $D$ equal to the Coverage of P-t-M Cell + HDD from the P-t-M BS (See Figure 7). On the other hand, if the UE is moving from a P-t-M towards a P-t-P Cell, the MBMS Handover should be triggered before the UE leaves the Coverage limit of the P-t-M Cell, at a distance $D$ equal to the Coverage of P-t-M Cell - HDD from the P-t-M BS (See Figure 8).

With the existing Handover Control approach, the main input in making the handover decision is the CPICH signal strength ($E_c/No$) received by the UE from the BSs within reach. In the proposed MBMS Handover approach, we use the same measurable input (i.e. the CPICH from the P-t-M BS) for triggering the handover, by expressing the distance $D$ as an equivalent CPICH signal strength (See Section 3.1). We refer to this value as the “MBMS Handover Trigger Threshold” and it is measured in decibel (dB). The UE during its mobility measures the CPICH signal

![Figure 6 Total Downlink Power required by the P-t-P Base Station (watts) after handover in the P-t-P Cell](image)
strength transmitted from the P-t-M BS. When the measured CPICH signal strength becomes equal to the “MBMS Handover Trigger Threshold” the MBMS Handover is triggered. This “MBMS Handover Trigger Threshold” is dynamically estimated by the UE during its mobility and its value mainly depends on the propagation environment (e.g. Pedestrian Outdoor, Vehicular, Open Space etc.), the Coverage of the P-t-M Cell and the HDD.

![Figure 7 Proposed MBMS Handover Control approach – From P-t-P to P-t-M Cell MBMS Handover case](image)

In order to prevent the UE from any unnecessary processing during mobility (e.g. estimation of “MBMS Handover Trigger Threshold”) we introduce the idea of an “MBMS Handover Activation Area”, inside which the MBMS Handover is most likely to happen. We define the “MBMS Handover Activation Threshold (HAT)” (See Section 3.2) as a point on the border of this area.

![Figure 8 Proposed MBMS Handover Control approach – From P-t-M to P-t-P Cell MBMS Handover case](image)

In order to simplify analysis and illustrate our ideas, we assume that the UE is on Line of Sight (LOS) with the P-t-M BS, the Coverage of the P-t-M cells is represented as homogeneous circles and the UE can accurately measure the CPICH transmitted from the P-t-M BS. Future extensions of this work aim to relax these assumptions by introducing shadow fading (NLOS) and non-homogeneous cell sizes.

### 3.1 Estimating the “MBMS Handover Trigger Threshold”

As discussed earlier, the “MBMS Handover Trigger Threshold” is an equivalent expression of distance to decibels (dB). In order to estimate this value, the pathloss between the UE and the P-t-M BS has to be considered. The pathloss can be estimated using the propagation model of the Cell environment [10] defined by the International...
Telecommunications Union (ITU). For example, for a Pedestrian Outdoor propagation model, the pathloss is estimated using the formula shown below; where \( R \) is the distance between the UE and BS in Km and \( \text{freq} \) is the Carrier frequency in MHz.

\[
\text{Pathloss} = 40 \times \log_{10} R + 30 \times \log_{10} \text{freq} + 49
\]

For \( \text{freq} \) equal to 2000 MHz used for UMTS band application and for \( R \) equal to the estimated distance \( D \), the formula becomes:

\[
\text{Pathloss} = 40 \times \log_{10} D + 148
\]

By estimating the pathloss and by taking into consideration the initial CPICH Transmission Power used by the P-t-M BS (\( \text{tx\_power} \)), fixed according to the network operator requirements, and the Antenna Transmit (\( \text{tx\_ant\_gain} \)) and Receive (\( \text{rx\_ant\_gain} \)) gain values, we can estimate the CPICH power that the UE should receive at distance \( D \) from the P-t-M BS (\( \text{rcvd\_power} \)). Then, by taking into consideration the total downlink interference caused by other Node_Bs (\( \text{inoise} \)) and the in-band noise caused from background and thermal sources (\( \text{rx\_bkgnoise} \)) measured by the UE, the “MBMS Handover Trigger Threshold” can be estimated. Assuming Line Of Sight (LOS), the MBMS Handover Trigger Threshold (\( \text{MBMS\_HT\_Thres} \)) is:

\[
\text{MBMS\_HT\_Thres} = 10 \times \log_{10} \left( \frac{\text{tx\_power} \times \text{tx\_ant\_gain} \times \text{rx\_ant\_gain}}{\text{inoise} + \text{rx\_bkgnoise} \times \text{pathloss}} \right) \tag{1}
\]

The UE during its mobility will measure the P-t-M BS CPICH signal strength (\( \text{Ec}/\text{No} \)) and when it is equal to the estimated MBMS Handover Trigger Threshold (1) the MBMS Handover will be triggered.

### 3.2 Estimating the “MBMS Handover Activation Threshold”

As discussed above, the aim of the “MBMS Handover Activation Threshold” is to indicate to the UE that it is entering an area where an MBMS Handover is most likely to happen (MBMS Handover Activation Area) and start measuring the required parameters for the efficient execution of the Handover (e.g. Speed, Direction, Handover Delay time, Handover Delay Distance, MBMS Handover Trigger Threshold). The aim of this threshold is to avoid any unnecessary processing outside of this area.

According to what type of MBMS Handover is likely to be executed, a different approach will be used for the estimation of this threshold. For example, if the UE is moving from a P-t-P towards a P-t-M Cell, the “MBMS Handover Activation Threshold” is estimated as the equivalent CPICH Signal Strength at an equivalent distance equal to the Coverage of P-t-M Cell + Handover Activation Distance from the P-t-M BS (See Figure 7). On the other hand, if the UE is moving from a P-t-M towards a P-t-P cell this threshold is estimated as the equivalent CPICH Signal Strength at an equivalent distance equal to the Coverage of P-t-M Cell - Handover Activation Distance from the P-t-M BS (See Figure 8).

The Handover Activation Distance is set at a safe fixed value that indicates the distance from the Coverage limit of the P-t-M Cell where an MBMS Handover is possible to be triggered. In this paper the Handover Activation Distance is set at 50
meters. We assume the Maximum Speed of the UE is 120 Km/hour (33.33 meters/second) and the maximum Handover Delay time (Δt) is set to 1.2 seconds (as indicated in Section 5.1), which is equivalent to ~40 meters, plus a 10 meters safety factor.

Note that the “MBMS Handover Activation Threshold” is calculated using eq. (1).

3.3 Estimating the distance D
As stated above, the value of the distance D depends on two parameters; the Coverage of P-t-M Cell (FACH Guaranteed Coverage) and the Handover Delay Distance (HDD). The section below describes how these two parameters are acquired.

3.3.1 Coverage of P-t-M Cell
The Coverage of a cell (and thus in our case the Coverage of the P-t-M Cell) is not the same for all Cells and might vary according to the network operator’s requirements (requirements concerning coverage and capacity) and the radio propagation in the area. For example, the coverage of cell varies depending on the environmental setting (e.g. Pedestrian, Vehicular, Open Space etc.) and user density (e.g. Hotspots, Rural area etc.). Since it is impossible for the UE to know the value of this parameter without any feedback from the Network, the task of informing the UEs about the value of this parameter is assigned to the RNC. The RNC will include this information in the MBMS Point-to-Multipoint Control Channel (MCCH) (an MBMS Specific Channel) [1][11] and broadcast it to the UEs. Since the MCCH already includes information in relation to the MBMS Service supported in the Current and Neighbouring Cells (MBMS Current Cell P-t-M Radio Bearer Information [11] and MBMS Neighbouring Cells P-t-M Radio Bearer Information [11] respectively) the “Coverage of P-t-M Cell” value can also be included there. Thus, according to the type of MBMS Handover that the UE is going to perform it will read the MCCH and retrieve the Coverage of P-t-M Cell either from the MBMS Current Cell P-t-M Radio Bearer Information (if the UE is moving from P-t-M towards a P-t-P Cell) or from the MBMS Neighbouring Cell P-t-M Radio Bearer Information (if the UE is moving from P-t-P towards a P-t-M Cell). This information needs to be retrieved only once for each cell since the Coverage of the P-t-M Cell is fixed and set according to the network operator’s requirements.

3.3.2 Handover Delay Distance (HDD)
The HDD denotes the distance between the UE and the Coverage limit of the P-t-M Cell that the MBMS Handover should be triggered in order for the handover to be efficiently executed on the Coverage limit of the P-t-M Cell. In contrast to the Coverage of P-t-M Cell parameter that is fixed, the HDD is dynamic and will be estimated by the UE during its mobility. The value of this parameter depends on the Handover Delay time (Δt) (measured in seconds), the Speed (measured in meters/second) and the Direction (measured in degrees – angle φ) of the UE.

The Handover Delay time (Δt), the Speed and the Direction of the UE are variable parameters and can change through time. The Handover Delay time (Δt), varies according to the different delays (e.g. Queuing Delay) that are caused during the handover signalling according to the current load in the RNC. Since it is impossible for the UE to know the value of this parameter without any feedback from the
Network, the task of evaluating this parameter is assigned to the RNC. The RNC will periodically estimate this value and broadcast it to the UEs through the MCCH. On the other hand, the Speed and the Direction of the UE can be estimated by itself during its mobility. For the estimation of the Speed and the Direction of the UE various positioning methods can be used [12] [13]. For example, the Observed Time Difference of Arrival (OTDOA) positioning and the Assisted GPS positioning approaches were selected for UMTS networks by the 3GPP [3]. After evaluating the aforementioned parameters (Handover Delay time ($\Delta t$), Speed and Direction) the UE is able to estimate the HDD. The HDD calculation formula depends on the type of MBMS Handover that the UE will execute.

First we describe the case where the UE is moving from a P-t-P towards a P-t-M Cell (See Figure 9). If the UE is moving with some Speed and the Handover Delay time is equal to $\Delta t$, then from the time the Handover is triggered the UE will switch channels after it covers a $\Delta t \times \text{Speed}$ distance. If the Direction of the UE is exactly towards the P-t-M BS (with an angle $\phi$ equal to 0°) the MBMS Handover will be triggered immediately since the UE will reach the coverage limit after $\Delta t \times \text{Speed}$ distance. Thus in this case ($\phi = 0^\circ$) the HDD is equal with $\Delta t \times \text{Speed}$. This is also equal to the maximum value that the HDD can take. On the other hand, if the Direction of the UE is not exactly towards the P-t-M BS (with an angle $\phi$ greater than 0°) the UE will have to cover a ($\Delta t \times \text{Speed}$) + $\Delta d$ distance until it reaches the coverage limit (See Figure 9). In this case the UE should cover a $\Delta d$ distance first before triggering the MBMS Handover, otherwise the channel switching will be performed at $\Delta d$ distance outside of the P-t-M Cell coverage, possibly resulting in degradation in the quality of the received signal. Thus a new HDD must be considered here. The formula used to estimate the HDD when the UE is moving from a P-t-P towards a P-t-M Cell is shown in (2) (its derivation is presented in Appendix A.1).

\[
\begin{align*}
HDD &= \begin{cases} 
\sqrt{\Delta d^2 + (\text{Cov} + a)^2 - 2 \times \Delta d \times (\text{Cov} + a) \times \cos \phi - \text{Cov}} \quad \text{if } \phi > 0^\circ \\
\text{Cov} \times \sin \left( \arcsin \left( \frac{\text{Cov} + a}{\text{Cov}} \times \sin \phi \right) - \phi \right) - a \quad \text{if } \phi = 0^\circ
\end{cases} \\
\Delta d &= \frac{\text{Cov} \times \sin \left( \arcsin \left( \frac{\text{Cov} + a}{\text{Cov}} \times \sin \phi \right) - \phi \right)}{\sin \phi} - a
\end{align*}
\]
\[ a = \Delta t \times \text{Speed} \quad \& \quad \text{Cov} = \text{Coverage \_ Of \_ PtM \_ Cell} \]

The case where the UE is moving from a P-t-M towards a P-t-P Cell follows a similar approach as above. What differs is the resultant formula (3) to estimate the HDD (its derivation is presented in Appendix A.2).

\[
\text{HDD} = \begin{cases} 
\frac{\text{Cov} - \sqrt{\Delta d^2 + (\text{Cov} - a)^2} + 2 \times \Delta d \times (\text{Cov} - a) \times \cos \phi}{a} & \text{if } \phi > 0^\circ \\
\frac{\text{Cov} \times \sin \left( \phi - \arcsin \left( \frac{\text{Cov} - a}{\text{Cov}} \times \sin \phi \right) \right)}{\sin \phi} - a & \text{if } \phi = 0^\circ 
\end{cases}
\]

\[ a = \Delta t \times \text{Speed} \quad \& \quad \text{Cov} = \text{Coverage \_ Of \_ PtM \_ Cell} \]

### 3.4 Proposed Algorithm

In this section we present the proposed algorithm. It is worth pointing out that in order to minimise execution time overhead the main algorithm is activated only when the UE is in the “MBMS Handover Activation Area”. Therefore, the proposed algorithm is divided into two phases:

- **Phase 1:** Outside of the MBMS Handover Activation Area
- **Phase 2:** Inside the MBMS Handover Activation Area

**Phase 1: Outside MBMS Handover Activation Area:**

The UE during mobility measures the CPICH Signal Strength (Ec/No) transmitted from Current and Neighbouring Base Stations. By ranking the neighbouring BS CPICH signal strength and the presence of the MBMS Neighbouring Cell P-t-M Radio Bearer Information (transmitted through the MCCH) the UE can determine the type of Cell (P-t-P or P-t-M) that is likely going to handover (Target Cell). By also taking into consideration the type of transmission mode currently supported in the Current Cell the UE determines if and what type of MBMS Handover is likely to be executed.
If an MBMS Handover is likely to be executed then the UE will estimate the “MBMS Handover Activation Threshold” (See Section 3.2).

**Phase 2: Inside the MBMS Handover Activation Area:**
Phase 2 is divided into three steps, initiated based on three thresholds.
- **Activation Step:** Initiated by the “MBMS Handover Activation Threshold”
- **Step 1:** Initiated by the “MBMS Handover Trigger Threshold 1”
- **Step 2:** Initiated by the “MBMS Handover Trigger Threshold 2”

**Activation Step:**
This step is activated by the “MBMS Handover Activation Threshold” notifying the UE that it has entered the “MBMS Handover Activation Area”. Upon entering this area, the UE will periodically (Period $T$) estimate the “MBMS Handover Trigger Threshold 1” based on the Coverage of the P-t-M Cell and the maximum value that the HDD can take (See Section 3.3.2). The maximum HDD will be equal to the current UE Speed $\times$ current Handover Delay time ($\Delta t$) during this Period.

The $Period T$ is a parameter that influences the efficiency of the MBMS Handover execution. For example, setting $T = 5$ sec might prove sufficient for a terminal with a speed of 5 km/hr (it covers ~7 meters in 5 sec). However, the same period might prove inefficient for a terminal with a speed of 120km/hr (it covers ~166 meters during 5 sec). Therefore, the selection of $Period T$ should be a function of the terminal speed. For example, given the tolerance of about 8 meters deviation from the Coverage limit of the P-t-M Cell (as discussed in section 5.1), for a mobile user moving with a speed of 120Km/hour a period $T=0.1$ seconds (that is sample every ~3 meters) is good choice, whilst for a mobile user with a speed of 30Km/hr a period $T=0.4$ seconds (that is sample every ~3 meters) is reasonable. To allow smooth changes in $T$, an exponential weighted moving average adaptive formula for $T$ is proposed as follows:

$$T = (1 - \gamma)T + \frac{3\gamma}{UE \_speed}$$  \hspace{1cm} (4)

Where UE speed is in meters/sec and $\gamma=0.8$ allows for the influence of past sample to decreases exponentially fast. A dead-zone can also be included to minimize changes in $T$.

**Step 1:**
This step is initiated by the “MBMS Handover Trigger Threshold 1”. Upon initiation of this step, the UE will estimate its Direction (angle $\varphi$). If the estimated angle $\varphi$ is equal to 0° then the MBMS Handover will be triggered (thus avoiding Step 2).

If not, the “MBMS Handover Trigger Threshold 2” will be estimated. This threshold will be estimated only once and will be based on the Coverage of the P-t-M Cell and a new HDD. The new HDD is estimated this time by taking into consideration not only the Speed of the UE and the Handover Delay time ($\Delta t$) but also the Direction of the UE (See Section 3.3.2). This threshold will be estimated only once since the distance between Step 1 and Step 2 are so close that providing minor possibilities for Speed, Direction and Handover Delay time to change considerably during this period.

**Step 2:**
This step is initiated by the “MBMS Handover Trigger Threshold 2”. Upon reached, the MBMS Handover is triggered. This is also the last step of the proposed approach.

Depending on the type of MBMS Handover that is executing, we have two variations of the algorithm. Below we present in detail the “from P-t-P to P-t-M Cell” MBMS Handover, and then sketch the differences when “from P-t-M to P-t-P Cell” MBMS Handover is executing.

### 3.4.1 From Point-to-Point to Point-to-Multipoint Cell MBMS Handover

The case where a UE is moving from a P-t-P towards a P-t-M Cell is depicted in Figure 11.

**Figure 11 Proposed MBMS Handover approach description: From P-t-P to P-t-M Cell MBMS Handover**

In this type of handover, the thresholds are estimated as follows:

- **“MBMS Handover Activation Threshold”:** Equal the P-t-M BS CPICH Signal Strength (Ec/No) that the UE would measure at a distance equal with Coverage of P-t-M Cell + Handover Activation Distance from the P-t-M BS.

- **“MBMS Handover Trigger Threshold 1”:** Equal the P-t-M BS CPICH Signal Strength (Ec/No) that the UE would measure at a distance equal with Coverage of P-t-M Cell + Maximum HDD from the P-t-M BS.

- **“MBMS Handover Trigger Threshold 2”:** Equal the P-t-M BS CPICH Signal Strength (Ec/No) that the UE would measure at a distance equal with Coverage of P-t-M Cell + new HDD from the P-t-M Base Station

**Phase 1: Outside of the MBMS Handover Activation area**

The UE determines that is likely going to execute a “from P-t-P to P-t-M Cell” and estimates the “MBMS Handover Activation Threshold” (See Section 3.2). The UE remains in this Phase if one of the following is met:

- If the UE is likely to execute a “from P-t-P to P-t-M” but the measured P-t-M BS CPICH Signal Strength is weaker (<) than the “MBMS Handover Activation Threshold”.

---

Figure 11 Proposed MBMS Handover approach description: From P-t-P to P-t-M Cell MBMS Handover

In this type of handover, the thresholds are estimated as follows:

- **“MBMS Handover Activation Threshold”:** Equal the P-t-M BS CPICH Signal Strength (Ec/No) that the UE would measure at a distance equal with Coverage of P-t-M Cell + Handover Activation Distance from the P-t-M BS.

- **“MBMS Handover Trigger Threshold 1”:** Equal the P-t-M BS CPICH Signal Strength (Ec/No) that the UE would measure at a distance equal with Coverage of P-t-M Cell + Maximum HDD from the P-t-M BS.

- **“MBMS Handover Trigger Threshold 2”:** Equal the P-t-M BS CPICH Signal Strength (Ec/No) that the UE would measure at a distance equal with Coverage of P-t-M Cell + new HDD from the P-t-M Base Station
• The UE is not likely going to execute an MBMS Handover
When the measured P-t-M BS CPICH Signal Strength becomes \textit{equal or stronger} (\(\geq\))
with the \textit{“MBMS Handover Activation Threshold”} the algorithm transits to Phase 2.

\textbf{Phase 2: Inside the MBMS Handover Activation Area}

\textit{Activation Step:}
Initiated when the measured P-t-M BS CPICH Signal Strength becomes \textit{equal or stronger} (\(\geq\))
with the \textit{“MBMS Handover Activation Threshold”}. This indicates that
the UE has entered the \textit{“MBMS Handover Activation Area”} and will start execution
by estimating (periodically – Period T) the \textit{“MBMS Handover Trigger Threshold 1”}.

Note that from within this Step, if the measured P-t-M BS CPICH Signal Strength
becomes \textit{weaker} (<) than the \textit{“MBMS Handover Activation Threshold”} then we go
back to Phase 1.

\textit{Step 1:}
Initiated when the measured P-t-M BS CPICH Signal Strength becomes \textit{equal or stronger} (\(\geq\))
with the \textit{“MBMS Handover Trigger Threshold 1”}. The UE will estimate
its Direction (Angle \(\phi\)). If the estimated angle \(\phi\) is equal to \(0^\circ\) then the MBMS
Handover will be triggered immediately, thus avoiding the \textit{Step 2} (in this case the
MBMS Handover ends here).

On the other hand, if the estimated angle if greater than \(0^\circ\), then the UE will estimate
the \textit{“MBMS Handover Trigger Threshold 2”}.

Note that from within this Step, if the measured P-t-M BS CPICH Signal Strength
becomes \textit{weaker} (<) than the \textit{“MBMS Handover Trigger Threshold 1”} then we go
back to Activation Step.

\textit{Step 2:}
Initiated when the measured P-t-M BS CPICH Signal Strength becomes \textit{equal or stronger} (\(\geq\))
than the \textit{“MBMS Handover Trigger Threshold 2”} then MBMS Handover
will be triggered.

For easy reference, the above algorithm is summarized in the following flow chart
\textit{(Figure 12)}. 15
3.4.2 From Point-to-Multipoint to Point-to-Point MBMS Handover

The case where the UE is moving from a P-t-M towards a P-t-P Cell (See Figure 12) is handled using the same approach as described above. What differs is the way the UE estimates the three thresholds (in this case subtracted instead of added) and the way the UE transits between the two Phases and the three Steps referred above (all comparisons are opposite from the algorithm for P-t-P to P-t-M MBMS Handover).
3.5 Processing Complexity and Signalling Overhead

In this section we analyze the processing complexity (both in UE and RNC) and the signalling overhead introduced (overhead in MCCH) with the proposed approach.

**Processing Complexity introduced in the UE:**

With the proposed approach the UE estimates the following parameters:

- MBMS Handover Activation Threshold using eq. (1)
- MBMS Handover Trigger Threshold 1 using eq. (1)
  - Maximum Handover Delay Distance ($\Delta t \times \text{Speed}$)
- MBMS Handover Trigger Threshold 2 using eq. (1)
  - Handover Delay Distance (using eq. 2 or eq. 3 according to the MBMS Handover that is executing).

The calculation of Eq. 1 involves the evaluation of about 2 logarithms, 2 additions and 5 multiplications. Eq. 2 and Eq. 3 are more complex and involve the evaluation of a sqrt, 4 trigonometric functions, 5 multiplications and 2 additions.

The “MBMS Handover Activation Threshold” is estimated using eq. (1). This parameter is estimated only once (outside of the “MBMS Handover Activation Area” when an MBMS Handover is likely to be executed). Its value is based on the Coverage of the P-t-M Cell and the Handover Activation Distance. The Coverage of the P-t-M Cell is acquired (only once since it is fixed and set according to the operator’s requirements) through the MCCH while the Handover Activation Distance is set at a constant value (known by the UE), thus no extra processing is required for their estimation. Therefore, the processing complexity introduced in the UE for the estimation of this parameter is negligible.
The “MBMS Handover Trigger Threshold 1” can also be estimated using eq. (1). This value of the parameter depends on the **Coverage of the P-t-M Cell** and the **Maximum Handover Delay Distance**. Due to the fact that the **Maximum Handover Delay Distance** varies according to the **current Speed** of the UE and **current Handover Delay time** ($\Delta t$) the value of “MBMS Handover Trigger Threshold 1” is variable. As indicated in **Figure 11**, the value of this parameter should be periodically (period $T$) estimated (by estimating its **current Speed** and by acquiring the **Handover Delay time** ($\Delta t$) from the MCCH) from the time the UE enters the “**MBMS Handover Activation Area**” (Activation Step) until Step 1 is reached. This is also the area where most of the processing occurs. As indicated in section 3.2 the UE during its mobility in this area will have to estimate its Speed and Handover Delay time ($\Delta t$) every ~3 meters distance. Taking into consideration that the “**MBMS Handover Activation Area**” is about 50 meters from the **Coverage limit of the P-t-M Cell**, the UE during its mobility towards the Coverage limit will have to take about 18 samples during this period. Thus although some processing complexity is introduced here, the effort taken by the UE can be considered acceptable, considering the gain benefits.

The “**MBMS Handover Trigger Threshold 2**” can also be estimated using eq. (1). This value of the parameter depends on the **Coverage of the P-t-M Cell** and the **new Handover Delay Distance**. As indicated above the **Coverage of the P-t-M Cell** is already known to the UE. Thus only the **new HDD** should be considered, which depends on the **Speed** and **Direction** of the UE and the **Handover Delay time** ($\Delta t$). The **Handover Delay time** ($\Delta t$) is obtained through the MCCH thus no processing complexity is introduced for the estimation of this parameter. On the other hand, the **Speed** and **Direction** of the UE will be estimated by itself during its mobility. Since the value of this parameter as indicated in the description of the algorithm will be estimated only once no heavy processing complexity is introduced.

**Processing Complexity introduced in the RNC:**

With the proposed approach the RNC will have to estimate the following parameters:

- **Coverage of P-t-M Cell**
- **Handover Delay time** ($\Delta t$)

No processing complexity is required for the estimation of **Coverage of the P-t-M Cell** parameter since it is fixed and set according to the operator’s requirements.

The **Handover Delay time** on the other hand requires some but minor computational effort since the RNC will have to estimate the **Handover Delay time** experienced by other UEs and include the estimated value in MCCH channel.

**Signalling Overhead introduced (in the MCCH):**

With the proposed approach the MCCH will have to accommodate two more values:

- **Coverage of P-t-M Cell**
- **Handover Delay time** ($\Delta t$)

The **Coverage of P-t-M Cell** can be accommodated in the **MBMS Current Cell P-t-M Radio Bearer Information [11]** and **MBMS Neighbouring Cells P-t-M Radio Bearer Information [11]** already included in the MCCH, thus not additional overhead will be experienced.
On the other hand, due to the fact that the MCCH currently does not include a field for the Handover Delay time it should be enhanced with one more field in the size of one byte, in order to accommodate this new parameter. Thus one extra byte signalling overhead is introduced by this additional field.

4 Performance Evaluation

For the performance evaluation of the proposed scheme the OPNET Modeller 11.0.A UMTS module [14] was used as a base for building the MBMS simulator [18]. The performance was evaluated by comparing the amount of capacity (total downlink power) that becomes available, and the QoS level experienced when the proposed scheme is used instead of the currently used Handover Algorithm. For the currently used algorithm the $AS_{Rep\_Hyst}$ was set at 0dB (see Figure 3). A series of 6 scenarios (Scenario 1 – Scenario 6) are used in order to illustrate the feasibility, the performance and the usefulness of the proposed scheme.

4.1 Scenarios Description

Scenario 1 to Scenario 4 are simple Two Cell Scenarios, while Scenario 5 and Scenario 6 are more complex Multi-Cell environment Scenarios.

4.1.1 Two Cells Scenarios

Scenario 1 considers the case where a group of 10 UEs are moving from a P-t-P Cell towards a P-t-M Cell with a speed of 60 Km/h, while scenario 2 considers the vice versa case (Figure 14). The simulation environment used is “Vehicular Outdoor”. All the UEs are expected to receive an MBMS Streaming video of 60 Kbits/sec. The coverage of the cells is 1 Km while the distance between the two BSs is 1800 meters (giving a space of 200 meters overlap). Scenario 3 and Scenario 4 on the other hand are exactly the same as 1 and 2, but with a pedestrian environment. The pedestrian speed is set at 6km/h. Two instances of each scenario have been simulated using the existing and proposed Handover Control approach respectively. Results concerning Scenario 1 to Scenario 4 have been collected, compared and illustrated in section 4.2.1.

![Figure 14 Two Cells Scenarios (1 - 4): Group of 10 UEs moving from a P-t-P towards a P-t-M Cell and vice versa](image)

4.1.2 Multi-Cell Scenarios

Scenario 5 (Figure 15) considers the case where groups of 5 UEs (a total of 30 UEs) are moving from surrounding Point-to-Multipoint Cells towards a central Point-to-Point Cell. Scenario 6 (Figure 16) on the other hand considers the case where group of 10 UEs (a total of 60 UEs) are moving from surrounding Point-to-Point Cells towards a central Point-to-Multipoint Cell. The following simulation parameters...
correspond to both aforementioned scenarios. The UEs are moving with a speed of 6 Km/h, in a “Pedestrian Outdoor” environment. All the UEs are expected to receive an MBMS Streaming video of 60 Kbits/sec. The coverage of all Cells is 1000 meters (with an overlap of 200 meters). Two instances of each scenario have been simulated using the existing and proposed Handover Control approach respectively. Results concerning Scenario 5 and Scenario 6 have been collected, compared and illustrated and described in section 4.2.2. UE 1 and UE 2 have been indicated in the figure below because results concerning the bit rate received for these two UEs are illustrated.

Figure 15 Multicell Scenario 5: Groups of 5 UEs moving from surrounding P-t-M Cells towards a Central P-t-P Cell

Figure 16 Multicell Scenario 6: Groups of 10 UEs moving from surrounding P-t-P Cells towards a Central P-t-M Cell

4.2 Results

In this section the results collected from the scenarios described above are illustrated compared and described.

4.2.1 Two Cells Scenarios (Scenario 1 to Scenario 4)

The results collected from the two instances of scenario 1 concerning the capacity requirements (watts) in the P-t-P Cell during the from P-t-P to P-t-M MBMS when the Existing and Proposed Handover approach is applied are compared and illustrated in Figure 17.
From Figure 17 we can deduce that the UEs moving from the P-t-P towards the P-t-M Cell increase the demanded capacity (power) in the P-t-P cell while moving away from the P-t-P BS. By using the proposed MBMS Handover approach instead of the existing one, a substantial decrease on the total power used is observed, thus reducing the maximum downlink power required in the P-t-P Cell from 2 watts to 1.03 watts (~50% decrease). This is caused due to the ability of the proposed scheme to release the DCH established in the P-t-P cell as soon as the FACH signal strength becomes adequate to ensure the detection of the signal with the requested Bit Error Rate (BER). This results in the execution of handover as close as possible to the P-t-P Base Station thus reducing the interference caused in the P-t-P Cell and achieving less power consumption per subscriber. Moreover, the radio resources in the P-t-P Cell are released much sooner (~20 seconds sooner as depicted in Figure 17), thus making space for new admissions in the cell.

The results collected from the two instances of Scenario 2 concerning the capacity requirements in the P-t-P Cell during the “From P-t-M to P-t-P MBMS Handover” when the Existing and Proposed Handover approach is applied are compared and illustrated in Figure 18.

From Figure 18, we can deduce that the UEs moving from the P-t-M towards the P-t-P Cell increase the demanded capacity (power) in the P-t-P cell after handover. By
using the proposed MBMS Handover approach instead of the existing one a substantial decrease on the total power used is observed, reducing the maximum downlink power required in the P-t-P Cell from 1.53 watts to 0.96 watts (~37% decrease). The reason for achieving this capacity gain is the ability of the proposed scheme to force the UE to stay tuned to the FACH channel as long as its signal strength is adequate for detecting the signal with the requested Bit Error Rate (BER). As in scenario 1, this will result in the execution of handover as close as possible to the P-t-P Base Station and reduce the demanded capacity in the P-t-P cell to the minimum. Moreover, the radio resources in the P-t-P Cell are allocated much later (~10 seconds later), thus not causing additional interference in the P-t-P cell during this period and giving space for other admissions.

The results obtained for Scenario 3 and Scenario 4 are similar. We tabulate and compare in Table 1 below:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Speed</th>
<th>Attribute</th>
<th>Proposed</th>
<th>Current</th>
<th>Gain over existing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario 1</strong></td>
<td></td>
<td>Max Power (W)</td>
<td>1.03 watts</td>
<td>2 watts</td>
<td>50%</td>
</tr>
<tr>
<td>P-t-P to P-t-M</td>
<td>60 km/h</td>
<td>Time to handover</td>
<td>164 sec, 171 sec</td>
<td>177 sec, 191 sec</td>
<td>~20 seconds earlier</td>
</tr>
<tr>
<td>P-t-M to P-t-P</td>
<td>60 km/h</td>
<td>Time to handover</td>
<td>0.96 watts, 1.53 watts</td>
<td>1.66 sec, 1.78 sec</td>
<td>37%</td>
</tr>
<tr>
<td>P-t-P to P-t-M</td>
<td>6 km/h</td>
<td>Max Power (W)</td>
<td>1.63 watts</td>
<td>2.76 watts</td>
<td>41%</td>
</tr>
<tr>
<td>P-t-M to P-t-P</td>
<td>6 km/h</td>
<td>Time to handover</td>
<td>444 sec, 556 sec</td>
<td>526 sec, 668 sec</td>
<td>~100 seconds earlier</td>
</tr>
</tbody>
</table>

4.2.2 Multi-Cell Scenarios (Scenario 5 and Scenario 6)
The results collected from the two instances of scenario 5 concern the capacity requirements (watts) in the central P-t-P Cell and the MBMS Service QoS experienced during Handover from the surrounding P-t-M Cells into the central P-t-P cell (Figure 19 - Figure 21).

![Figure 19](image)

*Figure 19 Average Total Downlink Power required in Central P-t-P Cell after Handover from surrounding P-t-M Cells (watts) – Existing Vs Proposed Handover Approach (Scenario 5)*
The collected results illustrated above reveal not only capacity optimization in the Central P-t-P Cell (up to ~54% decrease on the average demanded capacity as shown in Figure 19) but also the ability of the proposed scheme to avoid the QoS degradation experienced when the existing handover approach is used (See Figure 20 & Figure 21). Figure 20 and Figure 21 illustrate the traffic received by the last two UEs (UE 1 and UE 2) entering the central P-t-P Cell.

The results collected from the two instances of scenario 6 concern the gain on the signal quality in the P-t-M Cells due to the reduction of Inter-Cell interference experienced by the surrounding P-t-P Cells. This is illustrated in Figure 22 - Figure 23.
The function of the CPICH in a Cell is to aid the channel estimation at the terminal for the dedicated channel and to provide the channel estimation reference for the common channels. Figure 22 illustrates the CPICH signal strength (Ec/No) received by a UE near the P-t-M Cell edge while Figure 23 illustrates the CPICH signal strength received by a UE near the P-t-M BS. As it is shown, when the Proposed Handover approach is used we can have up to ~1.3 dB gain on the received channel quality for UEs near the P-t-M Cell edge and up to ~0.5 dB for UE near the P-t-M BS. The gain experienced is due to the advantage of the Proposed approach to minimize the total power required in the surrounding P-t-P Cells thus minimizing the Inter-Cell Interference caused in the Central P-t-M Cell.

5 Sensitivity of critical parameters
A comprehensive sensitivity analysis for the Proposed MBMS Handover Control algorithm is beyond the scope of the current paper. However, in this section we will
discuss the importance of the Handover Delay Distance (HDD) parameter, as well as the sensitivity of errors in the estimation of distance $D$, Speed and Direction.

### 5.1 Handover Delay Distance (HDD) Parameter

As discussed in section 3.3.2, the aim of the HDD parameter, is to anticipate the Handover Delay time ($\Delta t$) caused from the time the handover is triggered until the UE switches channels. In this section we demonstrate the importance of this parameter during an MBMS Handover.

In order to investigate the amount of Handover Delay time ($\Delta t$) that we can tolerate when an MBMS Handover is performing, a series of scenarios have been simulated. The following results have been observed:

- Up to 1.1 seconds (maximum) $\Delta t$ when the “From P-t-P to P-t-M” MBMS Handover is executing.
- Up to 1.2 seconds (maximum) $\Delta t$ when the “From P-t-M to P-t-P” MBMS Handover is executing. (The additional 0.1 delay is due to the fact that more time is needed for the establishment of the DCH in the P-t-P Cell).

According to the above observed Handover Delay time and depending on the different Speeds that the UE can have, the maximum Handover Delay Distance ($\Delta t \times \text{Speed}$) that should be covered from the time the MBMS Handover is triggered until the UE switches channels takes the values shown in Table 2 below:

<table>
<thead>
<tr>
<th>Speed</th>
<th>Covered Handover Delay Distance (meters)</th>
<th>From P-t-M to P-t-P</th>
<th>From P-t-P to P-t-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 km/h (1.39 m/sec)</td>
<td>1.67</td>
<td>1.53</td>
<td></td>
</tr>
<tr>
<td>15 km/h (4.16 m/sec)</td>
<td>5</td>
<td>4.58</td>
<td></td>
</tr>
<tr>
<td>30 km/h (8.33 m/sec)</td>
<td>8.33</td>
<td>9.16</td>
<td></td>
</tr>
<tr>
<td>60 km/h (16.66 m/sec)</td>
<td>20</td>
<td>18.33</td>
<td></td>
</tr>
<tr>
<td>120 km/h (33.33 m/sec)</td>
<td>40</td>
<td>36.66</td>
<td></td>
</tr>
</tbody>
</table>

Taking into consideration the values indicated in Table 2 above, we will demonstrate below the impact of the HDD parameter during an MBMS Handover.

First we consider the case where a UE is moving from a P-t-M towards a P-t-P Cell. In this case (as indicated in section 3), the MBMS Handover should be triggered at distance equal with Coverage of P-t-M Cell – HDD from the P-t-M BS in order for the MBMS Handover to be efficiently executed on the Coverage limit of the P-t-M Cell. It is obvious that if the HDD is not considered then the MBMS Handover would be triggered at distance equal with Coverage of P-t-M Cell from the P-t-M BS resulting in the execution of MBMS Handover at some distance outside of the P-t-M Cell Coverage. Since FACH coverage is guaranteed up to the Coverage limit of the P-t-M Cell this will have some impact on the MBMS Service QoS (Received Traffic). In Figure 24 the impact on the MBMS Service QoS when the HDD is considered and when the HDD is not considered is illustrated. In this scenario the Coverage of the P-t-M cell is 1000 meters and the UE is expected to receive an MBMS Streaming Video of 60 Kbits/sec using FACH.
On the figure above we marked the distances from the P-t-M BS that the UE will switch channels when its speed is 5, 15, 30, 60 and 120 Km/hour for the case we do not consider the HDD (red thin solid lines). Also, with the black thick solid line we indicate the point where the UE will switch channels if the HDD is considered (assuming negligible estimation error in its calculation). For many MBMS applications, an acceptable QoS degradation can still be provided, despite packet losses in the received service from the UE. For example, if we assume an error tolerance of the order of ~10% for a streaming video service of 60 Kbit/sec, the MBMS service QoS will be acceptable when the Traffic Received exceeds 53 Kbits/sec. As shown in Figure 24, this happens when the UE is at a distance of 1008 metres or less from the P-t-M BS (indicated in the figure by the black discontinued line). When a UE is moving with low speed, say from 5 to 15 Km/hour, there is no need to consider the HDD, as the required QoS is still supported.

In the case where a UE is moving from a P-t-P towards a P-t-M Cell, the MBMS Handover should be triggered (as indicated in section 3) at distance equal with Coverage of P-t-M Cell + HDD from the P-t-M BS in order for the MBMS Handover to be efficiently executed on the Coverage limit of the P-t-M Cell. It is obvious that if the HDD is not considered in this case, then the MBMS Handover would be triggered on the coverage limit of the P-t-M cell, resulting in the execution of MBMS Handover after entering the P-t-M Cell Coverage, at some distance away from the Coverage limit of the P-t-M Cell. Since FACH coverage is guaranteed up to the Coverage limit of the P-t-M Cell this will have some impact on the capacity efficiency in the P-t-P Cell. In Figure 25 the impact on the capacity efficiency (power consumption) in the P-t-P Cell when the HDD is considered and when the HDD is not considered is illustrated. In this Scenario, the UE is expected to receive an MBMS Streaming video of 60 Kbits/sec, and the coverage of the cells is configured to be 1000 meters. The distance between the two BSs is 1800 meters (i.e. 200 meters overlap). Since the Coverage of the P-t-M Cell is 1000 metres, the MBMS should be executed at 800 meters from the P-t-P BS.
Figure 25 illustrates the average total downlink power required by the P-t-P BS in order to reach the UE at different distances from it due to different speeds used. On the figure above we have marked (with the red thin solid lines) the distances from the P-t-P BS that the UE will switch channels when its speed is 5, 15, 30, 60 and 120 Km/hour and the HDD is not considered. On the other hand, with the black thick solid line we indicated the point where the UE will switch channels if the HDD parameter is considered. According to Figure 25, the following are observed for the average total downlink power used (See Table 3):

**Table 3: Power and capacity efficiency gain when the HDD parameter is considered.**

<table>
<thead>
<tr>
<th>Handover Delay Distance Considered</th>
<th>Speed (Km/h)</th>
<th>5</th>
<th>15</th>
<th>30</th>
<th>60</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Power (watts):</td>
<td>0.2875 watts (all cases)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handover Delay Distance Not considered</td>
<td>Speed (Km/h)</td>
<td>5</td>
<td>15</td>
<td>30</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Average Power (watts)</td>
<td>0.288</td>
<td>0.2905</td>
<td>0.2935</td>
<td>0.297</td>
<td>0.318</td>
</tr>
<tr>
<td><strong>Capacity Efficiency Gain when HDD is Considered (%)</strong></td>
<td>0.174</td>
<td>1.032</td>
<td>2.04</td>
<td>3.2</td>
<td>9.59</td>
<td></td>
</tr>
</tbody>
</table>

As we can see, in the cases where the Speed of the UE is low (5 – 30 Km/h) the capacity efficiency gain that we can have is quite small (in the order of up to ~2%). Thus when the UE is moving with a speed, say from 5 to 30 Km/hour, there is no need to consider the HDD parameter. On the other hand when the speed of the UE exceeds 60 Km/hour (Vehicular) the capacity gain that we can have exceeds 3 % (3.2 – 9.59 % capacity efficiency for the presented examples), which can be considered substantial, given the scarcity and limitation of wireless radio resources. Therefore, in these cases, the HDD parameter should be considered.

We therefore conclude that in the cases where the speed of the UE is low (Pedestrian), the HDD need not be considered when the Proposed MBMS Handover is executing. In these cases the same approach will be used but the extra effort of dynamically estimating HDD will be eliminated. Thus a fixed value for the “MBMS Handover Trigger Threshold” can be used, based on the P-t-M BS CPICH Signal Strength equivalent to the Coverage of P-t-M Cell distance from the P-t-M BS. The handover in this case will be triggered on the Coverage border, and due to the low speeds its...
execution will still be acceptably close to the border. On the other hand when the speed of the UE exceeds about 30 Km/hour (vehicular), if the HDD is not considered the QoS starts to degrade, resulting in the loss of packets (cases where the speed is from 30 to 60 Km/hour), or even severe degradation of throughput (for speeds over 90 Km/hour). Therefore, in these cases consideration of the HDD parameter is necessary in order to avoid QoS degradation.

5.2 Distance D, Speed and Direction

As discussed in Section 3, in order to take full advantage of Common Resources, the MBMS Handover should be triggered close to the coverage limit of the P-t-M Cell at a distance $D$ equal to the $\text{Coverage of the P-t-M Cell} \pm \text{Handover Delay Distance (HDD)}$ from the P-t-M BS. The UE during its mobility will calculate this distance $D$ and when reached it will trigger the handover. Thus the efficient execution of the MBMS Handover depends on the accurate estimation of the distance $D$. Since the distance $D$ depends on the $\text{Coverage of the P-t-M Cell}$ and the HDD, accurate estimation of these two parameters is essential. The $\text{Coverage of the P-t-M Cell}$ will be accurately acquired through the MCCH (See Section 3.3.1). On the other hand, the HDD will be estimated by the UE during its mobility.

As we have discussed in Section 3.3.2 the Handover Delay time ($\Delta t$), the Speed and the Direction of the UE are considered as vital parameters for the estimation of the HDD and moreover the accurate estimation of distance $D$. The Handover Delay time ($\Delta t$) will be accurately acquired through the MCCH. On the other hand, the Speed and the Direction is estimated by the UE during its mobility. Due to the inaccuracies of the different estimation techniques used, the estimation of these two parameters cannot be accurate. We run some scenarios in order to observe the impact (if any) on the optimum MBMS Handover efficiency.

In these scenarios we have added a $\pm 5\%$, $\pm 10\%$, $\pm 20\%$ and $\pm 40\%$ error on the Speed and the Direction estimates. The tables below show the deviations from the Coverage limit of P-t-M Cell (in meters) when using the corresponding errors. In these scenarios the UE is moving from a P-t-P (DCH) towards a P-t-M (FACH) Cell. Table 4 shows the deviation when the UE is moving with a Speed of 60 Km/hour and Table 5 the deviation when the UE is moving with 120 Km/hour.

Table 4: UE Speed 60Km/hour – Deviation from P-t-M Cell Coverage limit (metres) due to the corresponding estimate errors of Direction (angle) & Speed

<table>
<thead>
<tr>
<th>Direction Error</th>
<th>Speed Error</th>
<th>-40%</th>
<th>-20%</th>
<th>-10%</th>
<th>-5%</th>
<th>5%</th>
<th>10%</th>
<th>20%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-40%</td>
<td>4.398</td>
<td>1.548</td>
<td>0.123</td>
<td>-0.588</td>
<td>-2.012</td>
<td>-2.724</td>
<td>-4.148</td>
<td>-6.995</td>
</tr>
<tr>
<td></td>
<td>-20%</td>
<td>4.739</td>
<td>2.005</td>
<td>0.638</td>
<td>-0.044</td>
<td>-1.410</td>
<td>-2.093</td>
<td>-3.458</td>
<td>-6.187</td>
</tr>
<tr>
<td></td>
<td>-10%</td>
<td>4.944</td>
<td>2.279</td>
<td>0.948</td>
<td>0.282</td>
<td>-1.048</td>
<td>-1.713</td>
<td>-3.042</td>
<td>-5.700</td>
</tr>
<tr>
<td></td>
<td>-5%</td>
<td>5.055</td>
<td>2.428</td>
<td>1.115</td>
<td>0.459</td>
<td>-0.851</td>
<td>-1.507</td>
<td>-2.818</td>
<td>-5.437</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>5.294</td>
<td>2.748</td>
<td>1.476</td>
<td>0.840</td>
<td>-0.429</td>
<td>-1.064</td>
<td>-2.334</td>
<td>-4.870</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>5.422</td>
<td>2.919</td>
<td>1.668</td>
<td>1.044</td>
<td>-0.204</td>
<td>-0.828</td>
<td>-2.075</td>
<td>-4.567</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>5.692</td>
<td>3.282</td>
<td>2.078</td>
<td>1.476</td>
<td>0.274</td>
<td>-0.325</td>
<td>-1.525</td>
<td>-3.922</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>6.295</td>
<td>4.090</td>
<td>2.990</td>
<td>2.441</td>
<td>1.343</td>
<td>0.795</td>
<td>-0.298</td>
<td>-2.483</td>
</tr>
</tbody>
</table>
Table 5: UE Speed 120Km/hour – Deviation from P-t-M Cell Coverage limit (metres) due to the corresponding estimate errors of Direction (angle) & Speed

<table>
<thead>
<tr>
<th>Speed Error</th>
<th>- 40 %</th>
<th>- 20 %</th>
<th>- 10 %</th>
<th>5 %</th>
<th>10 %</th>
<th>20 %</th>
<th>40 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 40 %</td>
<td>8.730</td>
<td>3.037</td>
<td>0.192</td>
<td>-1.230</td>
<td>-4.073</td>
<td>-5.495</td>
<td>-8.337</td>
</tr>
<tr>
<td>- 5 %</td>
<td>10.060</td>
<td>4.824</td>
<td>2.210</td>
<td>0.904</td>
<td>-2.106</td>
<td>-3.430</td>
<td>-5.615</td>
</tr>
<tr>
<td>5 %</td>
<td>10.544</td>
<td>5.475</td>
<td>2.945</td>
<td>1.682</td>
<td>-0.841</td>
<td>-2.102</td>
<td>-4.621</td>
</tr>
<tr>
<td>10 %</td>
<td>10.802</td>
<td>5.823</td>
<td>3.339</td>
<td>2.098</td>
<td>-0.379</td>
<td>-1.617</td>
<td>-4.090</td>
</tr>
<tr>
<td>20 %</td>
<td>11.352</td>
<td>6.563</td>
<td>4.176</td>
<td>2.984</td>
<td>0.604</td>
<td>-0.584</td>
<td>-2.957</td>
</tr>
<tr>
<td>40 %</td>
<td>12.579</td>
<td>8.218</td>
<td>6.048</td>
<td>4.966</td>
<td>2.807</td>
<td>1.730</td>
<td>-0.417</td>
</tr>
</tbody>
</table>

The negative values in the Tables above indicate that due to the corresponding estimate errors on Speed and Direction, the MBMS Handover is executed before the UE enters the P-t-M Cell Coverage, which may result in a degradation of the requested service QoS. On the other hand the positive values indicate that the MBMS Handover is executed after the UE enters the P-t-M Cell Coverage. This will not have any impact on the MBMS Service QoS but it may have an impact on the capacity efficiency.

As we assumed in section 5.1, the QoS of the MBMS service will be supported when the Traffic Received is over 53,000 bits/sec and this happens when the UE is at distance closer than 1008 meters from the P-t-M BS (See Figure 24). Thus, for a deviation greater than 8 meters from the Coverage limit of the P-t-M Cell we will observe a QoS degradation. For this type of service, taking into consideration Table 4 and Table 5, we observe that the MBMS Service QoS might be affected only when the UE is moving with very high speed (120Km/h) and we have a high % error (about 40%) on the estimation of the Speed and the Direction (angle φ) of the UE resulting in a deviation from the coverage limit of P-t-M Cell up to 14 meters. Note that (as shown in Figure 24) at this distance (1014 meters from P-t-M BS) the Traffic Received drops only to 45 Kbits/sec. Taking into consideration that we can have up to 8 meters deviation from the Coverage limit of the P-t-M Cell without degradation on the MBMS Service QoS by executing the MBMS Handover at 14 meters away from the coverage limit the UE will experience a minor degradation of the MBMS Service QoS only for 6 meters (14 – 8 = 6). According to its speed (120 Km/hour = 33 meters/sec) this distance will be covered in 0.18 seconds. Therefore, the UE will have a minor but barely discernible impact on the MBMS Service QoS.

On the other hand, as discussed in section 5.1, any increase in the required capacity that is over 3% is considered important due to the scarcity of wireless resources. As shown in Figure 25 this occurs when the UE is at distance greater than ~19 meters from the Coverage limit of the P-t-M Cell (e.g. 819 meters from the P-t-P BS). By taking into consideration Table 4 and Table 5, the greater deviation that we have due to error estimations is up to about 12 meters from the Coverage limit of P-t-M Cell and this occurs only when the UE is moving with a very high speed (120Km/hr). Since the increase in the required capacity is less than 3% at that point, the resulting increase in the required capacity can be considered as acceptable.

The analysis presented above indicates that fairly large error estimates in Speed and Direction (in the order of ± 40%) and high vehicle speeds (about 100 km/sec) can be
tolerated and will only have a minor impact in the estimation of HDD and on the effectiveness of the algorithm. A comprehensive analysis of the sensitivities of the algorithm forms part of a separate study, as well as a decision as to when to include HDD or not in the calculation of the MBMS Handover algorithm.

6 Conclusions
In this paper, we propose a new MBMS Handover Control Algorithm which efficiently deals with the new aspects of handover introduced with MBMS. The proposed scheme guarantees Quality of Service (QoS) and achieves increased system capacity during an MBMS Handover, by taking into consideration the new aspects introduced. The key in accomplishing this lies in a fuller utilization of the broadcast nature (capacity and coverage characteristics) of Common resources (FACH channel). Considering Line-of-Sight and circular cell coverage, we show the importance of the proposed scheme on the QoS of MBMS Services during Handover and also that it achieves considerable enhanced system capacity (for presented scenarios a reduction in downlink power of up to 54% was observed in the P-t-P Cells). Moreover, by using the proposed scheme, we observed up to ~1.3 dB gain on the received channel quality for UEs near the P-t-M Cell edge and up to ~0.5 dB for UE near the P-t-M BS (this is caused due to the reduction of Inter-Cell Interference caused by the surrounding P-t-P Cells). We also show the importance of the Handover Delay Distance on the Proposed MBMS Handover Control algorithm and the operating regimes where this parameter needs to be considered. Moreover, we show that considerable estimation error in the distance and angle can be tolerated by the proposed algorithm.

In wireless/mobile environments where the radio resources are limited, any capacity increase and QoS enhancement is of major importance therefore the utility of the proposed algorithm for the MBMS system is evident. In this paper the presented results illustrate the usefulness of the proposed MBMS Handover Algorithm. For future work we will include the effects of shadow fading and non-homogeneous circle cells. Also, it is worth noting that currently there is discussion in the standards bodies for using the HSDPA channel, but as of present [1] there is nothing standardised. We plan to monitor this development and extend/modify our algorithm accordingly.

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References


APPENDIX A: DERIVATION OF HANDOVER DELAY DISTANCE FORMULA

A.1 From P-t-P to P-t-M Handover Delay Distance Formula derivation

In order to derive the formula that computes the Handover Delay Distance when the From P-t-P to P-t-M MBMS Handover is executing Figure 26 is used. The steps followed in order to derive the formula are described below.

First we find the distance $\Delta d$ 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:

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

According to the equation showed above we first find the $\kappa'$, $\kappa$ and $\lambda$ angles.

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

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

Now that we have found the angle $\kappa'$ we can easily find the $\kappa$ angle.

$$\kappa = 180^\circ - \kappa' \Rightarrow \kappa = 180^\circ - \arcsin \left( \frac{\text{Cov} + (\text{Speed} \times \Delta t)}{\text{Cov}} \times \sin \phi \right)$$

The sum of $\lambda$, $\kappa$ and $\phi$ angles of the triangle should be $180^\circ$.

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

$$\lambda = 180^\circ - \left[ \phi + \left( 180^\circ - \arcsin \left( \frac{\text{Cov} + (\text{Speed} \times \Delta t)}{\text{Cov}} \times \sin \phi \right) \right) \right]$$
Now that we have found the angle $\lambda$ we can find the $\Delta d$ distance using the following.

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

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

By finding the $\Delta d$ distance, we will use the Cosine Rule in order to find the Handover Delay Distance (HDD). Where $\alpha$ is equal with $\text{Speed} \times \Delta t$.

$$(\text{Cov} + \text{HDD})^2 = \Delta d^2 + (\text{Cov} + a)^2 - 2 \times \Delta d \times (\text{Cov} + a) \times \cos \varphi \Rightarrow$$

$$\text{HDD} = \sqrt{\Delta d^2 + (\text{Cov} + a)^2 - 2 \times \Delta d \times (\text{Cov} + a) \times \cos \varphi - \text{Cov}}$$

**A.2 From P-t-M to P-t-P Handover Delay Distance Formula derivation**

In order to extract the formula that computes the “New” Handover Delay Distance when the From P-t-M to P-t-P MBMS Handover is executing, Figure 27 is used. The steps followed in order to define the formula are described below.

![Figure 27 From P-t-M to P-t-P MBMS Handover Mathematical model Schema](image)

First we find the distance $\Delta d$ 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:
\[
\frac{\text{Cov} - (\text{Speed} \times \Delta t)}{\sin \kappa} = \frac{\text{Cov}}{\sin(180^\circ - \varphi)} = \frac{(\text{Speed} \times \Delta t) + \Delta d}{\sin \lambda}
\]

According to the equation showed above we will first find the \( \kappa \) and \( \lambda \) angles.

\[
\frac{\text{Cov} - (\text{Speed} \times \Delta t)}{\sin \kappa} = \frac{\text{Cov}}{\sin(180^\circ - \varphi)} \quad \Rightarrow \quad \sin \kappa = \frac{\text{Cov} - (\text{Speed} \times \Delta t)}{\text{Cov}} \times \sin(180^\circ - \varphi) \quad \Rightarrow
\]

\[
\kappa = \arcsin\left(\frac{\text{Cov} - (\text{Speed} \times \Delta t)}{\text{Cov}} \times \sin(180^\circ - \varphi)\right)
\]

The sum of \( \lambda \), \( \kappa \) and \( \varphi \) angles of the triangle should be 180\(^\circ\).

\[
\kappa + \lambda + (180^\circ - \varphi) = 180^\circ \quad \Rightarrow \quad \lambda = \varphi - \kappa \quad \Rightarrow
\]

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

Now that we have found the angle \( \lambda \) we can find the \( \Delta d \) distance using the following.

\[
\frac{\text{Cov}}{\sin(180^\circ - \varphi)} = \frac{(\text{Speed} \times \Delta t) + \Delta d}{\sin \lambda} \quad \Rightarrow \quad \Delta d = \frac{\text{Cov} \times \sin \lambda}{\sin(180^\circ - \varphi)} - (\text{Speed} \times \Delta t) \quad \Rightarrow
\]

\[
\Delta d = \frac{\text{Cov} \times \sin \left[\varphi - \arcsin\left(\frac{\text{Cov} - (\text{Speed} \times \Delta t)}{\text{Cov}} \times \sin(180^\circ - \varphi)\right)\right]}{\sin(180^\circ - \varphi)} - (\text{Speed} \times \Delta t)
\]

Now that we have found the \( \Delta d \) distance, we will use the Cosine Rule in order to find the Handover Delay Distance (HDD). In the following formula we replaced \( \text{Speed} \times \Delta t \) with the letter \( \alpha \).

\[
(C\text{ov} - \text{HDD})^2 = \Delta d^2 + (C\text{ov} - a)^2 - 2 \times \Delta d \times (C\text{ov} - a) \times \cos(180^\circ - \varphi) \quad \Rightarrow
\]

\[
\text{HDD} = \sqrt{(C\text{ov} - \Delta d)^2 + (C\text{ov} - a)^2 - 2 \times \Delta d \times (C\text{ov} - a) \times \cos \varphi}
\]