Chapter 9

Radio Resource Management for E-MBMS Transmissions towards LTE

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9.1 Introduction

Indisputably, tomorrow's mobile marketplace will be characterized by bandwidth-hungry multimedia services that are already experienced in wired networks. Long-term evolution (LTE), the evolutionary successor of Universal Mobile Telecommunication System (UMTS) and High Speed Packet Access (HSPA) networks, addresses this emerging trend, by shaping the future mobile broadband landscape. LTE promises a richer, more immersive environment that significantly increases peak data rates and spectral efficiency. However, the plethora of mobile multimedia services that are expected to face high penetration, poses the need for the deployment of a resource economic scheme. Multimedia Broadcast/Multicast Service (MBMS), also called Evolved MBMS (E-MBMS) in LTE terminology, constitutes an efficient way to compensate for this necessity since it allows resources' sharing during data transmission [1, 2].

The main requirement during the provision of MBMS multicast services is to make an efficient overall usage of radio and network resources. The system should conceive and adapt to continuous changes that occur in such dynamic wireless environments and optimally allocate resources. To this direction, a critical aspect of MBMS performance is the selection of the most efficient radio bearer, in terms of power consumption, for the transmission of multimedia traffic. The selection of the most efficient radio bearer is an open issue in today's 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 each mechanism may provide.

Additionally, this chapter examines the operation and performance of several techniques, such as Dynamic Power Setting (DPS), Macro Diversity Combining (MDC), and Rate Splitting (RS) that could be utilized in order to further minimize the base station's total 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, in this chapter the performance enhancements emerged from Multiple Input Multiple Output (MIMO) antennas used in next-generation mobile networks is highlighted. MIMO systems are a prerequisite for next-generation mobile networks and have the potential to address the unprecedented demand for wireless multimedia services and particularly for MBMS. In particular, the intention is to examine how the introduction of MIMO antenna systems affect the MBMS power planning strategy of next-generation cellular networks.

9.2 Multimedia Broadcast/Multicast Service

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 number of users.

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 turn 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 [3].

9.2.1 Operation

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 no matter 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 are 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 [2].

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.

9.2.2 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 [2].

The UMTS network is split into 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 9.1). 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 [3]. 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 9.1). 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.

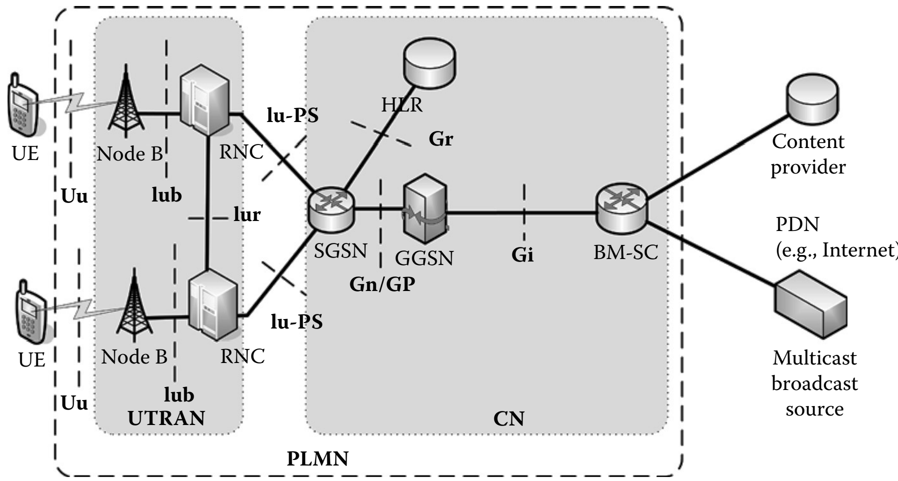

Figure 9.1 UMTS and MBMS architecture.

UTRAN consists of two kinds of nodes: the first is the RNC and the second is the NodeB. NodeB constitutes the base station and provides radio coverage to one or more cells (Figure 9.1). NodeB 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 NodeBs connected to it is called Radio Network Subsystem (RNS) [3].

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). Actually, BM-SC acts as an 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 [1, 2].

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 a 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

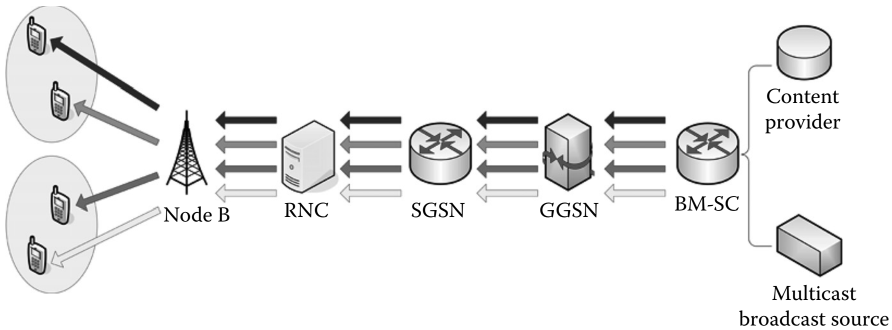

Figure 9.2 UMTS multicast without MBMS enhancement.

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.

9.2.3 Multicast Mode of MBMS

MBMS multicast efficiency improvement in UMTS networks can be derived from Figure 9.2 and Figure 9.3. More specifically, these figures present the 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 created when the number of users increases significantly. All interfaces are heavily 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,

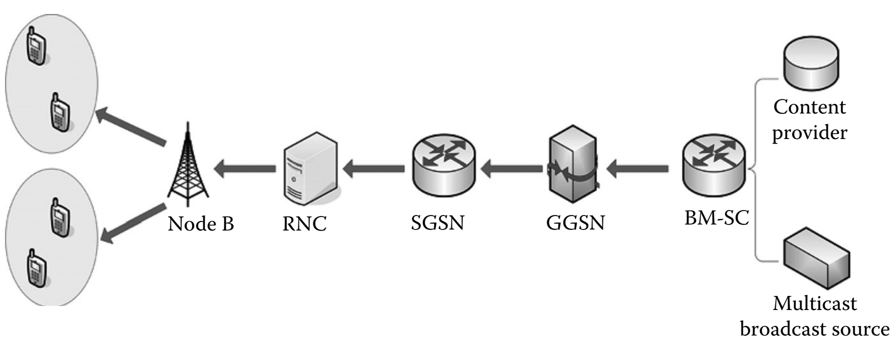

Figure 9.3 UMTS multicast with MBMS enhancement.

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 9.4 depicts a subset of a UMTS-MBMS network. In this architecture, there are two SGSNs connected to a GGSN, four RNCs, and twelve NodeBs. 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 9.4.

The analysis presented in this paragraph, covers the forwarding mechanism of the data packets between the BM-SC and the UEs. With multicast, the packets are forwarded only to those NodeBs that have multicast users. Therefore, in Figure 9.4, the NodeBs 2, 3, 5, 7, 8, and 9 receive the multicast packets issued by the BM-SC. We briefly summarize the five steps needed 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 9.4, the GGSN

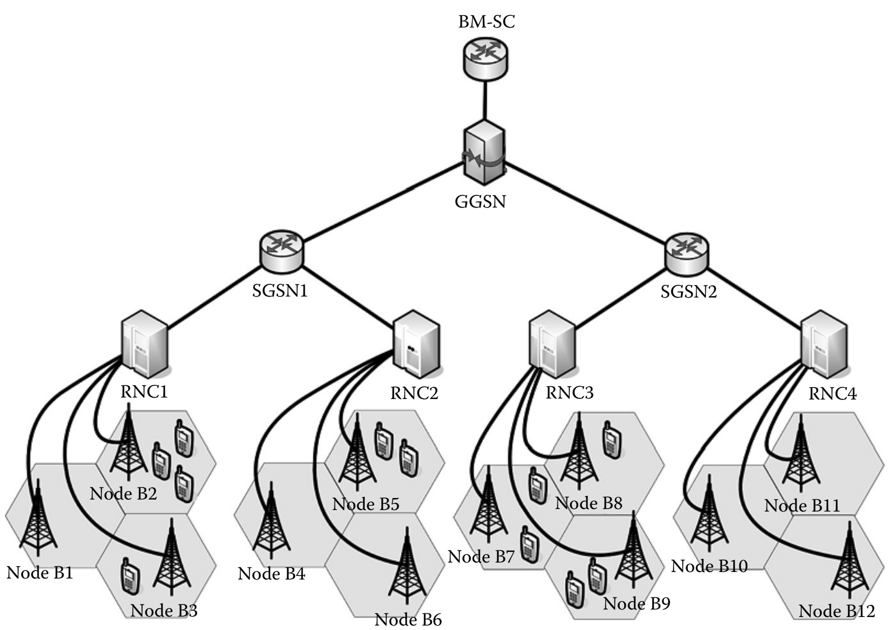

Figure 9.4 Packet delivery in MBMS multicast mode.

duplicates the multicast packet and forwards it to the SGSN1 and the SGSN2 [4]. 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 NodeBs that have established the appropriate radio bearers for the multicast application. In Figure 9.4, these are: NodeB2, 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 [4].

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 [1]. 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 [3], [5]. The allocation of HS-DSCH as a 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 [6].

9.3 Power Control in 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 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 there is minimum interference affecting the neighboring cells. However, when a user consumes a high portion of power, more than actually 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, NodeB 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 9.1 [3, 7].

Table 9.1 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 (3 km/h)
Orthogonality factor	0.5
E_b/N_o target	5 dB

9.3.1 The 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 [6], this chapter will focus on a dynamic method in order to provide only the required marginal amount of power needed to satisfy all the served 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 Equation 9.1 [6]:

$$SINR = SF_{16} \cdot \frac{P_{HS-DSCH}}{p \cdot P_{own} + P_{other} + P_{noise}} \tag{9.1}$$

where $P_{HS-DSCH}$ is the HS-DSCH transmission power, P_{own} is the own cell interference experienced by the mobile user, P_{other} is the interference from neighboring cells, and P_{noise} is the Additive White Gaussian Noise. Parameter p is the orthogonality factor ($p = 0$: perfect orthogonality), while SF_{16} is the spreading factor of 16.

The 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 Equation 9.2 [3]:

$$G = \frac{P_{own}}{P_{other} + P_{noise}} \tag{9.2}$$

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 this throughput relates to the *SINR* [6]. Finally, we can describe how the required HS-DSCH transmission power ($P_{HS-DSCH}$) can be expressed as a function of the *SINR* value and the user location (in terms of G) as in Equation 9.3 [6]:

$$P_{HS-DSCH} \geq SINR \cdot [p - G^{-1}] \cdot \frac{P_{own}}{SF_{16}} \tag{9.3}$$

When MIMO is supported in HS-DSCH, multiple transmit antennas and receive antennas are used (different data streams are transmitted simultaneously over each antenna) and *SINR* is further improved [8]. Early requirements consider two transmit and receive antennas (MIMO 2x2) and approximately, double data rates are obtained with the same base station transmission power. Therefore, without loss of generality, half power is required, compared to conventional HS-DSCH single antenna systems, for the delivery of the same MBMS session. In other words, MIMO further contributes in saving significant power resources and, in parallel, maximizing system capacity.

9.3.2 The DCH Power Profile

The total downlink transmission power allocated for all MBMS users in a cell served by multiple DCHs is variable. It mainly depends on the number of served users, their location in the cell, the bit rate of the MBMS session and the experienced signal quality, E_b/N_o, for each user. Equation 9.4 calculates the NodeB's total DCH transmission power required for the transmission of the data to n users in a specific cell [9].

$$P_{DCH} = \frac{P_P + \sum_{i=1}^{n} \frac{P_N + x_i}{\frac{W}{(E_b/N_o)_i \cdot R_{b,i}} + p} \cdot L_{p,i}}{1 - \sum_{i=1}^{n} \frac{p}{\frac{W}{(E_b/N_o)_i \cdot R_{b,i}} + p}} \tag{9.4}$$

where P_{DCH} 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, $R_{b,i}$ is the ith user transmission rate, W is the bandwidth, P_N is the background noise, p is the orthogonality factor ($p = 0$ for perfect orthogonality), and x_i is the intercell interference observed by the ith user given as a function of the transmitted power by the neighboring cells P_{Tj}, $j = 1, ..., K$, and the path loss from this user to the jth cell L_{ij}. More specifically [9]:

$$x_i = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{ij}} \tag{9.5}$$

DCH may be used for the delivery of PTP MBMS services, but can not be used to serve large multicast populations since high downlink transmission power would be required. Figure 9.5 depicts the downlink transmission power when MBMS multicast data are delivered over multiple DCHs (one separate DCH per user). Obviously, higher power is required to deliver higher MBMS data rates. In addition, an increased cell coverage area and larger user groups lead to higher power consumption.

9.3.3 The 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' locations. FACH power efficiency strongly depends

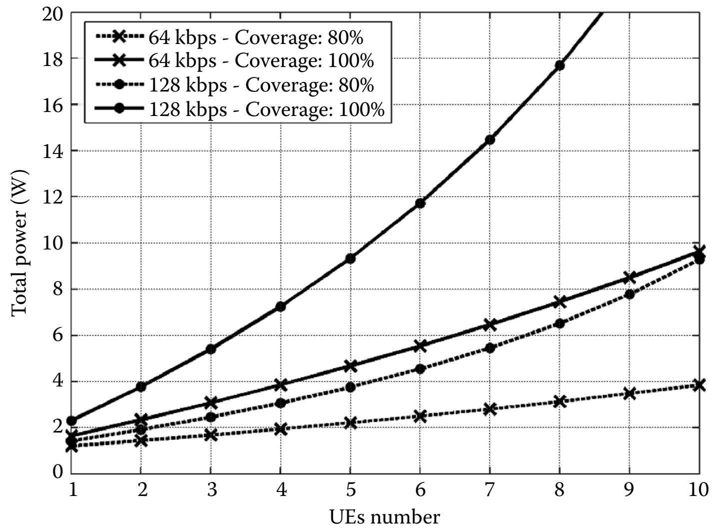

Figure 9.5 DCH transmission (Tx) power.

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 [10, 11].

Table 9.2 presents some indicative FACH downlink transmission power levels obtained for various cell coverage areas and MBMS bit rates, without assuming diversity techniques [10]. 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 watts). High bit rates can only be offered to users located very close to NodeB.

Table 9.2 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

9.4 Power Saving Techniques

The main problem during a MBMS session, in terms of power consumption, is the exceedingly high fixed power levels when allocating FACH as a transport channel. As an example, we mention that in order to provide a 128-kbps MBMS service with a FACH coverage set to 95% of the cell, 16 watts of power are required. If we contemplate that the maximum transmission power of the NodeB is 20 watts (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 stated in the remaining of this section partly overcome this problem, since they reduce the FACH transmission power levels.

9.4.1 Dynamic Power Setting

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 users are at the cell boundary. To perform DPS, the MBMS users need to turn on the measurement report mechanism while they are in the Cell_FACH state. Based on such measurement reports, the NodeB can adjust the transmission power of the FACH [12].

This is presented in Figure 9.6, where the NodeB 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 NodeB via uplink channels. The examination of Figure 9.6 reveals that 4.0 watts 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 watts are required. In that case, 3.1 watts (4.0 watts minus 0.9 watts) can be saved while delivering a 32-kbps service, since with DPS the NodeB will set its transmission power so as to cover only the 10% of the cell. The corresponding power gain increases to 6.2 watts for a 64-kbps service and to 13.4 watts for a 128-kbps service. These high sums of power underline the need for using this technique.

9.4.2 Macro Diversity Combining

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 9.7 presents how the FACH transmission power level changes with cell coverage when MDC is applied. For the needs of the simulation, we considered

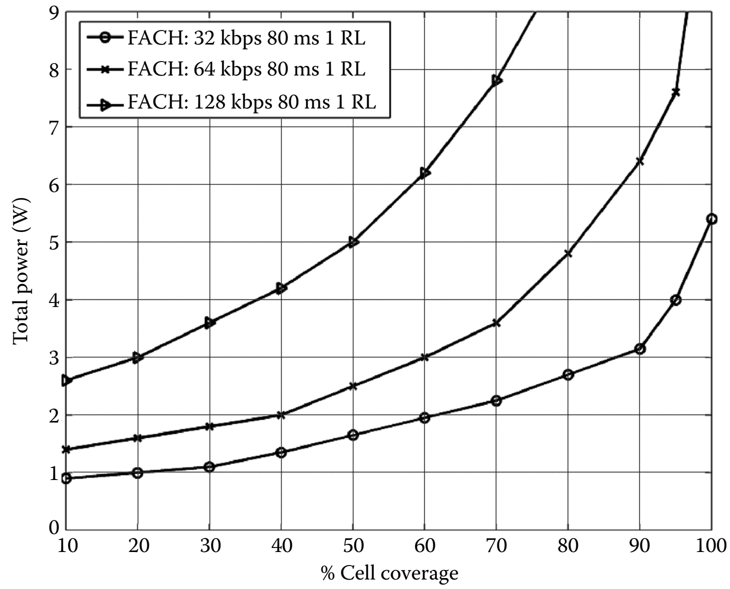

Figure 9.6 FACH Tx power with DPS (RL: Radio Link).

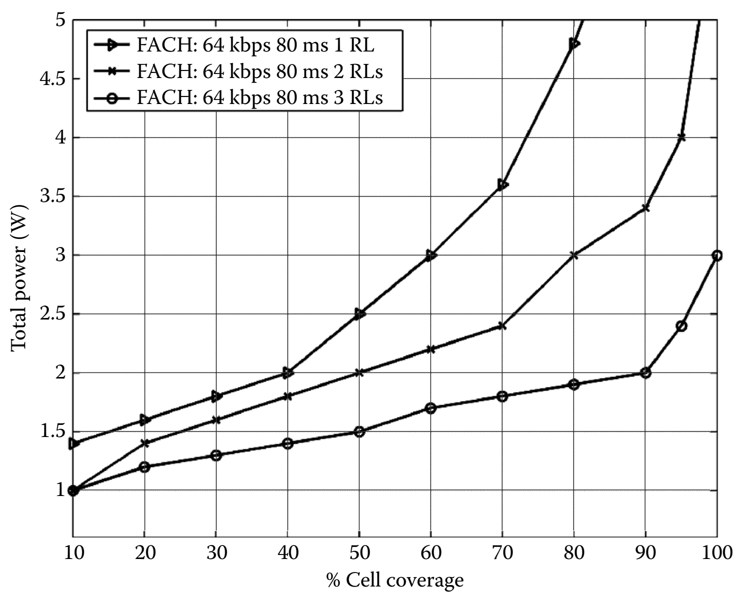

Figure 9.7 FACH Tx power with MDC (1 Radio Link [RL], 2 RLs, and 3 RLs).

that a 64-kbps service should be delivered, using one, two or three NodeBs (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 NodeB when it serves users near the cell edge. However, as we assume three sectors per cell (see Table 9.1), this technique can also be used for distances near the NodeB, where each sector is considered as one radio link (RL). Succinctly, in Table 9.3 we mention some cases that reveal the power gains with this technique.

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

9.4.3 Rate Splitting

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 streams are sent with less power or coding protection and only the users who have better channel conditions (i.e., the users close to NodeB) 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 [13].

In the following scenario, we consider that a 64-kbps service can be split into two streams of 32-kbps. The first 32-kbps stream (basic stream) is provided throughout the whole cell, because 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

Table 9.3 Indicative FACH Tx Power Levels with MDC

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

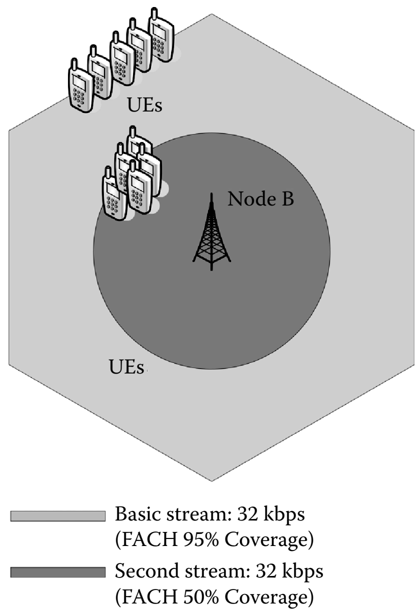

Figure 9.8 MBMS provision with RS.

who are close to the NodeB (50% of the cell area) providing the users in the particular region the full 64-kbps service. Figure 9.8 depicts the operation of the RS technique, in terms of channel selection and cell coverage.

From Table 9.2 it can be seen that this technique requires 5.8 watts (4.0 watts for the basic stream and 1.8 watts 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 Watts. Thus, 1.8 watts 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 32 kbps of the 64-kbps service, even if these 32 kbps carry the important information. As the observed difference will be small, the NodeB should weigh between the transmission power and the users' requirements.

9.5 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).

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.

The figures presented in the following paragraphs refer to the same scenario where a 64-kbps MBMS service is delivered to a constantly increasing number of MBMS users. The group initially consists of four users, and two users join the MBMS session every 5 sec. Each user appears in a random position and moves randomly throughout the cell area with a speed of 3km/h. The main target is to demonstrate the operation and power consumption of each mechanism.

9.5.1 The 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 [14]. 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 served 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. 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 NodeB to switch from DCH to FACH when the number of users exceeds this predefined threshold (at simulation time 10 sec), since HS-DSCH is not supported (Figure 9.9).

Figure 9.9 also reveals the inefficiencies of TS 25.346. This mechanism provides a non-realistic approach because the 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.

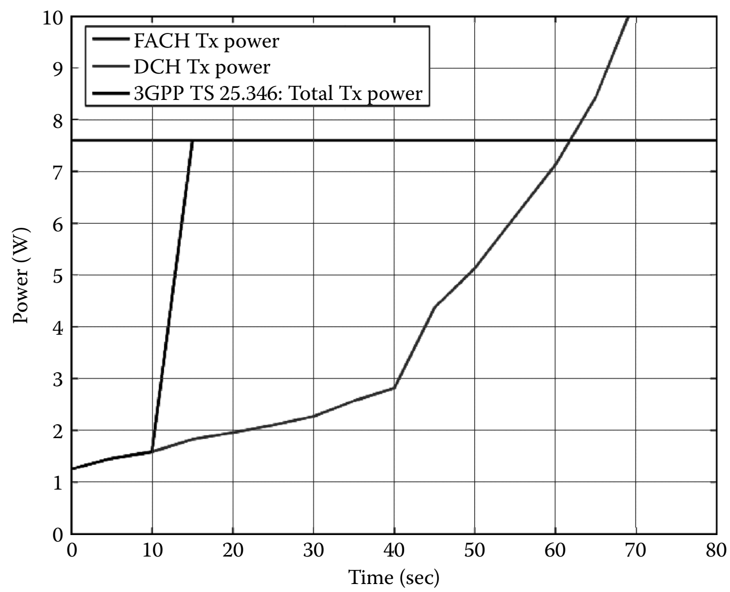

Figure 9.9 3GPP TS 25.346 Tx power levels.

9.5.2 The MBMS PTP/PTM Switching Algorithm (TR 25.922)

The 3GPP MBMS PTP/PTM switching algorithm, or TR 25.922 [15], 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 NodeB'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 (Figure 9.10) in PTP mode may result in 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 a small number of multicast users, PTP bearers are favored. As the number of users increases, the usage of a PTM bearer is imperative.

Even though TR 25.922 overcomes several inefficiencies of the TS 25.346 mechanism, it still does not support FACH Dynamic Power Setting, leading in turn to increased power consumption in PTM transmissions.

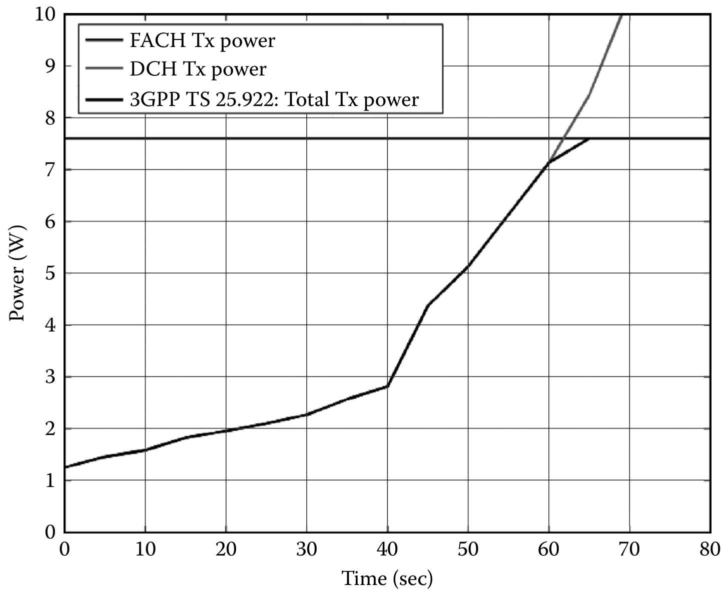

Figure 9.10 3GPP TR 25.922 (with DCH) Tx power levels.

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

The preceding mechanisms allow a single PTP or PTM transport channel deployment at any given time. In [16], 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 9.4. The total downlink power consumption, including FACH and dedicated channels, is the sum of these two power levels (Figure 9.11).

However, as clearly concluded in [16], 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.

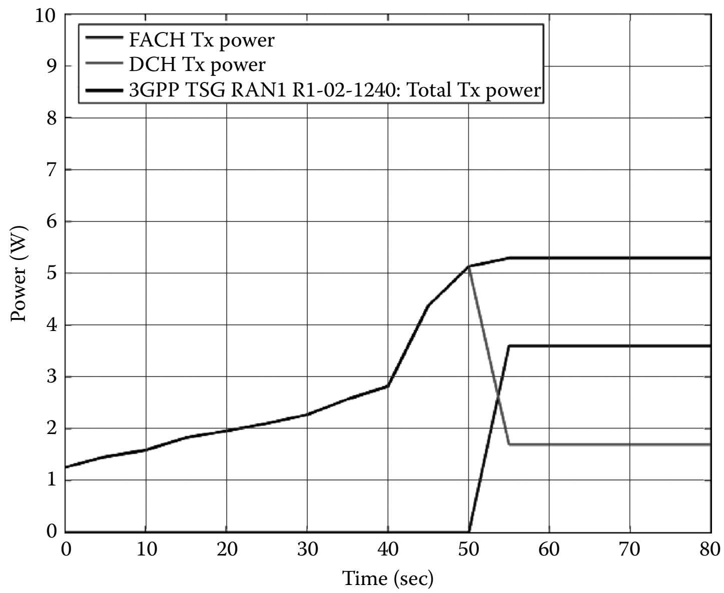

Figure 9.11 3GPP TSG RAN1 R1-02-1240 Tx power levels.

9.6 A Proposed MBMS Mechanism

This section proposes an advanced version of the aforementioned mechanisms that performs optimal power allocation during MBMS transmissions. The proposed mechanism dynamically determines the optimal MBMS radio bearer, based on the required transmission power to serve a multicast group. The scheme takes advantage of the HSPA technology (including MIMO support) and contributes to RRM mechanisms of UMTS by adopting a novel framework for MBMS that efficiently utilizes power resources. The main research motivation is to reduce MBMS power consumption, which translates into improved capacity, thus enabling the mass delivery of rich multimedia services in UMTS networks.

More specifically, the mechanism selects for the delivery of the multicast traffic the transport channel with the lowest power requirements. The fact that any changes in such dynamic environments are directly reflected to the base station transmission power makes the proposed mechanism highly adaptive. Furthermore, the proposed scheme incorporates the premier HS-DSCH transport channel used in HSPA, in contradiction to the MBMS Counting Mechanism that considers only Release'99 bearers (DCH and FACH). HS-DSCH in many cases is less power consuming, which combined with the power-based bearer switching criterion further improves MBMS power efficiency. However, even more power resources can be saved when MIMO technology is supported.

Next in this section, we present the architecture and the functionality of the proposed scheme, the block diagram of which is illustrated in Figure 9.12. More specifically, the mechanism comprises three distinct operation phases: the parameter retrieval phase, the power level computation phase and the transport channel selection phase. Additionally, a periodic check is performed at regular time intervals. The RNC is the responsible node of the MBMS architecture for the operation of this algorithm

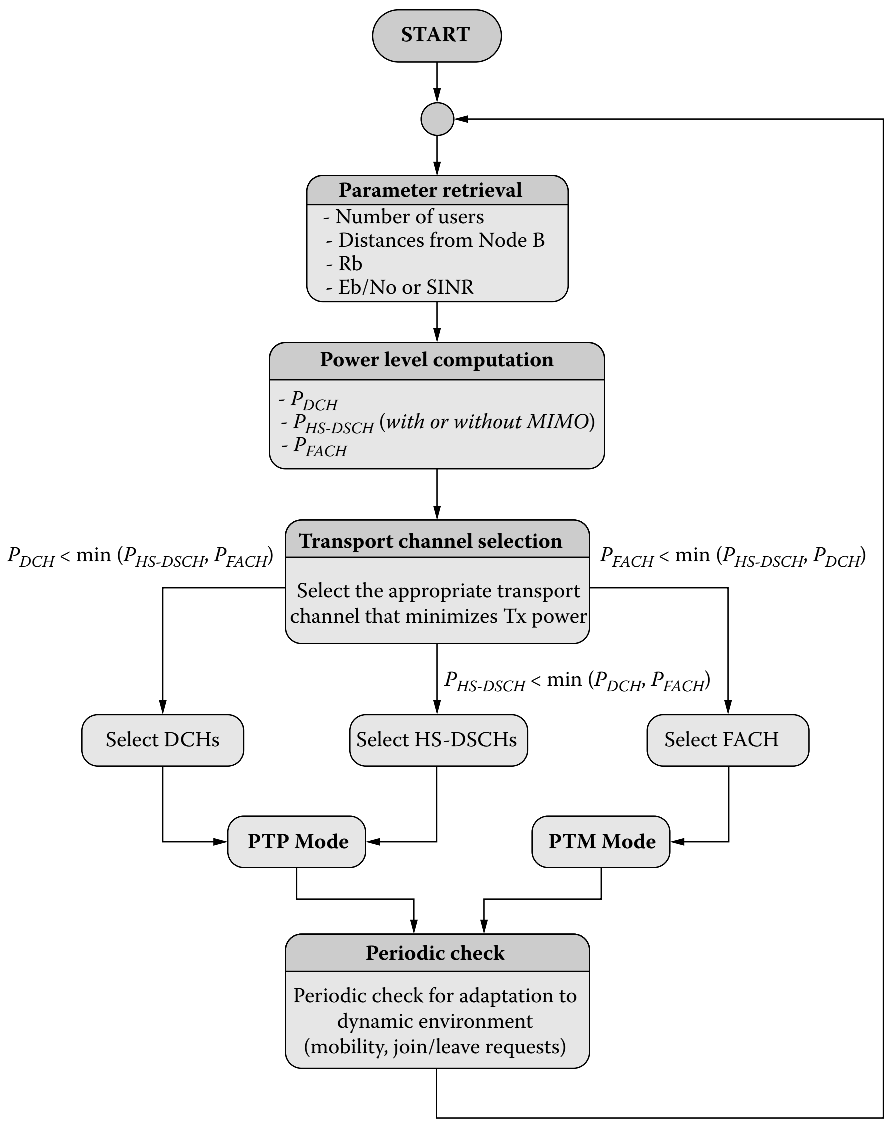

Figure 9.12 Power counting scheme with MIMO functionality.

and the final decision on the most efficient transport channel for the delivery of MBMS multicast data.

During the parameter retrieval phase (Figure 9.12) the mechanism retrieves parameters of the existing MBMS users and services in each cell. User-related parameters, such as the number of users requesting a specific MBMS session, their distances from the base station, and their QoS requirements are received from the RNC through appropriate uplink channels. Moreover, the MBMS bit rate service is retrieved from the BM-SC node.

The power level computation phase substantially processes the information received from the parameter retrieval phase. In this phase, the required power to be allocated for MBMS session delivery in each cell is computed. The computation is based on the assumption that the transmission of the multicast data can be performed over multiple DCHs, HS-DSCHs, or over a single FACH. Consecutively, P_{DCH}, $P_{HS-DSCH}$ (with or without MIMO), and P_{FACH} power levels are computed, respectively, for each type of transport channel.

During the transport channel selection phase, the appropriate transport channel for the transmission of the MBMS multicast content is selected. P_{DCH}, $P_{HS-DSCH}$, and P_{FACH} values are compared in order to select the most power-efficient bearer for an MBMS session in a cell. The algorithm dynamically decides which case requires less power and, consequently, chooses the corresponding transport channel for the session.

Finally, the mechanism performs a periodic check and re-retrieves user and service parameters in order to adapt to any changes during the service provision. This periodic check is triggered at a predetermined frequency rate and ensures the mechanism is able to conceive changes, such as users' mobility, join/leave requests, or any fading phenomena, and configure its functionality so as to maintain high resource efficiency.

9.6.1 Performance Evaluation

Efficient MBMS Transport Channel Selection

This subsection presents performance results concerning the most critical aspect of the proposed scheme: the transport channel selection phase. This power efficient channel deployment is illustrated in Figure 9.13, Figure 9.14, and Figure 9.15, for 60%, 80%, and 100% cell coverage areas, respectively. In these figures, transmission power levels (overall output of the power level computation phase) for DCH, HS-DSCH, (with and without MIMO support) and FACH channels are depicted. The simulation scenario considers a 64-kbps MBMS session delivery in a cell, whose users are assumed to be in groups (of varying population), located at the bounds of the earlier coverage areas each time.

Regarding the 60% cell coverage case (Figure 9.13), we observe that for a multicast group with ten or fewer users, DCH is the optimal transport channel. For a multicast

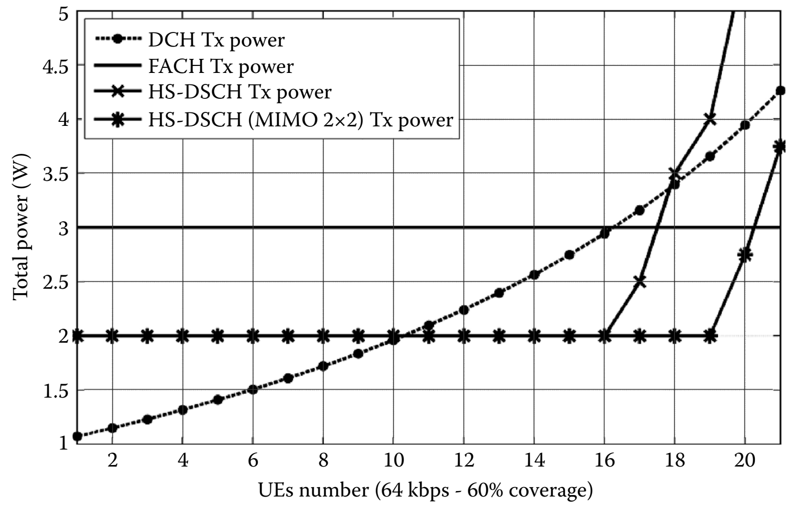

Figure 9.13 MBMS power allocation, 64 kbps, 60% coverage.

population of 10 to 17 users, HS-DSCH (without MIMO) is less power consuming and, thus, it should be preferred for MBMS content transmission (PTP mode). When MIMO 2 × 2 is supported, the above upper threshold is further increased to 20 users. For more than 17 users (or 20 users with MIMO support), FACH is more power efficient and should be deployed (PTM mode). Similar results can

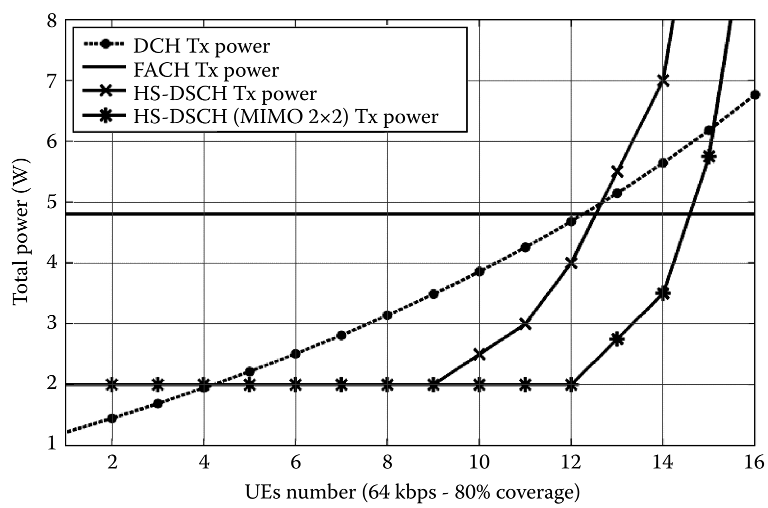

Figure 9.14 MBMS power allocation, 64 kbps, 80% coverage.

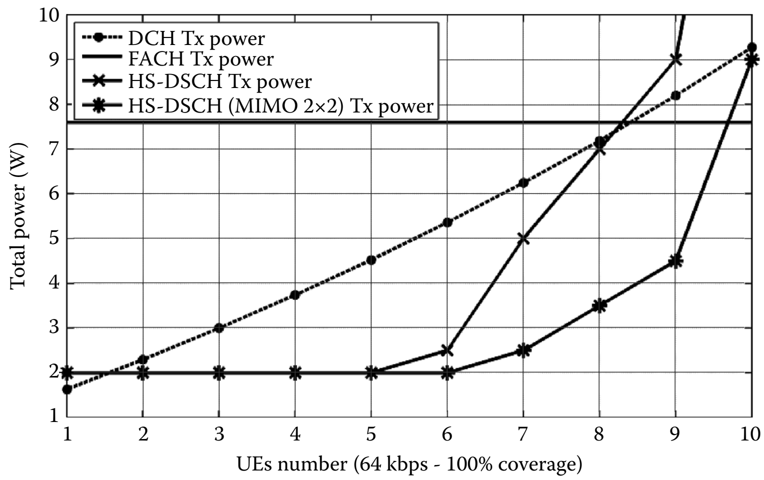

Figure 9.15 MBMS power allocation, 64 kbps, 100% coverage.

be extracted for the cases of 80% and 100% cell coverage from Figure 9.14 and Figure 9.15 respectively. However, from these figures we may additionally conclude that for higher cell coverage areas HS-DSCH is prevailing over the DCH even for a small multicast group and should be exclusively used instead of DCH in PTP mode.

In general, in cases where the number of users is small, PTP transmissions are preferred, while PTM transmissions are favored for a large multicast population. However, the enhanced mechanism does not only decide to use PTP or PTM transmissions, it makes a further distinction between DCH and HS-DSCH in PTP mode. This is an important notice since HS-DSCH appears to use less power than DCH in most cases, especially when MIMO is supported. MIMO schemes significantly reduce MBMS power consumption compared to other radio bearers and further maximize power efficiency. This power gain, in turn, leads to a major gain in capacity and enables the provision of multimedia services to a greater number of MBMS users in future mobile networks.

Comparison with the MBMS Counting Mechanism

The superiority of the mechanism can be better illustrated if we compare the performance of the proposed approach with the most prevailing 3GPP approach, the MBMS Counting Mechanism or TS 25.346. For a more realistic performance comparison, both mobility issues and a varying number of served users are taken into consideration and investigated.

At this point, it should be remembered that the MBMS Counting Mechanism considers a static switching point between PTP and PTM modes (or else between DCH and FACH), based on the number of MBMS served users. Such a reasonable

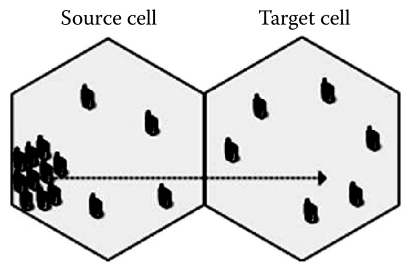

Figure 9.16 Simulation topology.

threshold for a macro cell environment would be eight multicast users. For less than eight users in PTP mode, multiple DCHs (and no HS-DSCH) would be transmitted, while for more than eight multicast users in PTM mode, a single FACH with such power as to provide full (100%) coverage would be deployed.

The simulation scenario considers the provision of a MBMS multicast session in a segment of a UMTS macrocellular environment. We examine the performance of both approaches for two neighboring cells (called source cell and target cell) as depicted in Figure 9.16. A 64-Kbps MBMS session with 2000-sec time duration is delivered in both cells.

Figure 9.17 and Figure 9.18 depict the downlink power of the available transport channels, as extracted from the power level computation phase, in source and target cells, respectively. Figure 9.19 and Figure 9.20 depict the transmission power of the transport channel that is actually deployed both for the proposed mechanism

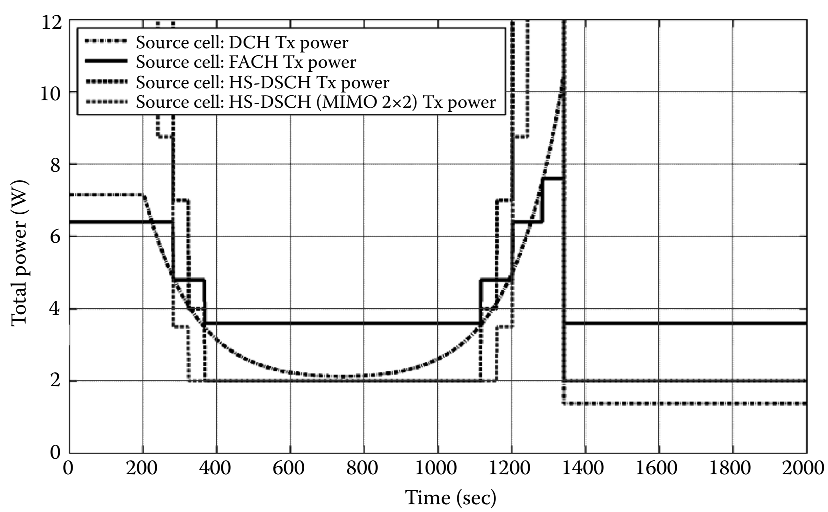

Figure 9.17 Source cell—output of power level computation phase.

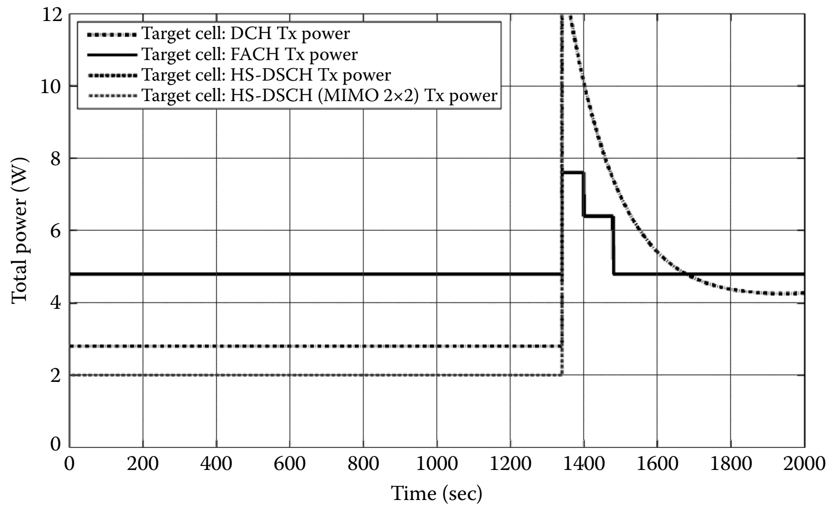

Figure 9.18 Target cell—output of power level computation phase.

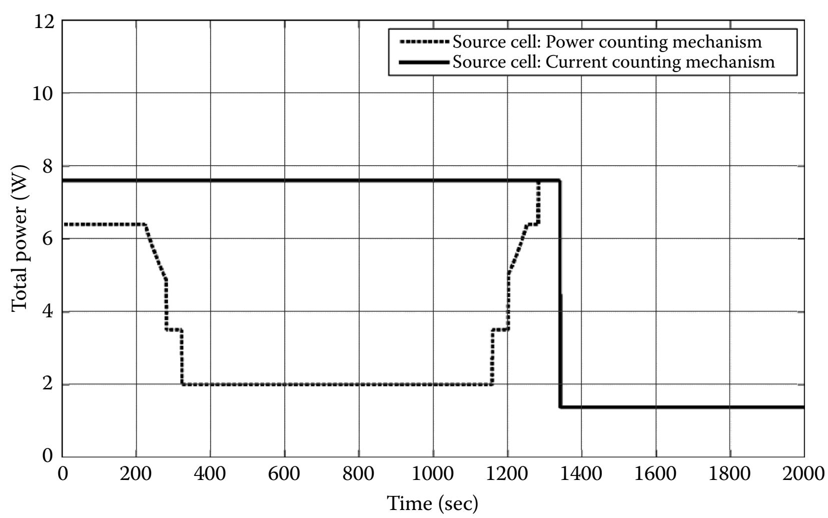

Figure 9.19 Source cell—proposed mechanism vs. the MBMS counting mechanism.

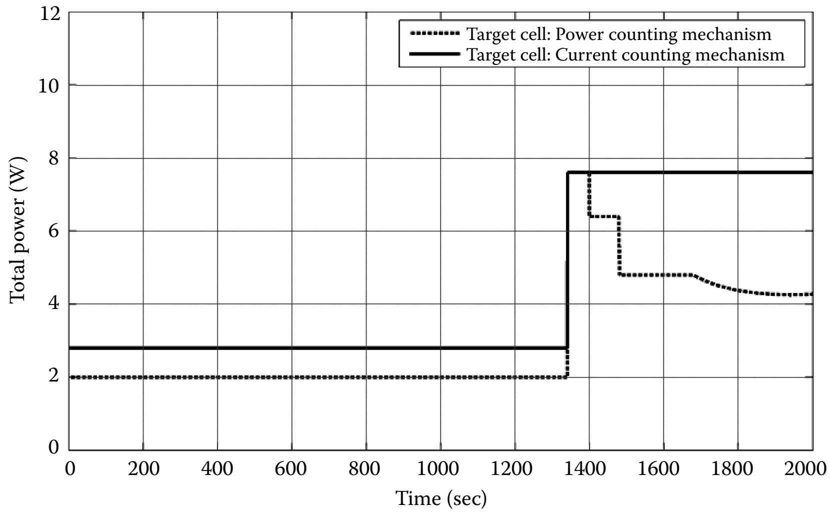

Figure 9.20 Target cell—proposed mechanism vs. the MBMS counting mechanism.

and the MBMS Counting Mechanism, in source and target cell, respectively. In the proposed approach, this transmission power level represents the power consumed by the channel selected in the transport channel selection phase. The selected channel for each cell can be easily extracted from Figure 9.17 and Figure 9.18 (the one with less power requirements for each time instance). Regarding the MBMS Counting Mechanism, this power level is either the total DCH power for less than eight users, or the fixed FACH power, equal to 7.6 watts, for more than eight users.

The source cell initially consists of 14 multicast users, while 6 users reside in the target cell. During the first 200 sec of the simulation time, all users in both cells are static. In the source cell, the proposed mechanism favors the transmission of MBMS content over FACH with a power set to 6.4 Watts in order to serve users with the worst path loss, located at a distance of 90% cell coverage. On the other hand, the MBMS Counting Mechanism uses a FACH with power set to 7.6 watts to provide full cell coverage, resulting in a power wasting of 1.2 watts in the source cell (Figure 9.19). The target cell is a PTP cell, since it serves less than eight users. However, we observe that HS-DSCH has better performance than DCH, with almost a 1 Watt power saving (Figure 9.20). Thus, the proposed scheme performs better than the MBMS Counting Mechanism in the target cell, too.

A group of ten users in the source cell, which is located near the cell edge (90% cell coverage), starts moving at time instance 201 sec towards the target cell, according to the trajectory depicted in Figure 9.16, while the rest of the users remain static. This group enters the target cell at time instance 1341 sec. During the time period 201–1341 sec, we can make the following observations for the source cell. The enhanced mechanism is able to track users' mobility and further improve power efficiency. When multicast users get close to the source cell's base station, PTP bearers (DCH and HS-DSCH) use less power than the PTM bearer (FACH) even for a large number of served users. Similarly, when users reside near the cell edge, FACH is more efficient. On the other hand, the MBMS Counting Mechanism fails to deal efficiently with users' mobility, in the absence of any adaptive procedure, and uses exclusively FACH since simultaneous users receiving the MBMS service exceed the threshold of eight users. As a result, we observe that a significant power budget, approaching 5.6 Watts, is wasted (Figure 9.19). Both mechanisms have identical performance (FACH deployment) only when moving users are on the cell border. Moreover, we observe that HS-DSCH with MIMO support requires less power compared to pure HS-DSCH for some time instances. The target cell still remains in PTP mode, with the same power gains arising from the proposed scheme during the first 200 sec of simulation (Figure 9.20).

Finally, at time instance 1341 sec, the group of ten moving users enters the service area of the target cell. At this point, according to the MBMS Counting Mechanism, the source cell switches to PTP mode (multiple DCHs) since it serves only four users. The enhanced mechanism also uses DCHs and, thus, both approaches have similar performance. At the same time, the target cell switches to PTM mode (a single FACH) and serves 16 users. However, as the moving group reaches the base station, the proposed scheme appropriately adapts its functionality and results to better utilization of power resources in contradiction to the static FACH channel assignment of the MBMS Counting Mechanism's specifications. Power gains approach almost 3 Watts.

Conclusively, from Figure 9.19 and Figure 9.20 it is obvious that the proposed approach is prevailing over the MBMS Counting Mechanism. The power-based criterion for switching between transport channels as well as the deployment of the HS-DSCH, especially when MIMO is supported, strongly optimizes resource allocation and enhances MBMS performance.

9.7 Open Issues

Regarding the operation of the proposed mechanism, several enhancements can be incorporated 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, except for the performance of the proposed mechanism, other parameters such as delays in UTRAN interfaces during MBMS transmissions could be measured.

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 can be achieved.

Finally, it may be considered whether the Multicast Broadcast Single Frequency Network (MBSFN) transmission mode, included in the evolved UTRAN technologies of the LTE, can 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 can be used in order to achieve very high receiver output SNR and significantly improve the overall spectral efficiency.

9.8 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 became familiar with techniques/solutions proposed to overcome such limitations.

Finally, this chapter proposed a novel mechanism for efficient transport channel selection during MBMS transmissions in UMTS networks. The proposed mechanism defines downlink power as the switching criterion between different radio bearers and is capable of conceiving any dynamic changes and, therefore, optimally adapting its functionality. Furthermore, the proposed mechanism conforms to next-generation mobile networks' requirements and takes advantages of MIMO antennas to further improve resource efficiency. Simulation results prove that the proposed scheme strongly outperforms the current Counting Mechanism of MBMS specifications, by maximizing power and capacity efficiency.

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