Wireless Network Traffic and Quality of Service Support:

Trends and Standards

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Chapter 18

Efficient Power Allocation in E-MBMS Enabled 4G Networks

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ABSTRACT

The plethora of mobile multimedia services that are expected to face high penetration, poses the need for the deployment of a resource economic scheme in Long Term Evolution (LTE) networks. To this direction, the Evolved - Multimedia Broadcast / Multicast Service (E-MBMS) is envisaged to play an instrumental role for LTE proliferation and set the basis for a successful 4th Generation (4G) standardization process. One of the most critical aspects of E-MBMS performance is the selection of the most efficient radio bearer, in terms of power consumption. This chapter presents the prevailing radio bearer selection mechanisms and examines their performance in terms of power consumption. Furthermore, it discusses problems regarding the high power requirements for the realization of E-MBMS and evaluates the proposed techniques/solutions. Finally, this chapter presents a novel mechanism for efficient power control during E-MBMS transmissions that conforms to LTE requirements for simultaneous provision of multiple multimedia sessions.

INTRODUCTION

Nowadays, mobile industry rapidly evolves towards a multimedia-oriented model for providing rich services, such as mobile TV and mobile streaming. Long Term Evolution (LTE) networks address this emerging trend, by shaping the future mobile landscape in a more power and spectral efficient way than its predecessors.

LTE technology improves spectral efficiency and sector capacity and lowers the telecommunication costs for service provision, making use of new and reformed spectrum opportunities and better integration with other open standards. These enhancements compared to Universal Mobile Telecommunication System (UMTS) technology, give LTE networks the

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opportunity to offer high throughput, low latency, plug and play, improved end-user experience and simple architecture resulting in low operating expenditures.

More specific, LTE networks provide high peak rates of at least 100 Mbps in the downlink and 50 Mbps in the uplink. Contrary to UMTS networks that provide peak rates of 384 Kbps (or 21 Mbps with HSDPA) in the downlink, LTE networks may overcome the recent increase of mobile data usage and emergence of new applications such as mobile TV and streaming contents. However, the plethora of mobile multimedia services that are expected to face high penetration, poses the need for deploying complementary resource economic schemes.

To this direction, the Evolved - Multimedia Broadcast/Multicast Service (E-MBMS) is envisaged to play an instrumental role for the LTE proliferation in mobile market and set the basis for a successful 4th Generation (4G) standardization process. E-MBMS constitutes the evolutionary successor of MBMS, which was introduced in the Release 6 of UMTS (3rd Generation Partnership Project TR 23.846, 2003; 3rd Generation Partnership Project TS 22.146, 2008). It is a unidirectional service which targets at the resource economic delivery of multimedia data from a single source entity to multiple recipients. The main requirement during the provision of E-MBMS services is to make an efficient overall usage of radio and network resources and more importantly, to reduce the power requirements for the provision of such demanding services.

Power in mobile networks is the most limited resource and may lead to significant capacity decrease when misused. Providing multicast or broadcast services to a meaningful proportion of a cell coverage area may require significant amounts of power dedicated to the multicast or broadcast transmission. Several techniques, such as Dynamic Power Setting (DPS), Macro Diversity Combining (MDC) and Rate Splitting (RS) have been introduced in order to minimize the base station's total E-MBMS transmission power. This chapter examines the operation and performance of these techniques and demonstrates the amount of power that could be saved through their employment.

Furthermore, a critical aspect of E-MBMS performance is the selection of the most efficient radio bearer, in terms of power consumption, for the transmission of multimedia traffic. The system should conceive and adapt to continuous changes that occur in such dynamic wireless environments and optimally allocate resources. The selection of the most efficient radio bearer is an open issue in today's E-MBMS infrastructure and several mechanisms have been proposed to this direction. Nevertheless, the selection of the most appropriate mechanism is plagued with uncertainty, since each mechanism may provide specific advantages. In this chapter, the prevailing radio bearer selection mechanisms are presented and compared in terms of power consumption so as to highlight the advantages that each mechanism may provide.

Finally, this chapter presents a novel mechanism for efficient power control during E-MBMS transmissions that incorporates the advantages of each mechanism. The most remarkable advantage of the proposed mechanism, that actually differentiates it from the other approaches, is that it conforms to LTE requirements for the simultaneous provision of multiple multimedia sessions. This approach is compared with the aforementioned approaches in terms of both power consumption and complexity so as to highlight its enhancements and underline the necessity for its incorporation in E-MBMS specifications.

Main objective of this chapter is to present the main characteristics regarding the operation and performance of E-MBMS and moreover to highlight the significance of power control during E-MBMS transmissions. The reader will become familiar with the most crucial problems that have a direct impact on E-MBMS performance; and moreover, the reader will be introduced to the proposed techniques/solutions.

BACKGROUND

In MBMS rich wireless multimedia data is transmitted simultaneously to multiple recipients, by allowing resources to be shared in an economical way. MBMS efficiency is derived from the single transmission of identical data over a common channel without clogging up the air interface with multiple replications of the same data.

The major factor for integrating MBMS into UMTS networks was the rapid growth of mobile communications technology and the massive spread of wireless data and wireless applications. The increasing demand for communication between one sender and many receivers led to the need for point-to-multipoint (PTM) transmission. PTM transmission is opposed to the point-to-point (PTP) transmission, using the unicast technology, which is exclusively used in conventional UMTS networks (without the MBMS extension). Broadcast and multicast technologies constitute an efficient way to implement this type of communication and enable the delivery of a plethora of high-bandwidth multimedia services to a large users' popularity.

From the service and operators' point of view, the employment of MBMS framework involves both an improved network performance and a rational usage of radio resources, which in turns leads to extended coverage and service provision. In parallel, users are able to realize novel, high bit-rate services, experienced until today only by wired users. Such services include Mobile TV, weather or sports news as well as fast and reliable data downloading (Holma & Toskala, 2007).

MBMS Operation Modes

As the term MBMS indicates, there are two types of service mode: the broadcast mode and the multicast mode. Each mode has different characteristics in terms of complexity and packet delivery.

The broadcast service mode is a unidirectional PTM transmission type. Actually, with broadcast, the network simply floods data packets to all nodes within the network. In this service mode, content is delivered, using PTM transmission, to a specified area without knowing the receivers and whether there is any receiver in the area. As a consequence, the broadcast mode requires no subscription or activation from the users' point of view.

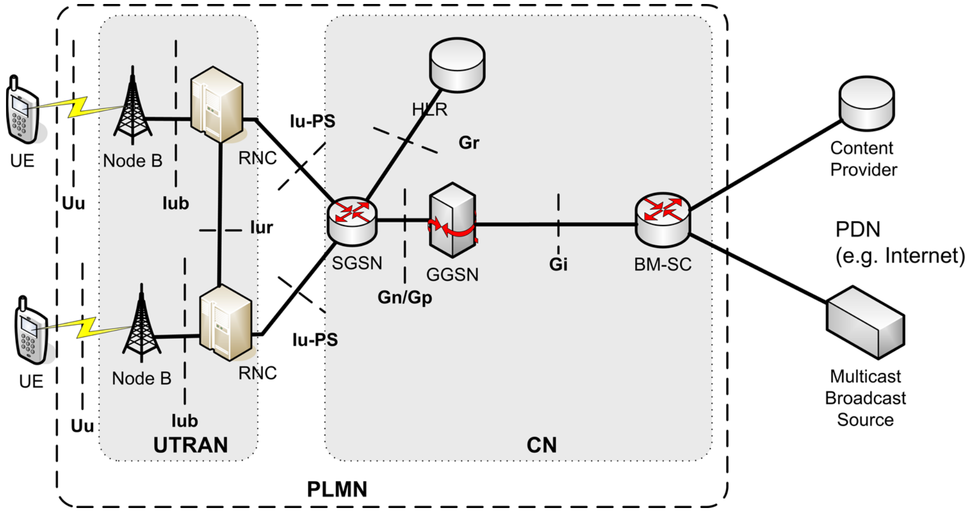
In the multicast operation mode, data is transmitted solely to users that explicitly request such a service. More specifically, the receivers have to signal their interest for the data reception to the network and then the network decides whether the user may receive the multicast data or not. Thus, in the multicast mode there is the possibility for the network to selectively transmit to cells, which contain members of a multicast group. Either PTP or PTM transmission can be configured in each cell for the multicast operation mode (3rd Generation Partnership Project TS 22.146, 2008).

Unlike the broadcast mode, the multicast mode generally requires a subscription to the multicast subscription group and then the user joining the corresponding multicast group. Moreover, due to the selective data transmission to the multicast group, it is expected that charging data for the end user will be generated for this mode, unlike the broadcast mode.

MBMS Architecture

The MBMS framework requires minimal modifications in the current UMTS architecture. As a consequence, this fact enables the fast and smooth upgrade from pure UMTS networks to MBMS-enhanced UMTS networks. Actually, MBMS consists of a MBMS bearer service and a MBMS user service. The latter represents applications, which offer for example multimedia content to the users, while the MBMS bearer service provides methods for user authorization, charging and Quality of Service (QoS) improvement to prevent unauthorized reception (3rd Generation Partnership Project TS 22.146, 2008).

Figure 1. UMTS and MBMS architecture



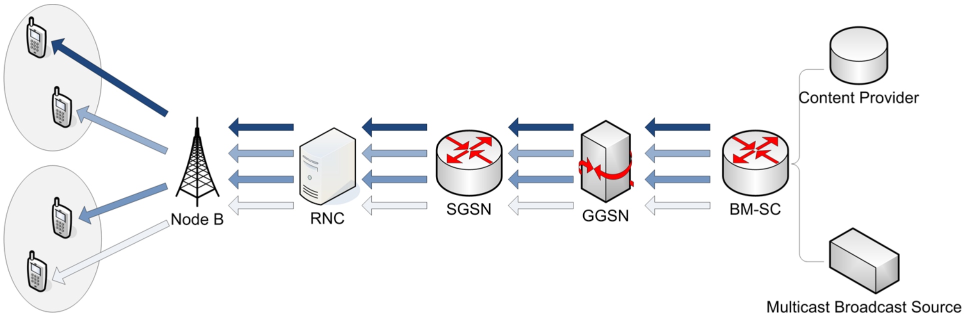
UMTS network is split in two main domains: the User Equipment (UE) domain and the Public Land Mobile Network (PLMN) domain. The UE domain consists of the equipment employed by the user to access the UMTS services. The PLMN domain consists of two land-based infrastructures: the Core Network (CN) and the UMTS Terrestrial Radio Access Network (UTRAN) (Figure 1). The CN is responsible for switching/routing voice and data connections, while the UTRAN handles all radio-related functionalities. The CN is logically divided into two service domains: the Circuit-Switched (CS) service domain and the Packet-Switched (PS) service domain (Holma & Toskala, 2007). The CS domain handles the voice-related traffic, while the PS domain handles the packet transfer. The remainder of this chapter will focus on the UMTS packet-switching mechanism.

The PS portion of the CN in UMTS consists of two kinds of General Packet Radio Service (GPRS) Support Nodes (GSNs), namely Gateway GSN (GGSN) and Serving GSN (SGSN) (Figure 1). SGSN is the centerpiece of the PS domain. It provides routing functionality, interacts with databases (like Home Location Register (HLR)) and manages many Radio Network Controllers (RNCs). SGSN is connected to GGSN via the Gn interface and to RNCs via the Iu interface. GGSN provides the interconnection of UMTS network (through the Broadcast Multicast–Service Center) with other Packet Data Networks (PDNs), like the Internet.

UTRAN consists of two kinds of nodes: the first is the RNC and the second is the Node B. Node B constitutes the base station and provides radio coverage to one or more cells (Figure 1). Node B is connected to the UE via the Uu interface (based on the Wideband Code Division Multiple Access, WCDMA technology) and to the RNC via the Iub interface. One RNC with all the connected to it Node Bs is called Radio Network Subsystem (RNS) (Holma & Toskala, 2007).

The major modification in the existing UMTS platform for the provision of the MBMS framework is the addition of a new entity called Broadcast Multicast–Service Center (BM-SC, see Figure 1). Actually, BM-SC acts as entry point for data delivery between the content providers and the UMTS network and is located in the PS domain of the CN. The BM-SC entity communicates with existing UMTS networks and external PDNs (3rd Generation Partnership Project TR 23.846, 2003; 3rd Generation Partnership Project TS 22.146, 2008).

Figure 2. UMTS multicast without MBMS enhancement



The BM-SC is responsible for both control and user planes of a MBMS service. More specifically, the function of the BM-SC can be separated into five categories: Membership, Session and Transmission, Proxy and Transport, Service Announcement and Security function. The BM-SC Membership function provides authorization to the UEs requesting to activate a MBMS service. According to the Session and Transmission function, the BM-SC can schedule MBMS session transmissions and shall be able to provide the GGSN with transport associated parameters, such as QoS and MBMS service area. As far as the Proxy and Transport function is concerned, the BM-SC is a proxy agent for signaling over Gmb reference point between GGSNs and other BM-SC functions. Moreover, the BM-SC Service Announcement function must be able to provide service announcements for multicast and broadcast MBMS user services and provide the UE with media descriptions specifying the media to be delivered as part of a MBMS user service. Finally, MBMS user services may use the Security functions for integrity or confidentiality protection of the MBMS data, while the specific function is used for distributing MBMS keys (Key Distribution Function) to authorized UEs.

Multicast Mode of MBMS

MBMS multicast efficiency improvement in UMTS networks can be derived from the following figures. More specifically, Figure 2 and Figure 3 present UMTS multicast functionality without and with MBMS enhancement respectively.

Without the MBMS enhancement, multicast data is replicated as many times as the total number of multicast users in all interfaces. Obviously, a bottleneck is placed when the number of users increases significantly. All interfaces are heavily

Figure 3. UMTS multicast with MBMS enhancement

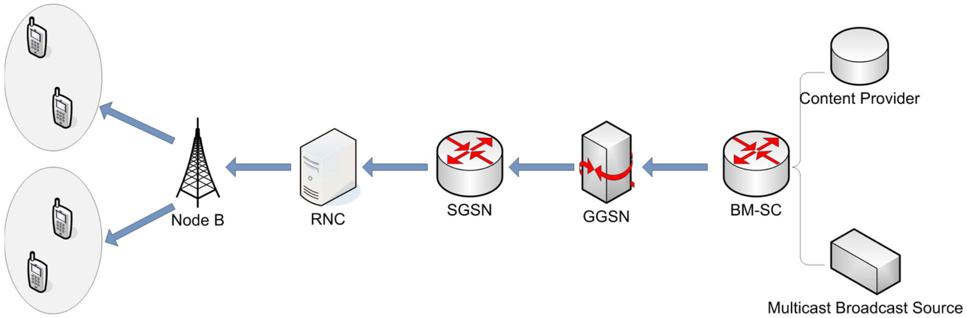
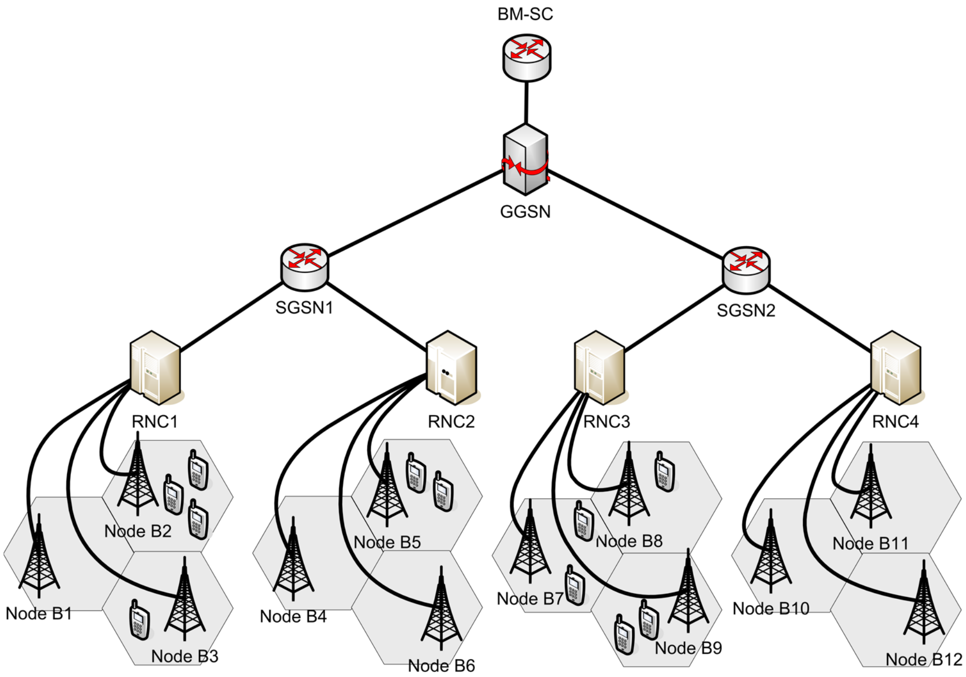


Figure 4. Packet delivery in MBMS multicast mode



overloaded due to the multiple transmissions of the same data. On the other hand, MBMS multicast benefits UMTS networks through the radio and network resources' sharing. Only a single stream per MBMS service of identical data is essential for the delivery of the multicast content, thus saving expensive resources. Conclusively, MBMS multicast data distribution is optimally configured throughout the UMTS network.

Packet Delivery Process

An overview of the multicast data flow procedure during a MBMS service provision is presented in this paragraph. Figure 4 depicts a subset of a UMTS-MBMS network. In this architecture, there are two SGSNs connected to a GGSN, four RNCs, and twelve Node Bs. Furthermore, eleven members of a multicast group are located in six cells. The BM-SC acts as the interface towards external sources of traffic. The presented analysis assumes that a data stream that comes from an external PDN, through BM-SC, must be delivered to the eleven UEs as illustrated in Figure 4.

The analysis presented in the following paragraphs, covers the forwarding mechanism of the data packets between the BM-SC and the UEs. With multicast, the packets are forwarded only to those Node Bs that have multicast users. Therefore, in Figure 4, the Node Bs 2, 3, 5, 7, 8, 9 receive the multicast packets issued by the BM-SC. We briefly summarize the five steps occurred for the delivery of the multicast packets.

Initially, the BM-SC receives a multicast packet and forwards it to the GGSN that has registered to receive the multicast traffic. Then, the GGSN receives the multicast packet and by querying its multicast routing lists, it determines which SGSNs have multicast users residing in their respective service areas. In Figure 4, the GGSN duplicates the multicast packet and forwards it to the SGSN1 and the SGSN2 (Alexiou, Antonellis, Bouras & Papazois, 2006). Then, both destination SGSNs receive the multicast packets and, having queried their multicast routing lists, determine which RNCs are to receive the multicast packets. The destination RNCs receive the multicast packet and send it to the Node Bs that have established the appropriate radio bearers for the multicast application. In Figure 4, these are: Node B2, B3, B5, B7, B8, and B9. The multicast users receive the multicast packets on the appropriate radio bearers, by dedicated channels transmitted to individual users separately or by common channels transmitted to all members in the cell (Alexiou, Antonellis, Bouras & Papazois, 2006).

MBMS Multicast Mode Radio Bearers

According to current MBMS specifications, the transmission of the MBMS multicast packets over the Iub and Uu interfaces may be performed on common (Forward Access Channel - FACH), on dedicated (Dedicated Channel - DCH) channels or on the shared channel named High Speed - Downlink Shared Channel (HS-DSCH), introduced in Release 5. The main requirement is to make an efficient overall utilization of the radio resources: this makes a common channel the favorite choice, since many users can access the same resource at the same time.

More specifically, the transport channel that the 3rd Generation Partnership Project (3GPP) decided to use as the main transport channel for PTM MBMS data transmission is the FACH with turbo coding and Quadrature Phase Shift Keying (QPSK) modulation at a constant transmission power (3rd Generation Partnership Project TR 23.846, 2003). DCH is a PTP channel and hence, it suffers from the inefficiencies of requiring multiple DCHs to carry the data to a group of users. However, DCH can employ fast closed-loop power control and soft handover mechanisms and generally is a highly reliable channel (Boni, Launay, Mienville & Stuckmann, 2004; Holma & Toskala, 2007). The allocation of HS-DSCH as transport channel affects the obtained data rates and the remaining capacity to serve Release '99 users (users served by DCH). High Speed Downlink Packet Access (HSDPA) cell throughput increases when more HSDPA power is allocated, while DCH throughput simultaneously decreases (Holma & Toskala, 2006).

Radio Bearers' Selection

The importance of the selection of the most efficient transport channel in terms of power consumption is a key point for MBMS, since a wrong transport channel selection for the transmission of the MBMS data could result to a significant decrease in the total capacity of the system. Several studies and simulations have been carried out focusing on the threshold for switching between dedicated and common resources. The 3GPP MBMS Counting Mechanism was the prevailing approach mainly due to its simplicity of implementation and function (3rd Generation Partnership Project TS 25.346, 2009). On the other hand, Vriendt, Gomez Vinagre & Van Ewijk (2004) claim that for a FACH with transmission power set to 4 Watt, the threshold for switching from dedicated to common resources is around 7 UEs per cell.

However, only the information about the number of users in a cell may not be sufficient so as to select the appropriate radio bearer (PTP or PTM) for the specific cell. The inefficiencies of the above works and the power limitations that wireless network encounter motivated novel approaches, indicating that there is no need for a priori information and predefined switching thresholds; while, the assignment of the radio bearer should be performed in order to minimize the Node B's power requirements (3rd Generation Partnership Project TR 25.922, 2007). An interesting study under these assumptions is presented in B-BONE (2003), where the authors propose a switching point between PTP and PTM bearers, based on power consumption; while, Alexiou, Bouras & Rekkas (2007) propose a power control scheme for efficient radio bearer selection in MBMS enabled UMTS networks.

However, none of these works and approaches considers the power saving techniques that have been proposed (Alexiou, Bouras & Kokkinos, 2007). Techniques, such as FACH Dynamic Power Setting and Rate Splitting are proven to reduce the power requirements during MBMS transmissions and should be incorporated in the MBMS operation.

POWER CONTROL IN E-MBMS MULTICAST MODE

Power control is one of the most critical aspects in MBMS due to the fact that downlink transmission power in UMTS networks is a limited resource and must be shared efficiently among all MBMS users in a cell. Power control aims at minimizing the transmitted power, eliminating in this way the intercell interference. However, when misused, the use of power control may lead to a high level of wasted power and worse performance results.

On the PTP downlink transmissions, fast power control is used to maintain the quality of the link and thus to provide a reliable connection for the receiver to obtain the data with acceptable error rates. Transmitting with just enough power to maintain the required quality for the link also ensures that there is minimum interference affecting the neighboring cells. However, when a user consumes a high portion of power, more than actually is required, the remaining power, allocated for the rest of the users, is dramatically decreased, thus leading to a significant capacity loss in the system.

During PTM downlink transmissions, Node B transmits at a power level that is high enough to support the connection to the receiver with the highest power requirement among all receivers in the multicast group. This would still be efficient because the receiver with the highest power requirement would still need the same amount of power in a unicast link, and by satisfying that particular receiver's requirement, the transmission power will be enough for all the other receivers in the multicast group. Consequently, the transmitted power is kept at a relatively high level most of the time, which in turn, increases the signal quality at each receiver in the multicast group. On the other hand, a significant amount of power is wasted and moreover intercell interference is increased.

As a consequence, downlink transmission power plays a key role in MBMS planning and optimization. This section provides an analytical description of the HS-DSCH, DCH and FACH power profiles that are employed during PTP and PTM transmission. The following analysis refers to a macrocell environment with parameters described in Table 1 (3rd Generation Partnership Project TR 101.102, 2002; Holma & Toskala, 2007).

HS-DSCH Power Profile

HS-DSCH is a rate controlled rather than a power controlled transport channel. Although there are two basic modes for allocating HS-DSCH transmission power (Holma & Toskala, 2006), this chapter will focus on a dynamic method in order to provide only the required, marginal amount of power so as to satisfy all the serving multicast users and, in parallel, eliminate interference. Two major measures for HSDPA power planning are: the HS-DSCH Signal-to-Interference-plus-Noise Ratio (SINR) metric and the Geometry factor (*G*). SINR for a single-antenna Rake receiver is calculated as in (1) (Holma & Toskala, 2006):

$$SINR = SF_{16}\frac{P_{HS-DSCH}}{pP_{own} + P_{other} + P_{noise}} \qquad (1)$$

where $P_{HS\text{-}DSCH}$ is the HS-DSCH transmission power, P_{own} is the own cell interference experienced by the mobile user, P_{other} the interference from neighboring cells and P_{noise} the Additive White Gaussian Noise. Parameter p is the orthogonality

Table 1. Macrocell simulation assumptions

Parameter	Value
Cellular layout	Hexagonal grid
Number of cells	18
Sectorization	3 sectors/cell
Site to site distance	1 Km
Cell radius	0.577 Km
Maximum BS Tx power	20 Watt (43 dBm)
Other BS Tx power	5 Watt (37 dBm)
Common channel power	1 Watt (30 dBm)
Propagation model	Okumura Hata
Multipath channel	Vehicular A (3km/h)
Orthogonality factor	0.5
E_b/N_0 target	5 dB

factor (p = 0: perfect orthogonality), while SF_{16} is the spreading factor of 16.

Geometry factor is another major measure that indicates the users' position throughout a cell. A lower G is expected when a user is located at the cell edge. G is calculated as in (2) (Holma & Toskala, 2007):

$$G = \frac{P_{own}}{P_{other} + P_{noise}} \tag{2}$$

There is a strong relationship between the HS-DSCH allocated power and the obtained MBMS cell throughput. This relationship can be disclosed in the three following steps. Initially, we have to define the target MBMS cell throughput. Once the target cell throughput is set, the next step is to define the way that this throughput relates to the SINR (Holma & Toskala, 2006). Finally, we can describe how the required HS-DSCH transmission power ($P_{HS\text{-}DSCH}$) can be expressed as a function of the SINR value and the user location (in terms of G) as in (3) (Holma & Toskala, 2006):

$$P_{HS-DSCH} \geq SINR[p - G^{-1}]\frac{P_{own}}{SF_{16}} \tag{3}$$

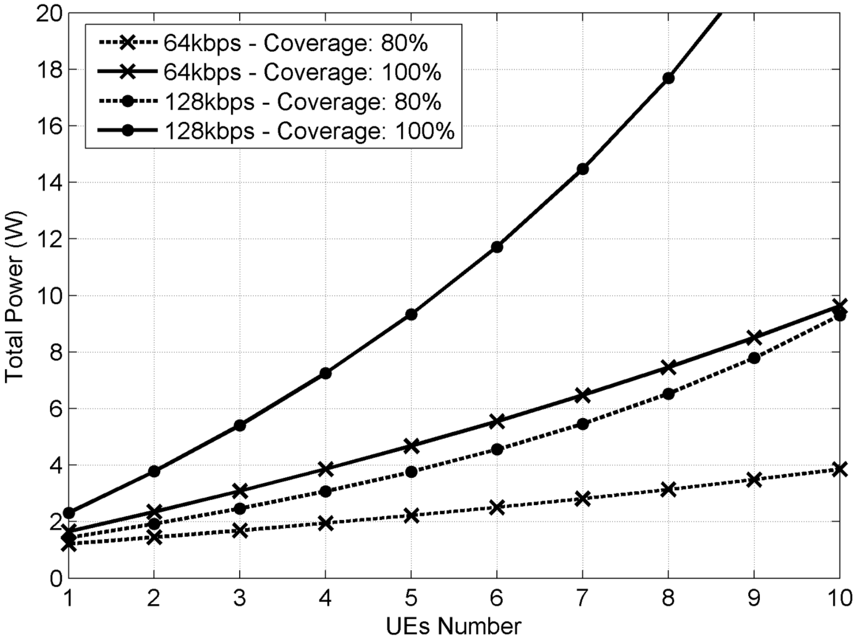
DCH Power Profile

The total downlink transmission power allocated for all MBMS users in a cell that are served by multiple DCHs is variable. It mainly depends on the number of serving users, their location in the cell, the bit rate of the MBMS session and the experienced signal quality E_b/N_0 for each user. Equation 4 calculates the Node B's total DCH transmission power required for the transmission of the data to n users in a specific cell (Perez-Romero, Sallent, Agusti & Diaz-Guerra, 2005).

$$P_T = \frac{P_P + \sum_{i=1}^{n} \dfrac{(P_N + x_i)}{\dfrac{W}{(E_b/N_0)_i R_{b,i}} + p} L_{p,i}}{1 - \sum_{i=1}^{n} \dfrac{p}{\dfrac{W}{(E_b/N_0)_i R_{b,i}} + p}} \tag{4}$$

where P_T is the base station's total transmitted power, P_P is the power devoted to common control channels $L_{p,i}$ is the path loss, $R_{b,\mathrm{i}}$ the i^{th} user transmission rate, W the bandwidth, P_N the background noise, p is the orthogonality factor (p = 0 for perfect

Figure 5. DCH transmission (Tx) power



orthogonality) and x_i is the intercell interference observed by the i^{th} user given as a function of the transmitted power by the neighboring cells P_{Tj}, $j=1,\ldots K$ and the path loss from this user to the j^{th} cell L_{ij}. More specifically (Perez-Romero, Sallent, Agusti & Diaz-Guerra, 2005):

$$x_i = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{ij}} \tag{5}$$

DCH may be used for the delivery of PTP MBMS services, while can not be used to serve large multicast populations since high downlink transmission power would be required. Figure 5 depicts the downlink transmission power when MBMS multicast data is delivered over multiple DCHs (one separate DCH per user). Obviously, higher power is required to deliver higher MBMS data rates. In addition, increased cell coverage area and larger user groups lead to higher power consumption.

FACH Power Profile

A FACH essentially transmits at a fixed power level since fast power control is not supported. FACH is a PTM channel and must be received by all users throughout the cell (or the part of the cell that the users reside in), thus, the fixed power should be high enough to ensure the requested QoS in the desired coverage area of the cell, irrespective of users' location. FACH power efficiency strongly depends on maximizing diversity as power resources are limited. Diversity can be obtained by the use of a longer Transmission Time Interval (TTI) in order to provide time diversity against fast fading (fortunately, MBMS services are not delay sensitive) and the use of combining transmissions from multiple cells to obtain macro diversity (3rd Generation Partnership Project TR 25.803, 2005; Parkvall, Englund, Lundevall & Torsner, 2006).

Table 2 presents some indicative FACH downlink transmission power levels obtained for various

Table 2. FACH Tx power levels

Cell Coverage	Service Bit Rate (Kbps)	Required Tx Power (Watt)
50%	32	1.8
	64	2.5
95%	32	4.0
	64	7.6

cell coverage areas and MBMS bit rates, without assuming diversity techniques (3rd Generation Partnership Project TR 25.803, 2005). A basic constraint is that the delivery of high data rate MBMS services over FACH is not feasible, since excessive downlink transmission power would be required (overcoming the maximum available power of 20 Watt). High bit rates can only be offered to users located very close to Node B.

POWER SAVING TECHNIQUES

In this section, the main problem during a MBMS session is highlighted and the proposed techniques to overcome this problems are presented. The analysis that follows will constitute the guide for our assumptions and simulation experiments.

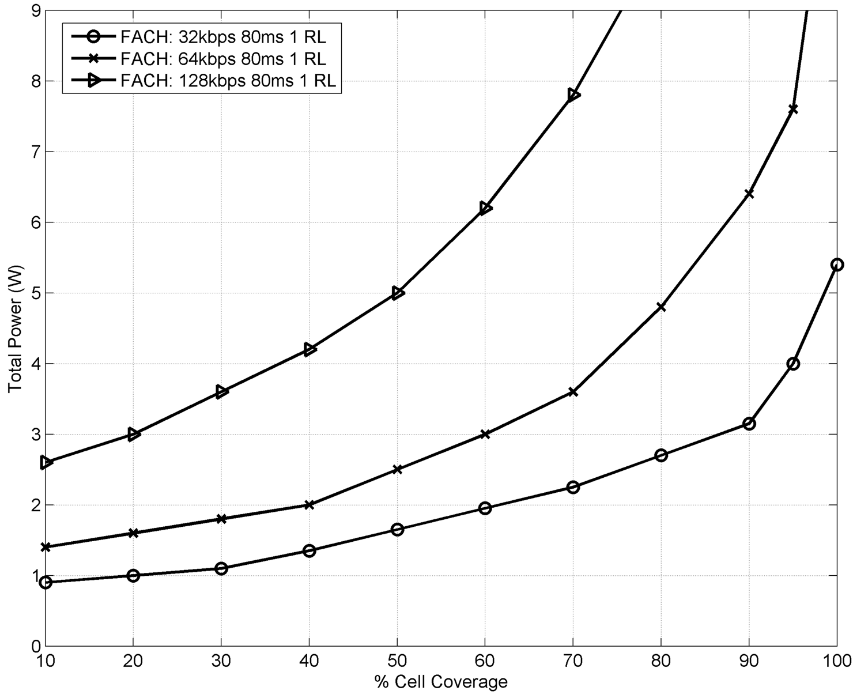
The main problem during a MBMS session, in terms of power consumption, is the exceedingly high fixed power levels when allocating FACH as transport channel. As an example, we mention that in order to provide a 128 Kbps MBMS service with a FACH coverage set to the 95% of the cell, 16 Watt of power are required. If we contemplate that the maximum transmission power of the Node B is 20 Watt (which should be shared among all the users of the cell and among all the possible services), it becomes comprehensible that this level of power makes impossible the provision of services with such bit rates. The techniques which are stated in the remaining of this section partly overcome this problem, since they reduce the FACH transmission power levels.

Dynamic Power Setting (DPS)

DPS is the technique where the transmission power of the FACH can be determined based on the worst user's path loss. This way, the FACH transmission power is allocated dynamically; and the FACH transmission power will need to cover the whole cell only if one (or more) user is at the cell boundary. To perform DPS, the MBMS users need to turn on measurement report mechanism while they are on the Cell_FACH state. Based on such measurement reports, the Node B can adjust the transmission power of the FACH (Chuah, Hu & Luo, 2004).

This is presented in Figure 6, where the Node B sets its transmission power based on the worst user's path loss (*i.e.* distance). The information about the path loss is sent to the Node B via uplink channels. The examination of Figure 6 reveals that 4.0 Watt are required in order to provide a 32 Kbps service to the 95% of the cell. However, supposing that all the MBMS users are found near the Node B (10% coverage) only 0.9 Watt are required. In that case, 3.1 Watt (4.0 Watt minus 0.9 Watt) can be saved while delivering a 32 Kbps service, as with DPS the Node B will set its transmission power so as to cover only the 10% of the cell. The corresponding power gain increases to 6.2 Watt for a 64 Kbps service and to 13.4 Watt for a 128 Kbps service. These high sums of power underline the need for using this technique.

Figure 6. FACH Tx power with DPS (RL: Radio Link)



Macro Diversity Combining (MDC)

Diversity is a technique to combine several copies of the same message received over different channels. Macro Diversity is normally applied as diversity switching where two or more base stations serve the same area, and control over the mobile is switched among them. Basically, the Diversity Combining concept consists of receiving redundantly the same information bearing signal over two or more fading channels, and combine these multiple replicas at the receiver in order to increase the overall received Signal-to-Noise Ratio (SNR).

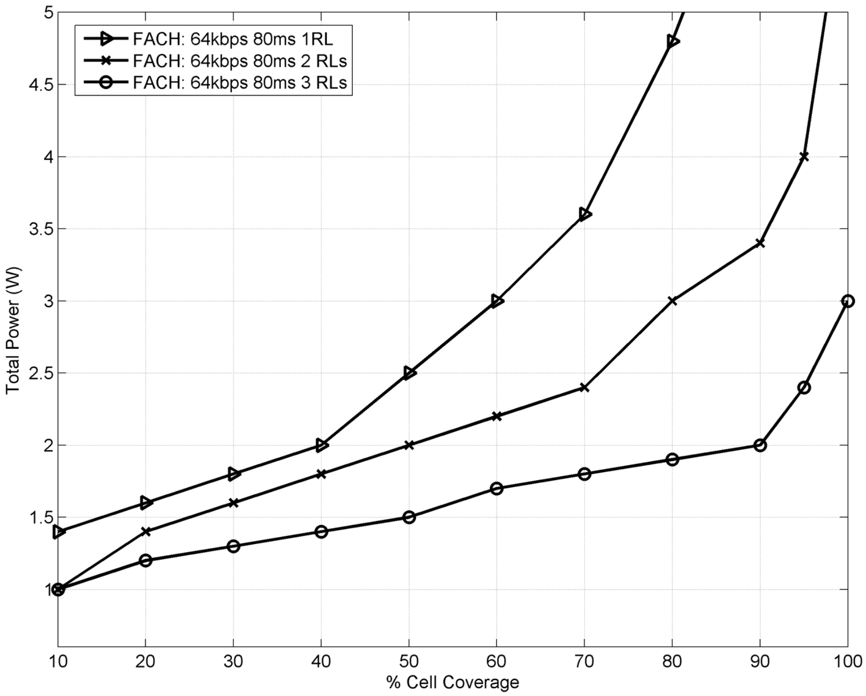
Figure 7 presents how the FACH transmission power level changes with cell coverage when MDC is applied. For the needs of the simulation we considered that a 64 Kbps service should delivered, using 1, 2 or 3 Node Bs (or radio links). TTI is assumed to be 80 ms. The main idea with regard to MDC is to decrease the power level from a Node B when it serves users near the cell edge. However, as we assume 3 sectors per cell (see Table 1), this technique can also be used for distances near the Node B, where each sector is considered as one radio link (RL). Succinctly, in Table 3 we mention some cases that reveal the power gains with this technique.

As the user receives data from two (or three) Node Bs, simultaneously the required power of each Node B is decreased; however, the total required power remains the same and sometimes it is higher. Nevertheless, this technique is particularly useful when the power level of a specific Node B is high, while respectively the power level of its neighboring Node B is low.

Rate Splitting (RS)

The RS technique assumes that the MBMS data stream is scalable, thus it can be split into several streams with different QoS. Only the most important stream is sent to all the users in the cell to provide the basic service. The less important

Figure 7. FACH Tx power with MDC (1Radio Link (RL), 2RLs and 3RLs)



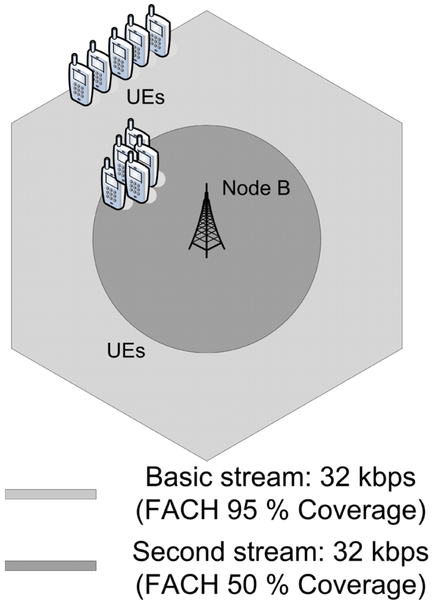
streams are sent with less amount of power or coding protection and only the users who have better channel conditions (*i.e.* the users close to Node B) can receive those to enhance the quality on top of the basic MBMS. This way, transmission power for the most important MBMS stream can be reduced because the data rate is reduced, and the transmission power for the less important streams can also be reduced because the coverage requirement is relaxed (3rd Generation Partnership Project R1-021239, 2002).

In the following scenario, we consider that a 64 Kbps service can be split in two streams of 32 Kbps. The first 32 Kbps stream (basic stream) is provided throughout the whole cell, as it is supposed to carry the important information of the MBMS service. On the contrary, the second 32 Kbps stream is sent only to the users who are close to the Node B (50% of the cell area) providing the users in the particular region the full 64 Kbps service. Figure 8 depicts the way the operation of

Table 3. Indicative FACH Tx power levels with MDC

Cell Coverage	Radio Links	Required Tx Power (Watt)
50%	1	2.5
	2	2.0
	3	1.5
95%	1	7.6
	2	4.0
	3	2.4

Figure 8. MBMS provision with RS



the RS technique, in terms of channel selection and cell coverage.

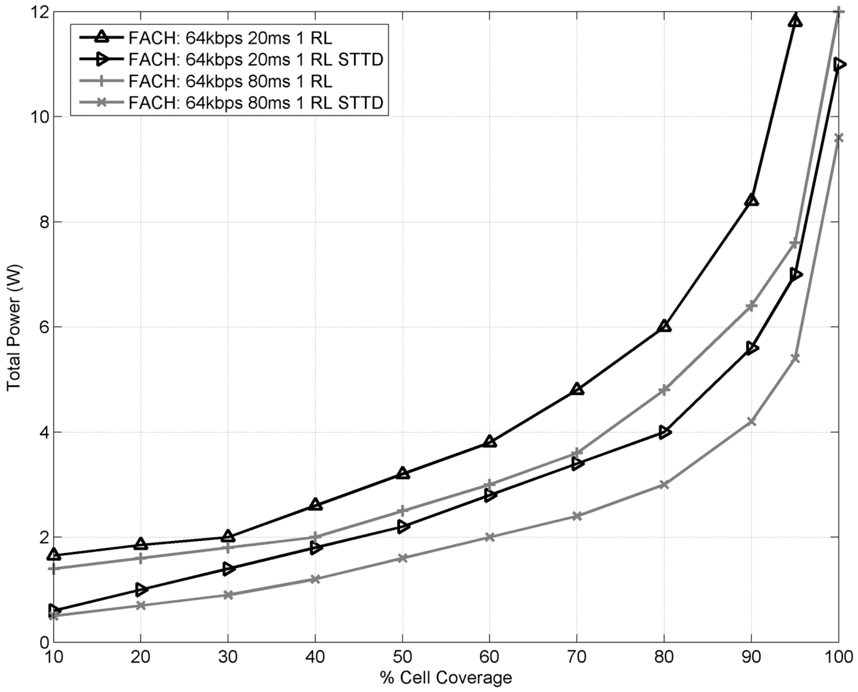
From Table 2 it can be seen that this technique requires 5.8 Watt (4.0 for the basic stream and 1.8 for the second). On the other hand, in order to deliver a 64 Kbps service using a FACH with 95% coverage the required power would be 7.6 Watt. Thus, 1.8 Watt can be saved through the RS technique. However, it is worth mentioning that this power gain involves certain negative results. Some of the users will not be fully satisfied, as they will only receive the 32 Kbps of the 64 Kbps service, even if these 32 Kbps have the important information. As the observed difference will be small, the Node B should weigh between the transmission power and the users' requirements.

Usage of Longer TTI and Space Diversity (LTTI)

These two methods can be employed in the physical layer to benefit every member of the MBMS group in a cell. Space-time processing techniques exploit diversity in both the spatial and temporal domains. On the one hand, an increment in TTI length (from 20 ms to 80 ms) can provide significant power gain; however, the use of longer TTI introduces more complexity and larger memory space requirement in the mobile station. On the other hand, space diversity assumes two transmit antennas and a single data stream in order to improve the signal quality and reduce the power requirements. The main benefit of using Space Time Transmit Diversity (STTD) is a reduction in the downlink E_b/N_0 requirement. These improvements in E_b/N_0 requirement impact upon both downlink system capacity and downlink service coverage (3rd Generation Partnership Project R1-021234, 2002; 3rd Generation Partnership Project TR 25.803, 2005). Fortunately, some MBMS services are not delay sensitive. In that case, diversity can be obtained by using the LTTI technique (Figure 9).

Table 4 demonstrates certain cases that reveal the sums of power that can be saved while delivering a 64 Kbps service, by increasing the TTI length and obtaining STTD. The above power levels are

Figure 9. FACH Tx power with LTTI



indicative of the sums of power that can be saved with the LTTI technique.

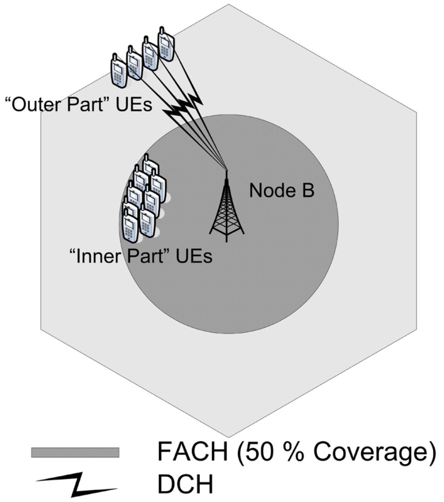
Mixed Usage of Multiple DCH channels and FACH (MDF)

The MDF can significantly decrease the Node B's transmission power, depending on the number and the location of the users that receive the MBMS service. In this approach, the FACH channel only covers the inner part of the sector (*e.g.* 50% of the sector area) and provides the MBMS service to the users that are found in this part ("inner part" users). The rest of the users are served using DCH to cover the remaining outer cell area ("outer part" users). Figure 10 represents the way of providing a MBMS service according to the MDF technique. The total downlink power consumption including

Table 4. Indicative FACH Tx power levels with LTTI

Cell Coverage	TTI (ms)	Required Tx Power (Watt)
50%	20 - no STTD	3.2
	20 - with STTD	2.2
	80 - no STTD	2.5
	80 - with STTD	1.6
95%	20 - no STTD	11.8
	20 - with STTD	7.0
	80 - no STTD	7.6
	80 - with STTD	5.4

Figure 10. MBMS provision with MDF



FACH and dedicated channels obviously depends on the number of users who are served by DCHs and their location (3rd Generation Partnership Project R1-021240, 2002).

The main goal is to examine how the transmission power is affected by the number of users. Figure 11 represents the Node B's total transmission power as a function of the number of the "outer part" users. The total power in Figure 11 includes the power that is required in order to cover the 50% of the cell with FACH (*i.e.* 2.5 Watt). Moreover, the number of the "inner part" users is assumed to be high enough, so as to justify the choice of FACH as the transport channel in the inner part.

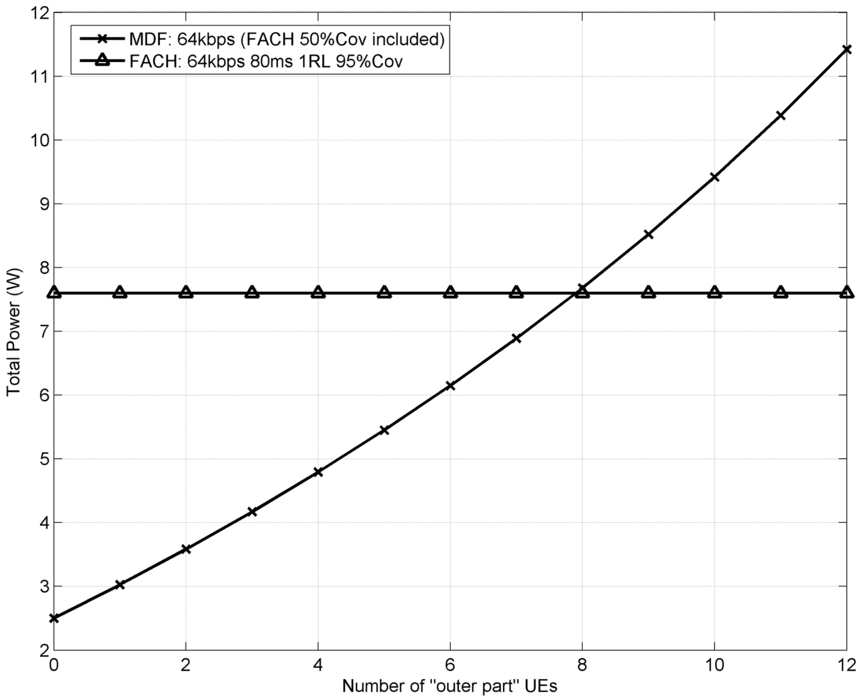
Apart from the power required for the MDF technique, the power allocation level of a FACH with 95% cell coverage is depicted. This parallel plot intends to highlight the fact that a switch from MDF to a pure FACH has to be performed or vice versa. For instance, in Figure 11 when the "outer part" users exceeds 7, the total power (*i.e.* the power to cover the inner part with FACH plus the power to cover the outer part with DCHs) exceeds the power that is required in order to cover the whole cell with a single FACH. Thereby, it is more "power efficient" to use a FACH with 95% coverage.

Except for the power gain described above, the MDF technique ensures one more advantage. This advantage relies to the fact that DCH supports soft handover, while FACH does not. Since with this technique the users that are found near the cell edge are served with DCHs, their transition to another cell will be smoother, as the MBMS service will be provided uninterruptedly.

EXISTING RADIO BEARER SELECTION MECHANISMS

During the provision of MBMS multicast services the system should conceive and adapt to continuous changes that occur in dynamic wireless environments and optimally allocate resources. Under this prism, a critical aspect of MBMS performance is the selection of the most efficient radio bearer for the transmission of MBMS multicast data. It is worth mentioning that this is still an open issue in today's MBMS infrastructure mainly due to its catalytic role in Radio Resource Management (RRM).

Figure 11. Node B's Tx power with MDF



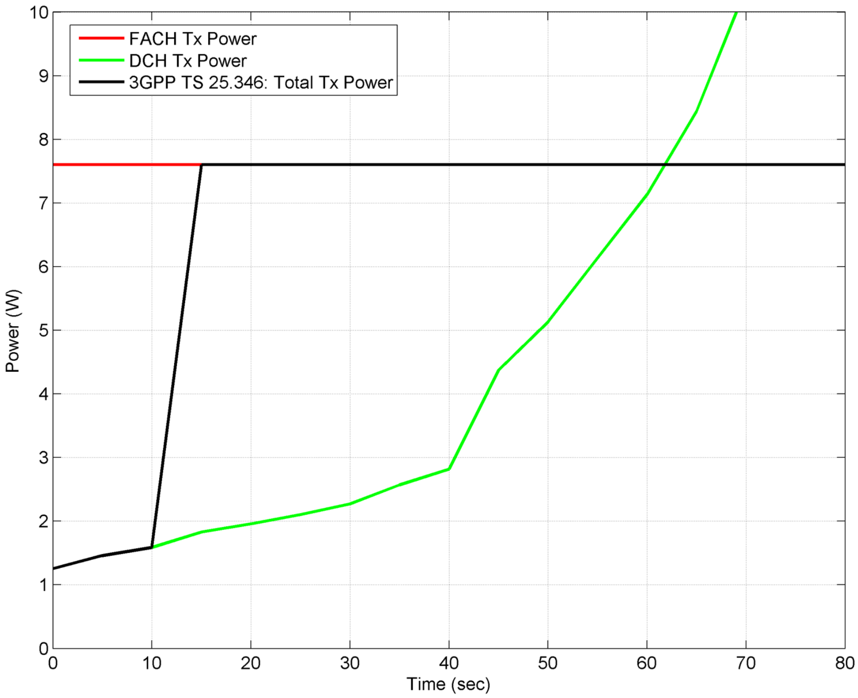
There exist two main research directions during the radio bearer selection procedure. According to the first approach, a single transport channel (PTP or PTM) can be deployed in a cell at any given time. In this case, a switching threshold is actually set that defines when each channel should be deployed. On the other hand, the second approach performs a simultaneous deployment of PTP and PTM modes. A combination of these modes is scheduled and both dedicated and common bearers are established in parallel in a cell. In the following paragraphs we present the main representative approaches of each of the two research directions.

MBMS Counting Mechanism (TS 25.346)

The 3GPP MBMS Counting Mechanism (or TS 25.346) constitutes the prevailing approach of switching between PTP (multiple DCHs) and PTM (FACH) radio bearers, mainly due to its simplicity of implementation and function (3rd Generation Partnership Project TS 25.346, 2009). According to this mechanism, a single transport channel (PTP or PTM) can be deployed in a cell at any given time. The decision on the threshold between PTP and PTM bearers is operator dependent, although it is proposed that it should be based on the number of serving MBMS users. In other words, a switch from PTP to PTM resources should occur, when the number of users in a cell exceeds a predefined threshold.

Figure 12 presents the operation of TS 25.346. Assuming that the threshold is 8 UEs (a mean value for the threshold proposed in the majority of research works), TS 25.346 will command Node B to switch from DCH to FACH when the number of users exceeds this predefined threshold, since HS-DSCH is not supported. Simultaneously, Figure 12 reveals the inefficiencies of TS 25.346. At simulation time 10 sec when the group that receives the MBMS service consists of 9 users (exceeding the switching threshold), this mecha-

Figure 12. 3GPP TS 25.346 Tx Power Levels



nism will switch from DCH to FACH, leading to a power wasting of 6 Watt.

Therefore, we could say that this mechanism provides a non realistic approach because mobility and current location of the mobile users are not taken into account. Moreover, this mechanism does not support FACH Dynamic Power Setting. Therefore, when employed, FACH has to cover the whole cell area, leading to power wasting. Finally, TS 25.346 does not support the HS-DSCH, a transport channel that could enrich MBMS with broadband characteristics.

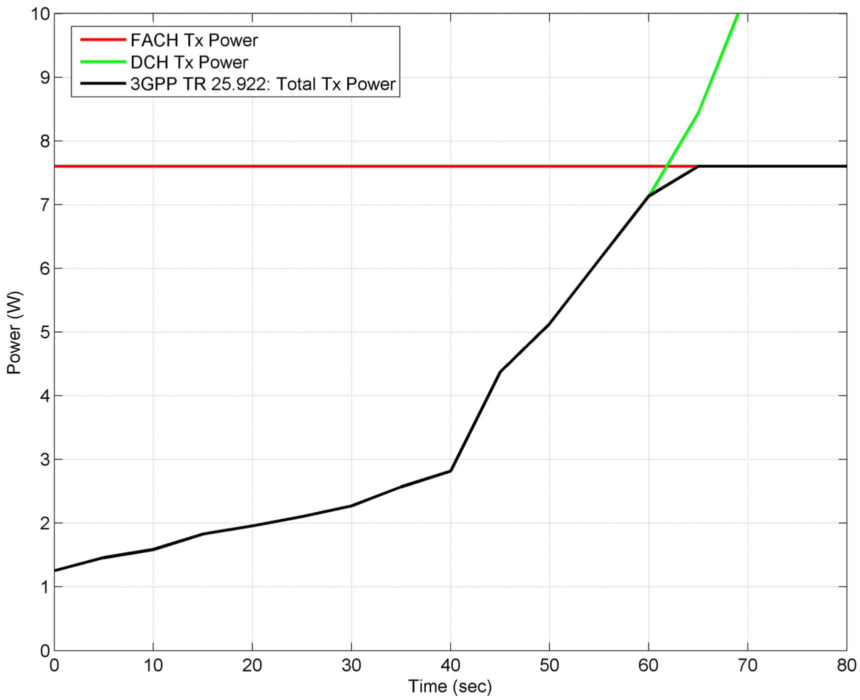
MBMS PTP/PTM Switching Algorithm (TR 25.922)

3GPP MBMS PTP/PTM switching algorithm, or TR 25.922 (3rd Generation Partnership Project TR 25.922, 2007), assumes that a single transport channel can be deployed in a cell at any given time. However, contrary to TS 25.346, it follows a power based approach when selecting the appropriate radio bearer, aiming at minimizing the Node B's power requirements during MBMS transmissions.

In TR 25.922, instead of using solely DCHs, HS-DSCH can also be transmitted. However, the restricted usage of either DCH or HS-DSCH in PTP mode may result to significant power losses. In both cases, the PTP (DCH or HS-DSCH, since the switching between HS-DSCH and DCH is not supported in this mechanism) and the PTM power levels are compared and the case with the lowest power requirements is selected. In general, for small number of multicast UEs, PTP bearers are favored. As the number of users increases, the usage of PTM bearer is imperative.

An example of this mechanism's operation is presented in Figure 13. In this example, TR 25.922 supports only DCH transmissions in PTP mode. According to Figure 13, for small UE population (up to simulation time 60 sec) DCH is preferred compared to FACH since its power consumption is lower. As the number of users increases (from

Figure 13. 3GPP TR 25.922 (with DCH) Tx Power Levels



simulation time 60 sec) a switch from DCH to FACH is performed in order to ensure the lowest possible power consumption. However, even though TR 25.922 overcomes several inefficiencies of the TS 25.346 mechanism, still it does not support FACH Dynamic Power Setting, leading in turn, to increased power consumption in PTM transmissions.

Mechanism Proposed in 3GPP TSG RAN1 R1-02-1240

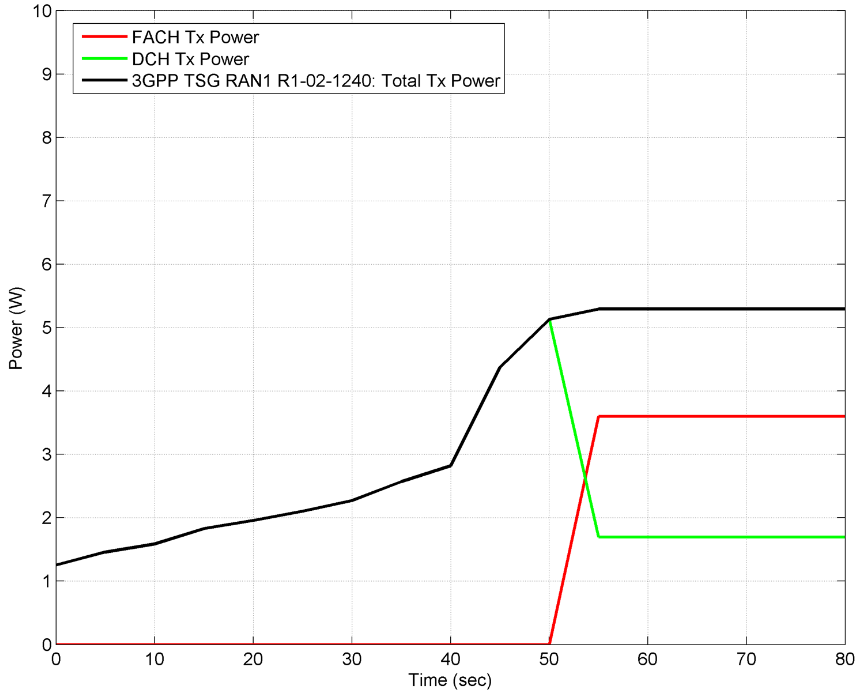
The above mechanisms allow a single PTP or PTM transport channel deployment at any given time. In 3rd Generation Partnership Project R1-021240 (2002), an alternative idea is presented, which is based on the simultaneous/combined usage of PTP and PTM bearers for MBMS transmissions. In particular, this approach considers the mixed usage of DCHs and FACH for the transmission of the MBMS data over the UTRAN interfaces. According to this approach, the FACH channel only covers an inner area of a cell/sector and provides the MBMS service to the users that are found in this part. The rest of the users are served using DCHs to cover the remaining outer cell area. The power for serving the outer part users is calculated as in equation (4). The total downlink power consumption, including FACH and dedicated channels, is the sum of these two power levels (Figure 14).

However, as clearly concluded in 3rd Generation Partnership Project R1-021240 (2002), this approach is only beneficial when the number of outer part users that use the DCHs is extremely small (less than 5). This suggests that the use of DCH in association with FACH for MBMS services is rather limited for real world traffic scenarios.

Novel Mechanism for PTP and PTM Bearers Combination

At this point, it should be mentioned that none of the above mechanisms takes into account the ability of the Node Bs to support many simulta-

Figure 14. 3GPP TSG RAN1 R1-02-1240 Tx Power Levels



neous MBMS sessions. MBMS transmissions have increased power requirements and consume a large portion of the available power recourses. Consequently, the number of parallel MBMS sessions that a base station could support is limited; and the selection of the appropriate radio bearer for a MBMS service should be done with respect to other existing MBMS sessions in the corresponding cell.

To this direction, this section presents a power control mechanism that considers the Node B's transmission power level as the key criterion for the selection of the appropriate MBMS radio bearer. The goal achieved by mechanism work is threefold: At a first level, our mechanism proposes a more realistic and adaptive to dynamic wireless environments approach, by employing a power based switching criterion and allowing the combined usage of transport channels. At a second level, our mechanism contributes to Radio Resource Management (RRM) mechanisms of UMTS by presenting a novel framework for MBMS that optimally utilizes power resources. At a third level, a major advantage of our mechanism is its ability to ensure the service continuity in the system when multiple parallel MBMS services are delivered.

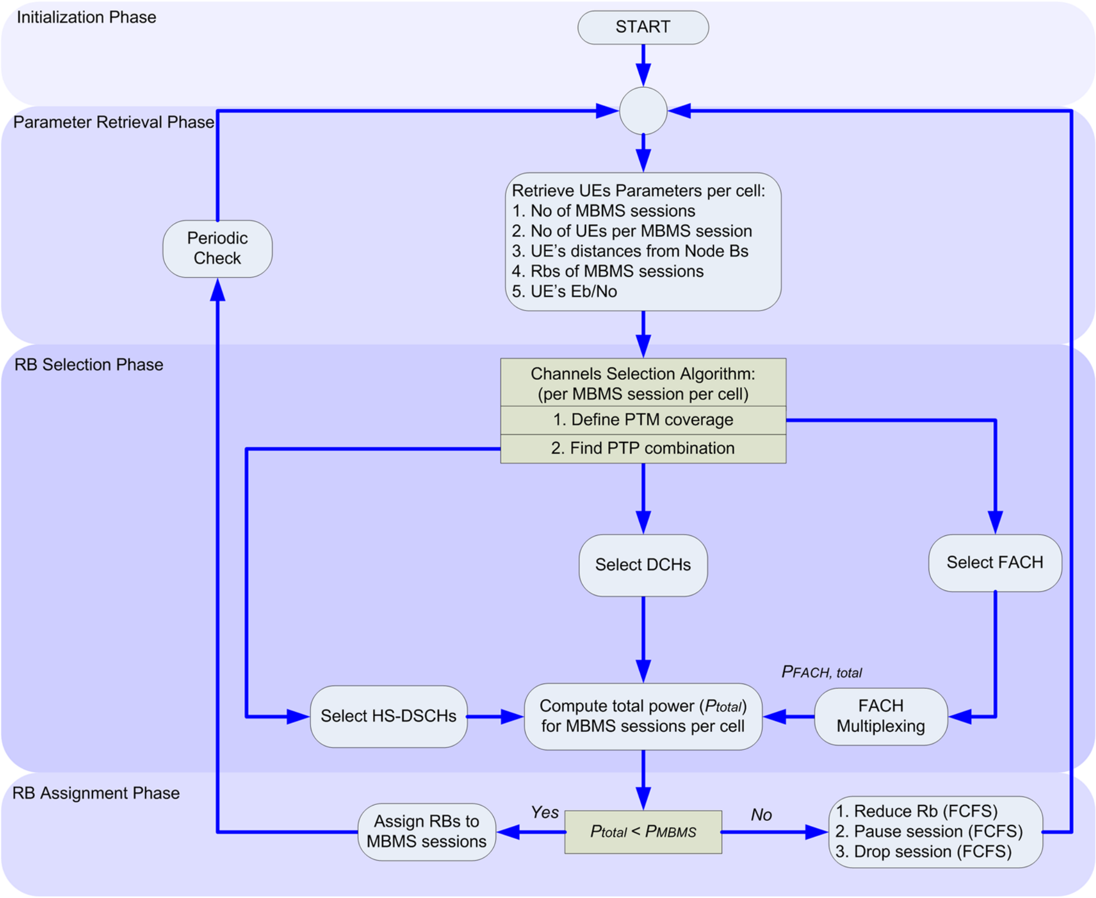
Parameters

The number of parallel MBMS sessions that a Node B could support depends on many parameters. We could classify these parameters in three categories:

- User related parameters,
- MBMS session related parameters and
- Provider related parameters.

User related parameters are parameters such as UEs' distances from the base stations and UEs' QoS parameters. The number of active MBMS sessions per cell, the number of UEs per MBMS session per cell and the bit rates of the MBMS services are some

Figure 15. Block diagram of the mechanism



of the MBMS session related parameters. Finally, the portion of the available power recourses of base stations that could be used for MBMS transmissions is a provider related parameter. All these parameters should be considered in the RRM of MBMS so as to have efficient power control.

Architecture and Functionality

The remaining of this paragraph presents the architecture and functionality of the proposed mechanism that is used for the efficient data transmission of parallel MBMS services in LTE. The block diagram of the proposed mechanism is illustrated in Figure 15. According to Figure 15, the mechanism consists of four distinct operation phases: the initialization phase, the parameter retrieval phase, the radio bearer (RB) selection phase and the RB assignment phase.

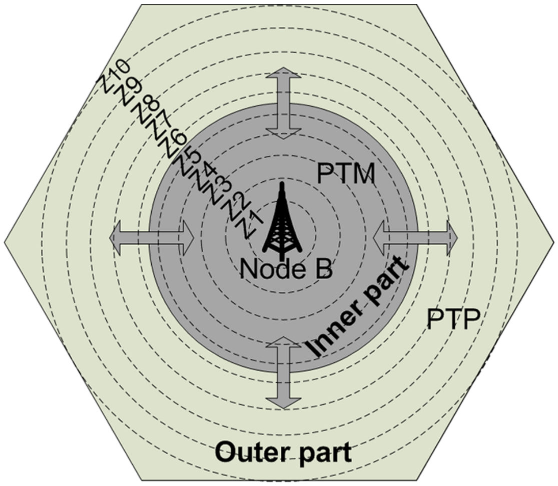
Initialization Phase

The initialization phase (Figure 15) launches the mechanism when one user expresses his interest in receiving a MBMS service (*i.e.* the mechanism begins when the first user requests the first MBMS service).

Parameter Retrieval Phase

The parameter retrieval phase is responsible for retrieving the parameters of the existing MBMS users and services in each cell. In this phase, the mechanism requires the two of the three types of

Figure 16. Cell areas and zones



parameters, mentioned in the beginning of this paragraph: the user related parameters and the MBMS session related parameters. Regarding the latter type of parameters, the mechanism requires information about the number of active MBMS sessions per cell, the number of UEs per MBMS session per cell and the bit rates of the MBMS sessions. This information is retrieved from the BM-SC. On the other hand, the user related parameters are retrieved from the UEs through uplink channels.

Radio Bearer Selection Phase

The RB selection phase is dedicated to the selection of the transport channels for the MBMS sessions in any cell of the network. The most critical operations of the phase are executed by the Channels Selection Algorithm block (Figure 15). The algorithm executed in this block selects the combination of PTP and PTM bearers that minimizes the downlink base station's transmission power in any cell of the network that multicast users are residing. In particular, the algorithm is executed in two steps. In the first step (Define PTM coverage) the algorithm estimates the optimum coverage of FACH for the users' distribution of any MBMS session in the cell. This coverage area is called inner part of the cell as illustrated in Figure 16. In the second step (Find PTP combination), the mechanism decides which PTP bearer(s) will cover the rest part of the cell (outer part - Figure 16). It has to be mentioned that the above cell characterization is done for every MBMS session of the corresponding cell.

In order to estimate the optimum coverage of FACH (for any MBMS session in the cell) in Define PTM coverage step (Figure 15), the algorithm initially divides the cell in ten zones (Z1 to Z10). Each zone Zi refers to a circle with radius equal to 10i% of the cell radius. Afterwards, the algorithm scans all the zones and calculates the total base station's transmission power for the following 21 transport Channel Configurations (CC):

- CC1: No FACH used. All users of the specific MBMS session are covered by DCHs.
- CC2: No FACH used. All users of the specific MBMS session are covered by HS-DSCHs.
- CC3: FACH for UEs up to Z1. All the rest UEs covered by DCHs.
- CC4: FACH for UEs up to Z1. All the rest UEs covered by HS-DSCHs.
- ………..

- CC19: FACH for UEs up to Z9. All the rest UEs covered by DCHs.
- CC20: FACH for UEs up to Z9. All the rest UEs covered by HS-DSCHs.
- CC21: FACH for all UEs (up to Z10). DCHs and HS-DSCHs are not used.

The CC that consumes less power indicates the coverage of the FACH and determines the inner part of the cell. The same procedure is executed simultaneously for any MBMS session in the cell. The output of the Define PTM coverage step is the coverage of the FACH for any MBMS session in the examined cell.

Once the appropriate FACH coverage is defined, the algorithm enters the Find PTP combination step (see Figure 15), which determines the appropriate PTP radio bearer(s) that will cover the MBMS users residing in the outer part of the cell. The procedure is similar to the procedure described in the Define PTM coverage step. The algorithm scans all the zones in the outer part of the cell and calculates the total base station's transmission power in order to cover all the outer part MBMS users only with PTP bearers. The first zone of the outer part is Z(inner part+1), therefore the algorithm will have to scan the following PTP transport Channel Configurations (PTP_CC):

- PTP_CC1: DCHs for outer part UEs up to Z(inner part+1). All the rest outer part UEs (up to Z10) covered by HS-DSCHs.
- PTP_CC2: DCHs for outer part UEs up to Z(inner part+2). All the rest outer part UEs (up to Z10) covered by HS-DSCHs.
- ………..
- PTP_CC(10-inner part): All MBMS users in the outer part cell are covered by DCHs. HS-DSCHs are not used.
- PTP_CC(10-inner part+1): HS-DSCHs for outer part UEs up to Z(inner part+1). All the rest outer part UEs (up to Z10) covered by DCHs.
- PTP_CC(10-inner part+2): HS-DSCHs for outer part UEs up to Z(inner part+2). All the rest outer part UEs (up to Z10) covered by DCHs.
- ………..
- PTP_CC(2*(10-inner part)): All MBMS users in the outer part cell for the specific session are covered by HS-DSCHs. DCHs are not used.

After these calculations, the different PTP_CCs are compared and the PTP_CC with the lowest power requirements determines the PTP transport channel configuration for the outer part MBMS UEs of the specific MBMS session in the cell. The procedure is recursively executed for any MBMS session in the examined cell.

Generally, the output of the Channels Selection Algorithm block is the combination of PTM and PTP transport channels that consumes the lowest power resources between all possible combinations in the corresponding cell for any MBMS session running in it.

In the case of FACH there is another block in the mechanism's block diagram named FACH Multiplexing. When the number of MBMS sessions requiring FACH in cell is greater than one, these FACHs should be multiplexed onto a Secondary Common Control Physical Channel (S-CCPCH) (3rd Generation Partnership Project TS 25.211, 2009; 3rd Generation Partnership Project TS 25.212, 2009). After the multiplexing procedure, the capacity of the S-CCPCH is calculated and based on this, the total power required for the common channels ($P_{FACH,total}$) in the corresponding base station is estimated. In this chapter we consider a one to one mapping between MBMS sessions (MBMS point-to-multipoint Traffic Channels - MTCHs) and FACHs.

The last action performed in the RB selection phase is the computation of the total base station's power (P_{total}) required so as to support all the MBMS sessions in each cell of the network.

Table 5. UE Number, Coverage per time period

Time (sec)	UEs Number	Coverage (%)	Best Performance
0-50	25	50	Our Mechanism
	7	80	
51-100	25	50	R1-02-1240 and Our Mechanism
	2	80	
101-150	17	50	TR 25.922 (HS-DSCH) and Our Mechanism
151-200	4	50	All except TR 25.922 (HS-DSCH)

However, at this point we have to mention that the selected radio bearers are not yet assigned to the MBMS sessions. This action is performed in the following phase.

Radio Bearer Assignment Phase

During the RB assignment phase, the P_{total} is compared with the available power assigned by the network provider to MBMS sessions in each base station (P_{MBMS}). Obviously, P_{MBMS} constitutes the third type of parameters, known as provider related parameter. If P_{total} is smaller than P_{MBMS} then the selected from the RB selection phase transport channels are assigned to MBMS sessions and the MBMS data transfer phase begins. In case when P_{total} is bigger than P_{MBMS}, a session reconfiguration procedure should occur due to the fact that the Node B has no available radio resources so as to serve all the MBMS sessions in the examined cell. Three possible reconfiguration events could be used in such a case. The first is the reduction of the transmission rate of a MBMS session, the second is the pause of a MBMS session for a short time period and the last is the cancellation of the service. The simplest policy that the mechanism could adopt in order to perform these reconfiguration events, is a First Come First Served (FCFS) policy. Following the FCFS policy and considering the available power, the mechanism performs the optimum event to the most recent sessions.

The above description refers to a dynamic model, in the sense that the UEs are assumed to be moving throughout the topology and the number of MBMS sessions varies. The parameter retrieval phase is triggered at regular time intervals so as to take into account the changes in user related parameters, MBMS session related parameters and operator related parameters. This periodic computation inserts a further complexity as this information is carried in through uplink channels. This entails that a certain bandwidth fraction must be allocated for the transmission of this information in uplink channels, thus resulting to a system's capacity reduction. A further complexity is inserted due to the fact that the mechanism is executed many times. In particular, if we suppose that N base stations are served with multicast users, while each of these base stations serves Mi ($i = 1...N$) parallel MBMS sessions, then the number of executions of the mechanism is computed as in (6):

$$K = \sum_{i=1}^{N} M_i \qquad (6)$$

Comparison with 3GPP Approaches

This scenario lasts for 200 sec and can be divided into four time periods, depending on the number of MBMS users. According to this scenario, a 64 Kbps service should be delivered to a group of users, whose initial position at each time period is presented in Table 5. For example, for the time period 0 to 50 sec, 25 UEs receive the 64 Kbps service at distance 50% of the cell radius and 7 UEs at distance 80% of the cell radius.

Figure 17. (a) Power consumption and (b) complexity comparison

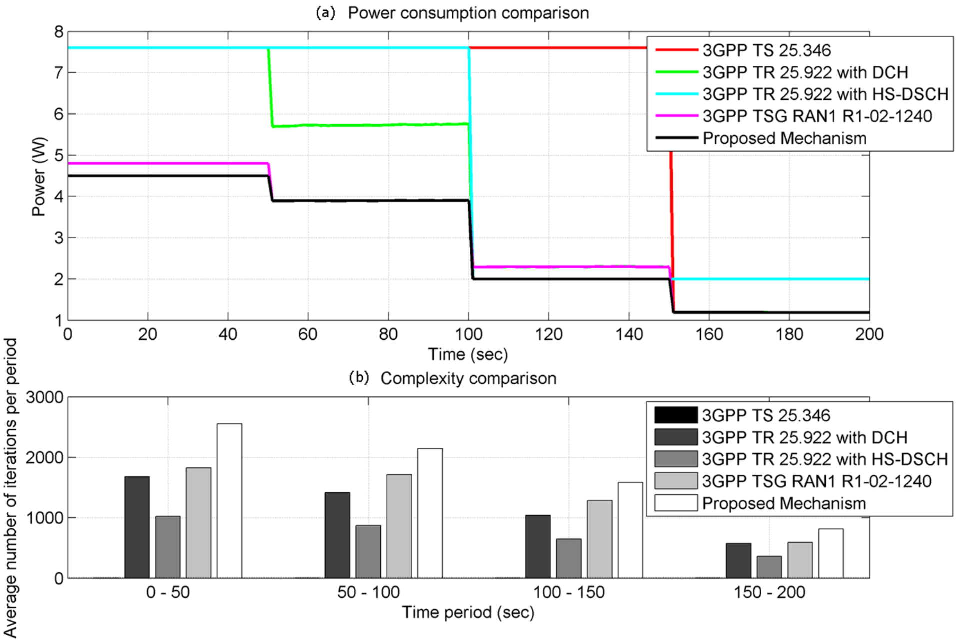


Figure 17a depicts the power levels of the examined radio bearer selection mechanisms. As it can be noticed from Figure 17, the proposed mechanism and the mechanism presented in 3GPP TSG RAN1 R1-02-1240 have the best performance in general.

For example, for the period 0-50 sec, the total number of users in the cell is 32. By assuming that the threshold for switching between DCH and FACH (HS-DSCH is not supported) in TS 25.346 is 8 UEs, TS 25.346 will deploy a FACH with 100% cell coverage (requiring 7.6 W).

The high initial users' population favors the deployment of FACH in order to serve all the UEs in 3GPP TR 25.922. However, as TS 25.346, TR 25.922 does not support FACH Dynamic Power Setting. This is the reason why TR 25.922 (with DCH or HS-DSCH) has the same power requirements with TS 25.346 (7.6 W) for the time period 0-50 sec.

The mechanism proposed in 3GPP TSG RAN1 R1-02-1240 allows the mixed usage of DCHs and FACH and supports FACH Dynamic Power Setting. As shown in Figure 17a, this mechanism requires 4.8 W in order to serve all the users in the cell, for the first time period. This derives from the fact that for the specific scenario, this mechanism will deploy only a FACH with 80% coverage, while the user with the worst path loss resides in the borders of zone Z8.

Finally, Figure 17a depicts the power requirements of the proposed mechanism for the examined scenario. For the time period 0-50 sec, the output of the Channels Selection Algorithm block (Figure 15) specifies that the users up to Z5 should be server by a FACH. Moreover, the most efficient combination of PTP bearers for the outer part MBMS users is to serve the remaining 7 users in zone Z8 with HS-DSCH. Therefore, 4.5 W in total are required in order to serve all the MBMS users with this mechanism. Obviously, the proposed mechanism ensures minimized power consumption. A significant power budget, ranging from 0.3 to 3.1 W, may be saved for the period 0-50 sec compared with the other approaches.

On the other hand, Figure 17b presents the computational overhead that each mechanisms inserts (number of iterations required to calculate

Table 6. Comparison of the mechanisms

Mechanism	Advantages	Disadvantages
TS 25.346	1) Low complexity 2) Easy to implement 3) 3GPP standardized	1) High power requirements 2) No mobility support 3) No HS-DSCH support 4) No dynamic FACH support
TR 25.922	1) Support all transport channels 2) 3GPP standardized	1) High power requirements 2) No switching between HS-DSCH and DCH support 3) No dynamic FACH support
3GPP R1-02-1240	1) Power efficient 2) Support combined usage of FACH and DCH 3) Support dynamic FACH	1) High complexity 2) No standardized 3) No HS-DSCH support
Proposed Mechanism	1) Power efficient 2) Support combined usage of all transport channels 3) Support dynamic FACH 4) Support multiple MBMS sessions	1) High complexity 2) No standardized (Novel Mechanism)

the power of the available transport channels and assign the ideal channel), based on the above scenario.

In general, TS 25.346 inserts the lowest computational overhead (number of iterations constant and equal to one), because TS 25.346 requires only the number of served MBMS users in order to assign the appropriate transport channel. On the other hand, the other approaches have higher computational overhead due to the fact that these mechanisms have to periodically retrieve the parameters of existing MBMS users. Moreover, these approaches have to calculate the power consumption of the transport channels that each mechanism supports; and based on this calculation to assign the ideal radio bearer. The fact that the proposed mechanism supports all the available transport channels and examines all possible transport channels configurations explains why the number of iterations in this case is higher than the other approaches.

To sum up, Table 6 presents a cumulative, direct comparison between all mechanisms analyzed in this chapter. The main conclusion is that the proposed mechanism outperforms the other approaches in terms of power consumption, since significant power budget is saved. It puts together the benefits of all mechanisms by providing a scheme that is based on the concept of transport channels combination; and performs an optimal power resource allocation in LTE base stations. And even if the complexity of the proposed mechanism is higher than the complexity of the other mechanisms, the benefits from the optimal power planning counterbalance the complexity issues raised. This fact is strongly enhanced mainly due to the power limited LTE networks, which entails that power strategies are of key importance in order to obtain high capacity.

Managing Parallel MBMS Sessions

The major advantage of the proposed mechanism is its ability to manage multiple parallel MBMS sessions. In order to evaluate this ability, we setup a simulation scenario where multiple MBMS services are transmitted in parallel to several user groups residing in a cell. In particular, we suppose that four user groups receive four distinct MBMS services with characteristics presented in Table 7.

Table 7. Scenario parameters

MBMS No.	Duration (sec)	Rb (Kbps)	UEs Number	Maximum Coverage	Channel
1	0 - 600	64	10	80%	HS-DSCH
2	50 - 600	64	22 + 6	20%+50%	FACH+DCH
3	100 - 150	64	2 to 13	60%	DCH
	151 - 300	64	14 to 19	60%	HS-DSCH
	301 - 600	64	20 to 27	60%	FACH
4	150 - 560	64	7	70%	DCH
	561 - 600	32	7	80%	DCH

Moreover, Table 7 presents the appropriate transport channel (with respect to power consumption as presented in previous sections) to serve each group at each time interval.

Figure 18 depicts the power consumption of each MBMS session as well as the total, aggregative power required to support the transmission of all services to the multicast users in the corresponding cell.

Users of the 1st MBMS session are served with a HS-DSCH channel, due to the small population, throughout the whole service time. At simulation time 50 sec, MBMS service 2 is initiated (Figure 18). At this time instant, the mechanism, through the RB selection phase, selects FACH (for the 22 inner part users) and DCHs (for the 6 outer part users) as the most efficient transport channel combination for the transmission of the MBMS traffic.

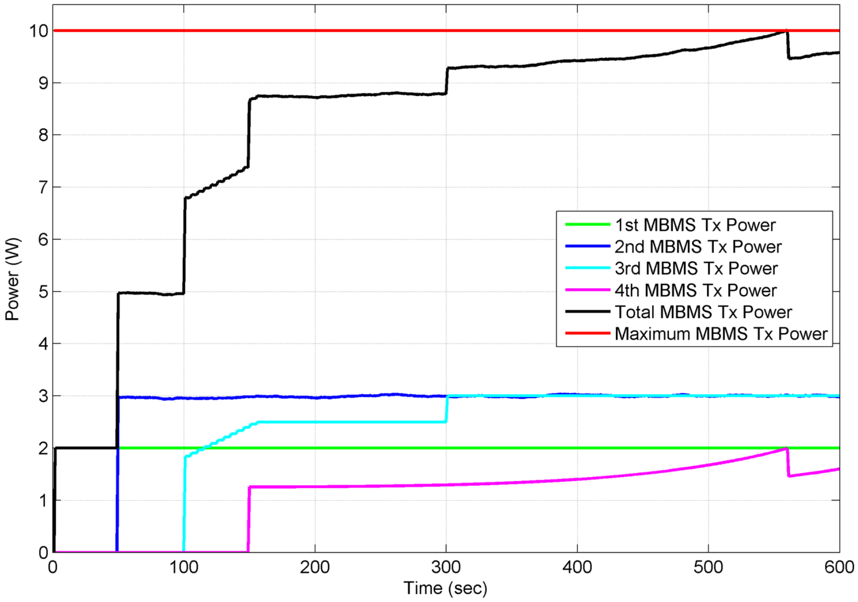
MBMS service 3 starts at simulation time 100 sec. At this time the 3rd multicast group consists of only two UEs; thus, the mechanism selects multiple DCHs for this MBMS service. The number of users receiving the service successively increases (join requests), reaching 13 UEs at simulation time 150 sec, 19 at simulation time 300 sec and 27 at the end of the simulation time. The increasing number of users in the group forces the mechanism to perform a channel switching from DCH to HS-DSCH at simulation time 151 sec and another one from HS-DSCH to FACH at simulation time 301 sec, securing, in this way, the efficient resource utilization.

At this point we have to mention that from simulation time 300 sec until the end of the simulation, MBMS services 2 and 3 employ FACHs for the transmission of the MBMS data (see Table 7). During this time interval, the deployment of two parallel FACHs forces the mechanism to perform a FACH multiplexing procedure in the RB selection phase. Consequently, a single S-CCPCH with bit rate of 128 Kbps is used to deliver MBMS services 2 and 3. Moreover, P_{total} is lower than P_{MBMS}, which translates into efficient provision of the three parallel MBMS sessions.

At simulation time 150 sec, the MBMS service 4 is initiated and is targeted to a multicast group consisting of seven members. Multiple DCHs are selected by the mechanism to deliver the MBMS content to the 4th multicast group. Additionally, at the same time instance, P_{total} still remains smaller than P_{MBMS}, which means that the MBMS service 4 is accepted for transmission in the system. From simulation time 150 until the end of the simulation, four parallel MBMS sessions running in the system and the proposed mechanism handles them in an efficient way.

Due to the fact that the users of the 4th multicast group are moving towards the cell edge an increase in P_{total} occurs and at simulation time 560 sec; P_{total} exceeds P_{MBMS} value (Figure 18). Thus, a session reconfiguration procedure is performed,

Figure 18. Power levels of the MBMS sessions



forcing the MBMS service 4 to reduce its bit rate from 64 Kbps to 32 Kbps in order to ensure the efficient service of four parallel MBMS sessions without any interruption.

FUTURE RESEARCH DIRECTIONS

Regarding the operation of the proposed mechanism, several enhancements could be incorporated in order to further improve the MBMS performance. The steps that follow this work could be at a first level the evaluation of the mechanism through additional simulation scenarios. The scenarios could be simulated in the ns-2 simulator, in which the proposed mechanism could be implemented. In that way, we could measure, except from the performance of our mechanism, other parameters such as delays in UTRAN interfaces during MBMS transmissions. Furthermore, several power saving techniques such as Rate Splitting and Macro Diversity Combining could be integrated in the proposed mechanism. The use of these techniques will further improve the overall performance of the proposed mechanism, which in turn means that a better utilization of radio and network resources could be achieved.

Additionally, the capacity and functionality of the proposed mechanism may be further improved by incorporating the enhancements that could be obtained from the use of Multiple Input Multiple Output (MIMO) antenna techniques in HSDPA. MIMO systems are a prerequisite for LTE networks. Early LTE requirements consider two transmit and receive antennas (MIMO 2x2) and approximately, double data rates are obtained with the same base station power compared with conventional HS-DSCH single antenna systems. Therefore, MIMO antenna techniques have the potential to address the unprecedented demand for wireless multimedia services and in particular for MBMS. Finally, it may be examined whether the Multicast Broadcast Single Frequency Network (MBSFN) transmission mode, included in the evolved UTRAN technologies of the LTE, could be used as an alternative PTM transmission mode for MBMS. MBSFN tries to overcome the cell edge problems of MBMS and to reduce the intercell interference. Therefore, MBSFN could be used in order to achieve very high receiver output SNR and significantly improve the overall spectral efficiency.

CONCLUSION

This chapter introduced the key concepts of MBMS services. The main target was to highlight the importance of power control and its commanding role during the delivery of MBMS multicast content, for the overall efficiency of next generation networks. To this direction, the power profiles of several transport channels which could be employed for the transmission of MBMS services to the mobile users were investigated. Moreover, the reader was introduced to certain problems that MBMS current specifications are facing and become familiar with techniques/solutions proposed to overcome such limitations.

Finally, this chapter underlined the significance of selecting the appropriate transport channel for the delivery of MBMS services so as to optimally allocate power resources. The reader was introduced to several radio bearer selection mechanisms that focus on conceiving and adapting to continuous changes that occur in dynamic wireless environments. These mechanisms could further improve the MBMS performance since they ensure the economic and rational usage of the expensive radio and network resources, enabling in this way the mass market delivery of multimedia services to mobile users.

REFERENCES

Alexiou, A., Antonellis, D., Bouras, C., & Papazois, A. (2006, October). *An Efficient Multicast Packet Delivery Scheme for UMTS*. Paper presented at the 9th ACM/IEEE International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2006), Torremolinos, Malaga, Spain.

Alexiou, A., Bouras, C., & Kokkinos, V. (2007, October). *Power Saving Techniques in MBMS Multicast Mode*. Paper presented at the 3rd ACM International Workshop on Wireless Multimedia Networking and Performance Modeling (WMuNeP 2007), Chania, Greece.

Alexiou, A., Bouras, C., & Rekkas, E. (2007, June). *A Power Control Scheme for Efficient Radio Bearer Selection in MBMS*. Paper presented at the 8th IEEE International Symposium on World of Wireless, Mobile and Multimedia Networks (WoWMoM 2007), Helsinki, Finland.

B-BONE. (2003). *Final Results with combined enhancements of the Air Interface*. Deliverable of the project (D2.5), IST-2003-507607.

Boni, A., Launay, E., Mienville, T., & Stuckmann, P. (2004, October). *Multimedia Broadcast Multicast Service – Technology Overview and Service Aspects*. Paper presented at the 5th IEE International Conference on 3G Mobile Communication Technologies (3G 2004), London, UK.

Chuah, P., Hu, T., & Luo, W. (2004, June). *UMTS Release 99/4 Airlink Enhancement for supporting MBMS Services*. Paper presented at the 2004 IEEE International Conference on Communications (ICC 2004), Paris, France.

Holma, H., & Toskala, A. (2006). HSDPA/HSUPA for UMTS: High Speed Radio Access for Mobile Communications. Chichester, UK: John Wiley & Sons.

Holma, H., & Toskala, A. (2007). WCDMA for UMTS: HSPA Evolution and LTE (4th edition). Chichester, UK: John Wiley & Sons.

Parkvall, S., Englund, E., Lundevall, M., & Torsner, J. (2006). Evolving 3G Mobile Systems: Broadband and Broadcast Services in WCDMA. *IEEE Communications Magazine*, *44*(2), 30–36. doi:10.1109/MCOM.2006.1593548

Perez-Romero, J., Sallent, O., Agusti, R., & Diaz-Guerra, M. (2005). Radio Resource Management Strategies in UMTS. Chichester, UK: John Wiley & Sons.

3rd Generation Partnership Project R1-021234. (2002). *Evaluation of combining gains for MBMS (incl. STTD)*. Qualcomm, TSG-RAN WG1#28.

3rd Generation Partnership Project R1-021239. (2002). *MBMS Power Usage, Lucent Technologies*. Lucent Technologies, TSG-RAN WG1#28.

3rd Generation Partnership Project R1-021240. (2002). *Power Usage for Mixed FACH and DCH for MBMS*. Lucent Technologies, TSG-RAN WG1#28.

3rd Generation Partnership Project TR 101.102. (2002).*Universal Mobile Telecommunications System (UMTS); Selection procedures for the choice of radio transmission technologies of the UMTS*. Version 3.2.0.

3rd Generation Partnership Project TR 23.846. (2003). *Technical Specification Group Services and System Aspects; Multimedia Broadcast/Multicast Service; Architecture and functional description (Release 6).* Version 6.1.0.

3rd Generation Partnership Project TR 25.803. (2005). *Technical Specification Group Radio Access Network; S-CCPCH performance for MBMS, (Release 6)*. Version 6.0.0.

3rd Generation Partnership Project TR 25.922. (2007). *Technical Specification Group Radio Access Network; Radio resource management strategies (Release 7)*. Version 7.1.0.

3rd Generation Partnership Project TS 22.146. (2008). *Technical Specification Group Services and System Aspects; Multimedia Broadcast/Multicast Service; Stage 1 (Release 9)*. Version 9.0.0.

3rd Generation Partnership Project TS 25.211. (2009). *Physical channels and mapping of transport channels onto physical channels (FDD) (Release 8)*. Version 8.4.0.

3rd Generation Partnership Project TS 25.212. (2009). *Multiplexing and channel coding (FDD) (Release 8)*. Version 8.5.0.

3rd Generation Partnership Project TS 25.346. (2009). *Technical Specification Group Radio Access Network; Introduction of the Multimedia Broadcast Multicast Service (MBMS) in the Radio Access Network (RAN); Stage 2, (Release 8)*. Version 8.3.0.

Vriendt, J., Gomez Vinagre, I., & Van Ewijk, A. (2004). Multimedia Broadcast and Multicast Services in 3G Mobile Networks. Alcatel Telecommunication Review.

ADDITIONAL READING

Aho, K., Kurjenniemi, J., Haikola, V., Callender, C., & Ristaniemi, T. (2008). Multimedia Broadcast Multicast Service Performance and its Enhancements in WCDMA Networks. *Springer International Journal of Wireless Personal Communications*, *46*(2), 115–142. doi:10.1007/s11277-007-9413-x

Alexiou, A., Bouras, C., & Kokkinos, V. (2009, April). *An Efficient Mechanism for Power Control Optimization in MBMS Enabled UTRAN*. Paper presented at the IEEE Wireless Communications and Networking Conference 2009 (WCNC 2009), Budapest, Hungary.

Alexiou, A., Bouras, C., Kokkinos, V., & Rekkas, E. (2009). An improved mechanism for multiple MBMS sessions assignment in B3G cellular networks. Springer Wireless Networks.

Alexiou, A., Bouras, C., Kokkinos, V., & Rekkas, E. (2009, April). *Optimal MBMS Power Allocation Exploiting MIMO in LTE Networks*. Paper presented at the IEEE 69th Vehicular Technology Conference (VTC2009 Spring), Barcelona, Spain.

Christophorou, C., & Pitsillides, A. (2008, July). *A New Approach for Efficient MBMS Service Provision in UTRAN*. Paper presented at the IEEE Symposium on Computers and Communications 2008 (ISCC 2008), Marrakech, Morocco.

Dahlman, E., Parkvall, S., Sköld, J., & Beming, P. (2007). 3G EvolutionHSPA and LTE for Mobile Broadband. Linacre House, Jordan Hill, Oxford, United Kingdom: Elsevier.

Laiho, J., Wacker, A., & Novosad, T. (2006). Radio Network Planning and Optimisation for UMTS. The Atrium, Southern Gate, Chichester, England: John Wiley & Sons.

Lescuyer, P., & Lucidarme, T. (2008). Evolved Packet System (EPS) The LTE and SAE Evolution of 3G UMTS. The Atrium, Southern Gate, Chichester, England: John Wiley & Sons.

Nawrocki, M., Dohler, M., & Aghvami, H. (2006). Understanding UMTS Radio Network Modelling, Planning and Automated Optimisation. The Atrium, Southern Gate, Chichester, England: John Wiley & Sons.

Panayides, A., Christophorou, C., Antoniou, J., Pitsillides, A., & Vassiliou, V. (2008, July). *Power Counting for Optimized Capacity in MBMS Enabled UTRAN*. Paper presented at the IEEE Symposium on Computers and Communications 2008 (ISCC 2008), Marrakech, Morocco.

Rong, L., Haddada, O., & Elayoubi, S. (2008, December). *Analytical Analysis of the Coverage of a MBSFN OFDMA Network*. Paper presented at the IEEE Global Telecommunications Conference 2008 (GLOBECOM 2008), New Orleans, LA, USA.

Weng, J., Chen, J., & Cheng, K. (2008). Comparative study of broadcast and multicast in 3GPP and 3GPP2 networks. Elsevier Computer Communications.