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Multicast Delivery of File Download Services in E3G Mobile Networks – an Overview

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Abstract: *In this article we discuss multicast file delivery in Evolved 3G (E3G) mobile networks equipped with HSDPA (High-Speed Downlink Packet Access) and MBMS (Multimedia Broadcast Multicast Services). HSDPA supports high speed point-to-point (p-t-p) transmissions (up to several Mb/s), whereas with MBMS the same content is transmitted with a point-to-multipoint (p-t-m) connection to multiple users in a unidirectional fashion.*

Multicast delivery can be implemented through p-t-p transmissions with HSDPA or a single p-t-m transmission with MBMS. Reliable delivery of files is a challenging task, as an error-free reception of the files is required. In order to increase the robustness of the MBMS transmission, an additional Forward Error Correction (FEC) mechanism at the application layer based on Raptor coding has been introduced. Moreover, users not able to receive the file after the initial MBMS transmission can complete the download in a post-delivery repair phase, where it is possible to perform both p-t-p and p-t-m connections with HSDPA and MBMS.

The article focuses on the efficient transmission of file download services in future E3G mobile networks. The approach of minimizing the transmission energy to achieve a target file acquisition probability (percentage of users that successfully receive the file), defined as the product of the transmit power times the transmission time, has been adopted. We investigate the optimum MBMS transmission configuration, including the initial file transmission and the trade-off between the initial file transmission phase and the post-delivery repair phase. Moreover, we also investigate the optimum resource allocation for the multicast delivery of a file with p-t-p transmissions with HSDPA, in order to identify the situations where MBMS should be employed.

I. INTRODUCTION

After a slow start, third-generation (3G) mobile networks are now being deployed on a broad scale all over the world, and mobile operators have started to provide multimedia services, as video clips from sports events or live TV programs. However, the capabilities of the first release of the 3G standard are still considerably limited, from both a cost and a technical viewpoint. In order to offer a viable business model, and to not overload the network capacity to the point of preventing subscribers from placing voice calls (which is the main function and value of the cellular networks), only short video clips are offered at low-resolution (e.g., 2 minutes at 128 kb/s) [1].

Another important bottleneck is the fact that 3G cellular systems have been optimized for *unicast* services delivered through dedicated point-to-point (p-t-p) connections for each individual user, even if the same content should be delivered to many users. This limits the maximum number of active users the system can handle, since both radio and transport network resources are physically limited. *Multicast* and *broadcast*¹ are more appropriate transport technologies to cope with high numbers of users consuming simultaneously the same service when compared to unicast, as there is no limit to how many users can receive the content. Multicast/broadcast transmissions employ a common point-to-multipoint (p-t-m) radio bearer for all users, which allows delivering the same content to an unlimited number of users within the coverage area [2].

¹ Multicasting and broadcasting describe different, although closely related, scenarios. Whereas broadcast transmissions are intended for all users in the service area, multicast transmissions are addressed to a specific group of users (usually called the multicast group).

To meet the increasing demands for high-speed data access and multicast services, the 3G standard has been enhanced with the introduction of [3]:

- HSDPA (High-Speed Downlink Packet Access).
- Enhanced uplink.
- MBMS (Multimedia Broadcast Multicast Services).

These improvements will lead to a better utilization of the existing radio resources provided by 3G, enabling the provision of new multimedia services. HSDPA supports higher peak data rates (up to several Mb/s), considerably increasing the network capacity, and with enhanced uplink the packet data capabilities in the uplink are improved. Both are meant for dedicated p-t-p connections, and for a more detailed description of them we refer to [4]. MBMS brings support for multicast services.

In MBMS, multimedia content is delivered either as a *streaming service* or as a *file download service* to the end user, in a time-constrained or unconstrained manner [5]. For streaming services a continuous data flow of audio, video and subtitling is transmitted to the terminals using RTP (Real-time Transport Protocol), which is directly consumed by the users. Occasional data errors may be tolerated if the quality of the audio and video is enough for providing a satisfactory user experience. The most representative service is mobile TV. For file download services, a finite amount of data is delivered and stored into the terminals as a file, using FLUTE (File Delivery over Unidirectional Transport Protocol). Applications that fall within this category are: video clips, digital newspapers, software download, etc. On the contrary to streaming services, file download services require of an *error-free transmission of the files* (i.e., even a single bit error corrupts the whole file and makes it useless for the receiver).

In order to increase the robustness of the MBMS transmission, an additional FEC mechanism at the application layer using Raptor coding [6] has been adopted for both streaming and file download services [7]. FEC mechanisms rely on the transmission of *additional parity data* that allows recovering the original information when transmission errors occur without a need for feedback, as it does not matter which data packets are received but that enough packets are received correctly. For file download services, as it cannot be guaranteed that each and every user will be able to recover the file after the MBMS transmission, as some users might have experienced too bad reception conditions, a post-delivery repair phase can be performed to complete the file download. The repair phase employs by default p-t-p transmissions with HSDPA, although it is also possible to employ p-t-m transmissions with MBMS in case too many users fail to receive the file [8]. Nevertheless, the initial MBMS transmission must ensure that the file is transmitted error-free to nearly all users in the radio environment, in order to avoid congestion issues in the post-delivery repair phase (the well-known *feedback implosion problem* in multicast file delivery).

In this article we specifically focus on the efficient multicast transmission of file download services in Evolved 3G (E3G) mobile networks equipped with HSDPA and MBMS. Multicast delivery can be implemented through p-t-p transmissions with HSDPA or a single p-t-m transmission with MBMS [9]. The approach of minimizing the transmission energy to achieve a certain file probability acquisition target (percentage of users that successfully receive the file) has been employed to determine the optimum configurations. The transmission energy is defined as the product of the transmit power and the transmission time. For MBMS the energy is constant and independent of the number of users, whereas for HSDPA it is directly proportional to the number of users. Thus, the initial goal has been to determine the minimum average number of users that should be within a cell such that is it more efficient to serve them with MBMS. For this reason we have studied the cases when MBMS and HSDPA are used separately, identifying their optimum transmission configurations. Furthermore, we have also considered the case when both are used jointly to study the trade-off between the initial MBMS file transmission and the file repair phase with HSDPA to evaluate the potential gain of a hybrid unicast-multicast delivery. In our investigations we have considered a background service without any time constraint to deliver the file, but we have also studied the effect of reducing the time to deliver the file.

The rest of the paper is organized as follows. First we provide an overview of MBMS in Section 2. Then in Section 3 we explain how file download services are transmitted in MBMS, describing the main parameters that influence the overall system performance. In Section 4 we describe the system models adopted in our radio network simulations. In Section 5 we provide some illustrative results of multicast file delivery with MBMS and HSDPA when used separately, and also when they are used jointly (hybrid approach). Finally, we give some concluding remarks.

II. MULTIMEDIA BROADCAST MULTICAST SERVICES (MBMS)

A. Main Features

With MBMS the same content is transmitted with a p-t-m connection to multiple users in a unidirectional fashion. Usually in several cells, in order to cover the area in which the service is provided. MBMS uses the Forward Access Channel (FACH), QPSK modulation and turbo codes at the physical layer, and a constant transmission power and bearer data rate during the complete transmission of the service. Control information about the services available, neighbouring cells that transmit the same contents, etc. are transmitted in a specific FACH.

As MBMS services are intended for multiple users, it is not possible to adapt the transmission parameters dynamically according to the user reception conditions as in a p-t-p connection like in HSDPA. Moreover, during the MBMS transmission the uplink is not utilized, and there is no communication between the terminals and the server. The Radio Link Control (RLC) layer operates in unacknowledged mode, and thus terminals identify and discard erroneously received transport blocks each Transmission Time Interval (TTI) and do not request any retransmission. In practice, as all transport blocks sent during one TTI are encoded at once by the turbo encoder in the physical layer, which is characterized by a very rapid transition from near perfect reception and no reception at all, they are with high probability either all correct or all corrupted.

The configuration of the MBMS transmission parameters should be done statistically, in order to serve the worst-case user contemplated. In general this case is at the cell edge, as 3G systems are limited by interferences (both from the own cell and from neighbouring cells). For this reason it is usually stated that MBMS services are power-limited, since very high coverage levels are required. However these very same users can benefit from the fact that they receive signals from different cells to combine the transmissions obtaining a macro diversity gain. In this way a significant reduction in transmit power can be achieved compared to the single cell reception case, in the order of 4-6 dB [3]. However these techniques increase the complexity and cost of the terminals. Two combining strategies are supported in MBMS: selection combining and soft combining. With selection combining, signals received from different cells (sectors) are decoded individually, such that terminals select each TTI the correct transport blocks (if any). In this way, the chances of receiving correctly the information are increased at the expense of a more complex decoding process in the turbo code. A simpler implementation consists on decoding only the strongest signal. With soft combining, the soft bits received from the different radio links prior to decoding are combined. Soft combining results in higher improvements, in the order of 2-3 dB, as it provides not only a macro diversity gain but also a power gain, due to the received power from several cells is added coherently. However, this technique requires more memory at the terminals to buffer the soft bits from each radio link (similar to a HSDPA class 6 terminal up to 3.6 Mb/s), and that the transmissions between cells are coarsely synchronized within a range of 80 ms, which is not foreseen in the initial MBMS deployment stage.

MBMS also supports long TTIs (up to 80 ms), in order to provide time diversity against fast fading at the expense of increasing the system latency. However the unidirectional nature of MBMS hides it from the user perception.

Finally, in MBMS it has also been adopted an additional FEC mechanism at the application layer based on Raptor codes in order to benefit from the spatial diversity introduced by users' mobility. With Raptor coding, a number of source packets are first coded into a larger number of coding packets, which are then transmitted to the terminals, being possible to recover the original content even if some packets are lost. In this way it is possible to cope with the radio transmission errors experienced by mobile users due to the fact of employing a constant transmit power and bearer data rate during the transmission, and to handle packet losses in the transport network as well. Moreover it also allows the terminals to autonomously perform Radio Resource Management (RRM) related procedures without causing degradation in the service quality (e.g., tune to a different frequency for measurements for a short period).

B. Architecture

MBMS provides a seamless integration of multicast/broadcast transport technologies into the existing 3G networks and service architectures, reusing much of the existing 3G functionalities. It introduces only small changes into the existing radio and core network protocols, as well as into most of the functional entities of the architecture, and adds a new entity called Broadcast/Multicast-Service Center (BM-SC) [9]. This new element is located between the 3G core network and the content providers, and it serves as an entry point for the content delivered with MBMS. The BM-SC acts as an MBMS server, and it manages certain control tasks, as setting up and releasing the MBMS bearers, service announcements, Raptor coding, billing, security, etc.

In MBMS there are defined two basic operation modes: broadcast mode and multicast mode. In the broadcast mode, the information is transmitted through p-t-m connections in all the cells within the MBMS service area. The transmission should be configured to serve to the worst-case user contemplated, as the network does not have any kind of information about the active users. Moreover, terminals do not need to report that they have received the service correctly. The typical service example of the broadcast mode is mobile TV. On the other side, in the multicast mode the information is transmitted to a group of users, which should have requested the service before. In this case the network tracks users' positions, both at the radio network level and at the core network level, being able to adjust the transmission configuration according to the actual position of the users. In this mode it is possible for example to employ p-t-p connections with HSDPA in cells with few users. Besides these two basic modes, there is an enhanced broadcast mode, in which the network monitors only the number of active users per cell to be able to determine whether MBMS is actually needed or not.

C. Raptor Codes

Raptor codes² are a computationally efficient implementation of *fountain codes* that achieve close to ideal performance and allows for a software implementation without the need of dedicated hardware [6]. This, in turn, allows to efficiently support a large range of file sizes.

Fountain codes are a special class of FEC codes that can generate an infinite amount of parity data on the fly (i.e., they are rateless). They were originally designed to allow very efficient asynchronous file downloading over broadcast channels without the need of a feedback channel [10]. However they have been found to be very suitable for data delivery in wireless broadcast systems when working at the application layer; outperforming other FEC solutions in terms of reliability, spectrum efficiency and flexibility [11]. The main benefits are:

- They can recover packet losses of all underlying layers and protocols, providing end-to-end error recovery (e.g., they can even recover IP packets lost in the core network or the Internet).

² Raptor codes are patented by Digital Fountain Inc. and subject to Intellectual Property Rights (IPR).

- They provide the longest time interleaving possible, being able to recover the source data file even if all lost packets are consecutive.
- No standardization or modification is required below the application layer.

In practice, the standardized version of Raptor codes adopted in MBMS can generate up to 65.536 encoding symbols on-the-fly from the source file [5]. The adopted version is a systematic code, meaning that the original source data packets are transmitted first followed by additional parity packets. In order to not overload the processing capacity of mobile devices, files are first partitioned into source blocks (maximum size for first terminals 4 MB). The Raptor encoder is then applied independently to each source block. At the terminals, obviously if all source packets are correctly received, no parity data is needed at all. Otherwise, the Raptor decoder is able to recover the source block after receiving a certain total amount of packets (both source and parity packets) which is slightly greater than source block size (i.e., 1-2 % reception overhead, in average).

IV. FILE DELIVERY IN MBMS

Generally speaking, a file download service in MBMS consists in three phases:

- 1) **Service advertisement phase**; in which the service is announced and set-up by the network and the users discover the service.
- 2) **MBMS initial file transmission phase**; in which both source data file and a fixed pre-configured amount of parity data are initially transmitted through MBMS.
- 3) **Post-delivery repair phase**; in which users not able to decode the file after the initial MBMS transmission are served by default via HSDPA to complete the reception of the file, although it is also possible to employ MBMS in case too many users fail to receive the file.

In this section we highlight the most important concepts in the last two phases that affect the overall system performance. Fig. 1 shows a temporal diagram of both phases, as well as the messages exchanged in a p-t-p based repair procedure.

A. MBMS Initial File Transmission Phase

In this phase the MBMS server must ensure that the file is successfully received by most of the users to avoid congestion problems in the error repair phase. The robustness of the MBMS transmission is given by the coverage level and the amount of parity data transmitted. The coverage level depends on many factors: scenario, macro diversity technique implemented in the terminals, interference conditions, etc.

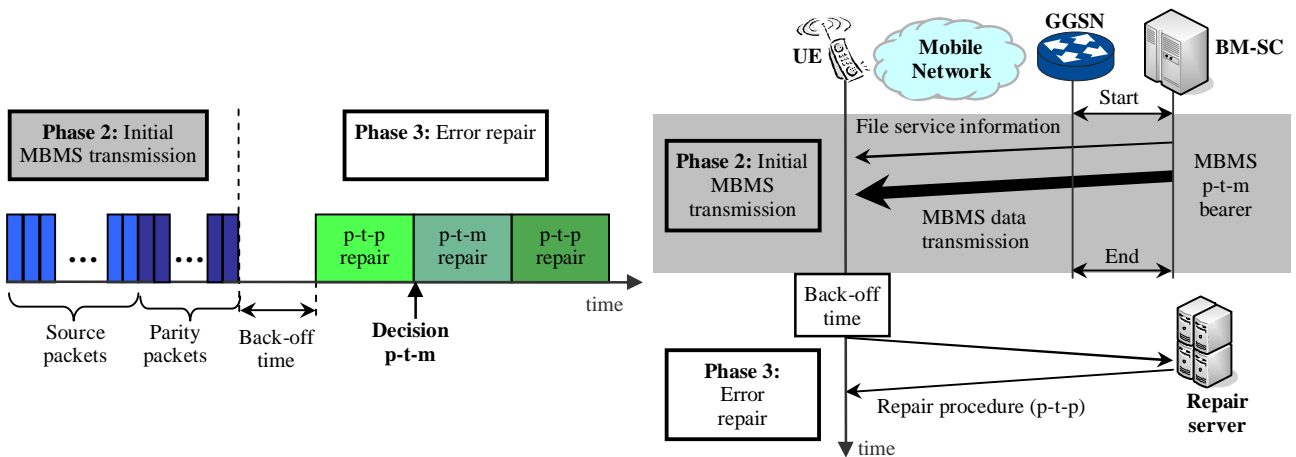


Fig. 1: MBMS file download service. Initial MBMS transmission phase and error repair phase.

The only parameters that the network operator can control are the transmit power, the bearer data rate, and the amount of parity data transmitted (or alternatively the transmission time, which can be limited by a maximum time to complete the transmission of the service).

The transmit power and the bearer data rate yield the area coverage. The transmission time should be adjusted such that the desired file acquisition probability for this phase is reached (percentage of users that receive the file). Obviously, the higher the transmit power, the larger the coverage level (keeping the bearer data rate constant), and thus the amount of required parity data will be smaller, and the service transmission time will be reduced. However, maximizing the transmit power does not necessarily need to be the optimum configuration, as 3G systems are interference-limited as mentioned before, and the interference level is directly proportional to the transmit powers. On the other side, when increasing the bearer data rate the file should be in theory received faster by the users. However, it should be taken into account that an increase in the bearer data rate results in a reduction of the area coverage (keeping the transmit power constant), what implies an increase in the transmission time as we have already explained. The optimum configuration will be the one that minimizes the *transmission energy*, defined as the product of the transmit power and the transmission time:

$$E_{MBMS} = P_{MBMS} \cdot T_{Tx} \quad (1)$$

By minimizing the energy, the number of services that can be provided with the same amount of power and during the same time period is maximized. Therefore, this performance measure is inversely proportional to the system capacity. Finally, it should be pointed out that the optimum transmission configuration will depend on the maximum service transmission time.

B. Post-Delivery Repair Phase

The purpose of this phase is to repair erroneous received files in the previous phase. To avoid congestion issues, error reporting messages from terminals are usually distributed over time within a back-off window. Terminals compute a random access time to the repair procedure within the window. The time period should be large enough to prevent congestion, but should not unnecessarily increase the duration of the repair phase. Moreover, it is also possible to distribute error reporting messages across multiple repair servers.

Terminals can notify the minimum set of data packets required to repair the file or simply the total number of correctly received packets. As mentioned before, terminals start the repair phase using dedicated p-t-p connections with HSDPA. In this case, the repair data can consist of the specific packets requested by the terminal or simply additional parity packets generated. One important benefit of Raptor coding is that it can generate additional parity packets on-demand without knowing the total number of packets needed. If the number of active users in this phase is high enough, it is possible to employ a p-t-m connection with MBMS. In this case the repair data consist of additional parity packets, as they can be used by all users. Once the p-t-m repair session is completed, a new p-t-p repair session can be initiated if needed.

As during the initial file transmission there is no communication between the terminals and the server, once the MBMS transmission is finished the server does not have any information about the number of users that have not received the file and the amount of repair data needed by each of them. This information can be estimated in the beginning of the p-t-p repair session. The decision of performing a p-t-m repair transmission should be taken as soon as possible once a representative number of error reporting messages have been collected. Usually it is recommended to take this decision once the 10% of the back-off window has elapsed [8]. The amount of repair data transmitted through the p-t-m connection can be for example the maximum amount of repair data requested by the users at that time. On the other hand, the repair server should immediately proceed to initiate a p-t-m repair session as soon as a congestion issue is detected. According to [8], the link

most likely to become the bottleneck is the one between the repair server and the cellular network (more precisely the GGSN).

Besides the duration of the back-off window, the main parameter that the network operator should configure in the p-t-p repair session is the HSDPA transmit power devoted to repair the file. Higher power levels will imply that the users receive the file faster, although it may not be the most efficient resource allocation as we have explained before. In this case it is also possible to employ the approach of minimizing the transmission energy required to achieve a certain total file acquisition probability between both phases for a given average number of users in the cell. Note that the performance of the p-t-p repair phase with HSDPA depends on the number of users that fail to receive the file after the initial MBMS transmission and their positions.

IV. SYSTEM MODELS

A. Deployment Scenario

Radio network simulations have been performed in a typical urban scenario. The deployment scenario consists of 19 cells, with the cell under study in the centre (i.e., two interfering rings are considered). No cell sectorization is considered and omnidirectional antennas have been assumed. The cell radius is 866 m and the inter-site distance is 1.5 km.

All users are assumed to be located outdoors moving according the urban mobility model described at the end of this section. Users are initially uniformly distributed over the cell under study, and they do not leave the service area but bounce at the cell edges.

B. Link Budget

Link budget values corresponding to an urban scenario at a frequency of 2000 MHz have been considered. We assume lognormal shadowing with a standard deviation of 8 dB and a correlation distance of 50 m (correlation factor between cells is 0.5). Fast fading (Rayleigh distributed) is also considered. The distance dependent path loss, L_D , has been modeled with an Okumura-Hata propagation model. Equation 2 gives L_D in dB as a function of the distance d in meters, being β and α the parameters of the distance independent and dependent terms respectively. The values employed in the simulations for β and α are 15.3 and 3.76.

$$L_D = \beta + 10 \cdot \alpha \cdot \log_{10}[d] \quad (2)$$

The thermal noise power at the terminals is -103 dBm, which are modelled with an omnidirectional antenna of -0 dBi gain.

The maximum total transmission power per cell is 20 W, and it has been considered that control channels use 20% out of the maximum 20 W (i.e., 4 W). All simulated cells transmit with the same power.

C. Interference Model

In the simulations, both intra and inter-cell interferences are considered. A constant orthogonality factor is used to characterize the interference between channels of the same cell in the downlink. It indicates how much users suffer from signals that were orthogonal to the desired signal at the base station. However neither speech users nor other services have been considered in this paper, and thus the interference condition correspond to a best-case situation. The average Signal-to-Interference plus Noise Ratio (SINR) during the TTI for user i and base station j is computed as:

$$\overline{SINR}_{i,j} = \frac{g_{i,j} \cdot P_{Useful,j}}{(1-\rho) \cdot g_{i,j} \cdot (P_{Total,j} - P_{Useful,j}) + \sum_{k \neq j} g_{i,k} \cdot P_{Total,k} + P_N} \quad (3)$$

Where $g_{i,j}$ is the path gain between user i and base station j including shadowing, $P_{Useful,j}$ is the transmitted power of the desired channel, ρ is the orthogonality factor (the value employed in the simulations is 0.6), $P_{Total,j}$ is the total transmitted power of base station j , and P_N is the thermal noise. It should be pointed out that the spreading factor of the channel also affects the average SINR, but in our case it is included in the radio link performance model described next.

In the simulations, we upgrade the propagation losses including shadowing every 80 ms (MBMS TTI period), and the fast fading every 2 ms (HSDPA TTI period). For MBMS, in order to average the instantaneous SINR (average SINR plus fast fading) to obtain an effective SINR value in the TTI we have employed the ECM method (Equivalent SNR Method based on Convex Metrix) [12]. The technique is based on Shannon's channel capacity formula, and it consists on the following three steps:

1. Compute the channel capacity C_i for each 2 ms ($i = 1, 2, \dots, 40$).
2. Compute the average capacity, such that $\bar{C} = (Q/n) \cdot \sum_{i=1}^{n=40} C_i$.
3. Compute $SINR_{eff}$, such that $C(SINR_{eff}) = \bar{C}$.

The factor Q is a correction factor that depends mainly on the mobile speed and the interleaver. For pedestrian speeds and the 3G physical layer interleavers, it has been found that $Q = 1$ is a good value [12].

D. Radio Link Performance Model

For the sake of simplicity, the radio link performance model is based on a shifted version of the Shannon limit, as proposed in [14]. The maximum Modulation and Coding Rate (MCR), in b/s/Hz, that can be achieved for a given SINR can be computed as:

$$MCR = \log_2[1 + \gamma \cdot SINR] \quad (4)$$

where $0 < \gamma \leq 1$ is a degradation term, which shifts the link performance away from the Shannon limit for all MCR. The effective data rate is obtained from multiplying the MCR with the amount of spectrum utilized for the transmission (5 MHz in our case). In our simulations we have chosen a value of $\gamma = 0.4$ (4 dB degradation from Shannon limit and assumption of BER 10^{-4}), what resembles quite accurately the performance of HSDPA terminals of category 6 (up to 2 Mb/s).

E. MBMS and HSDPA Performance Model

In our MBMS simulations, we compute the number of correctly received TTI by each user (TTI duration 80 ms). We first compute the average SINR considering path loss and shadowing in the TTI, and the fast fading experienced by each 2 ms slot in the TTI, assuming that the channel is stationary in that period (i.e., the channel coherence time is larger than 2 ms). Then we compute the effective SINR in the TTI using the ECM method explained above. Finally, we compare the effective SINR to the threshold given by (4) for the bearer data rate employed to decide whether it is correctly received or not. For the sake of simplicity we have assumed that one Raptor-coded packet is transmitted per TTI.

In our HSDPA simulations, we compute the instantaneous SINR for each user every 2 ms considering path loss, shadowing and fast fading, and perform a MaxCIR scheduling algorithm. This strategy consists on serving the user who presents the best reception conditions in terms of SINR, or equivalently, the one with the highest achievable data rate. We have assumed that the effective data rate given by (4) is always correctly received (i.e., ideal link adaptation), and thus there are no retransmissions of lost packets. Moreover, we have considered a minimum data rate

equal to 68.5 kb/s (minimum velocity that can be achieved in HSDPA), meaning that users can be in outage, and a maximum data rate equal to 2 Mb/s.

F. Raptor Code Model

For the sake of simplicity, to account for a practical implementation of a Raptor code, a constant 5% reception overhead has been assumed, as this will generally allow recovery of the file in most of the cases [12].

G. Mobility Model

The mobility model captures the users' movements with three random variables: street distance, relative change in direction when entering a new street, and speed. Basically, the model assigns to the users a new speed, street direction, and street distance once they finish moving across their current street. In our simulations, we have employed a Rayleigh distribution with a mean equal to 3 km/h to compute the speed of the users in the streets. We have adopted the distribution functions to compute the street distance and the direction changes at crossroads proposed in [14], using the parameters shown in Table I. The parameters are: direction change probabilities p_0 , p_{90} , p_{-90} and p_{180} , standard deviation of direction distributions σ_φ (equal for all four distributions), average length of major roads \bar{d} , and variance of the length of minor city roads σ_d^2 .

Table I: Mobility model parameters.

σ_φ	p_0	p_{90}	p_{-90}	p_{180}	\bar{d}	σ_d^2
$\pi/32$	0.595	0.25	0.15	0.005	250 m	$\bar{d} \cdot \sqrt{(2/\pi)}$

V. RESULTS AND DISCUSSIONS

In this section we present results obtained for a download service of a 512 KB file. To obtain a good accuracy with a 1% resolution, we have considered 10.000 users in our simulations. In the simulations with only MBMS, a single iteration with 10.000 users has been performed, whereas when simulating HSDPA (either for unicast delivery or hybrid unicast-multicast delivery), multiple iterations have been performed such that the total number of users simulated equals 10.000. In this way, by averaging over all iterations we can obtain results in terms of file acquisition probability, similar to the ones obtained with MBMS. We have analysed the cases when no macro diversity is employed (reference case), and the case with selective combining with 2 radio links (as the gain obtained by using 3 links is not significant). Feasible MBMS bearer data rates employed in the simulations are: 64, 96, 128, 192, and 256 kbps, and useful transmit power values from 0.5 up to 16 W (for both MBMS and HSDPA).

A. File Delivery Results with MBMS

Fig. 2 shows the energy required to achieve a 95% file acquisition probability with MBMS as a function of the transmit power for different bearer data rates for the reference case without any macro diversity combining technique. We can see how the energy is proportional to the transmit power, and that the minimum energy point regardless the bearer data rate is the minimum transmit power considered, 0.5 W, in agreement with the results presented in [12]. In this case the optimum configuration is P_{MBMS} 0.5 W and R_b 96 kbps, which provides an energy value of 90.6 J. The required transmission time is 181.3 s, and the effective bearer data rate is 23.1 kbps. The effective service data rate is defined as the ratio between the file size and the transmission time required to achieve the target acquisition probability:

$$R_{b,eff} = \frac{F_S}{T_{Tx}} \quad (5)$$

It has nothing to do with the energy but the transmission time. The higher is the effective data rate, the faster is delivered the service. Obviously, smaller powers imply larger transmission times as discussed previously in Section 3, and as we can see if Fig. 3. Therefore, there is a clear trade-off between minimizing the resource consumption and the transmission time of the service. Fig. 3 shows the transmission time required to achieve a 95% acquisition probability as a function of the transmit power. The fastest delivery is achieved for the largest transmit power (16 W) and the highest bearer data rate (256 kbps), 41 s in this case, yielding an effective bearer data rate equal to 101.8 kbps.

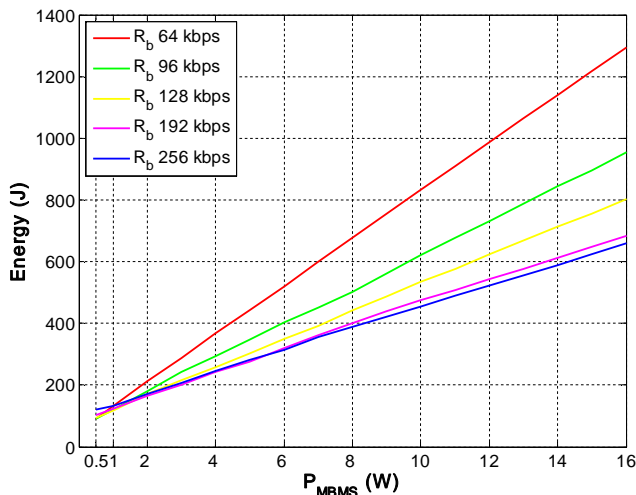


Fig. 2: MBMS energy (J) vs. MBMS transmit power (W). No selective combining.

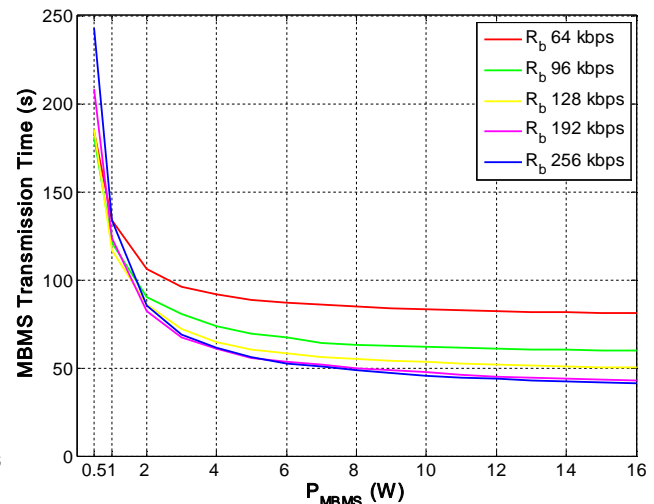


Fig. 3: MBMS transmission time (s) vs. MBMS transmit power (W). No selective combining.

In Fig. 3 we can note that for low transmit power values the energy provided by the different bearer data rates is rather small, and thus the preferred choice should be the one with the minimum bearer data rate. If two rates provide the same energy for a given transmit power, that means that they require the same transmission time to achieve the desired acquisition probability. However, the amount of transmitted data is not the same, and the bearer with higher data rate will consume more resources (spreading codes).

For large powers, there is a larger difference between the different bearer data rates, and thus it becomes more important to choose the optimum bearer. In Fig. 3 we can see that for large power values, the optimum bearer is the maximum considered, 256 kbps. The reason is that the coverage level is high enough so most users can benefit of transmitting more data per TTI. When the transmit power (and coverage level) decreases, the optimum bearer data rate decreases. We can clearly see this effect in Fig. 4. Fig. 4 shows the optimum transmit power as a function of the transmission time, highlighting the ranges where each bearer data rate is optimum. Notice that in this case the minimum bearer considered (64 kbps) is never the optimum.

Fig. 5 depicts the minimum energy as a function of the transmission time for the reference case without any macro diversity technique and with selective combining. We can note a significant performance improvement with selective combining, in both reduced transmission time and energy. With selective combining the minimum transmission energy is reduced down to a third (29.6 J, transmission time 59.2 s, effective data rate 88.6 kbps), and the minimum transmission time is reduced from 41 s down to 18 s (maximum effective data rate 238 kbps).

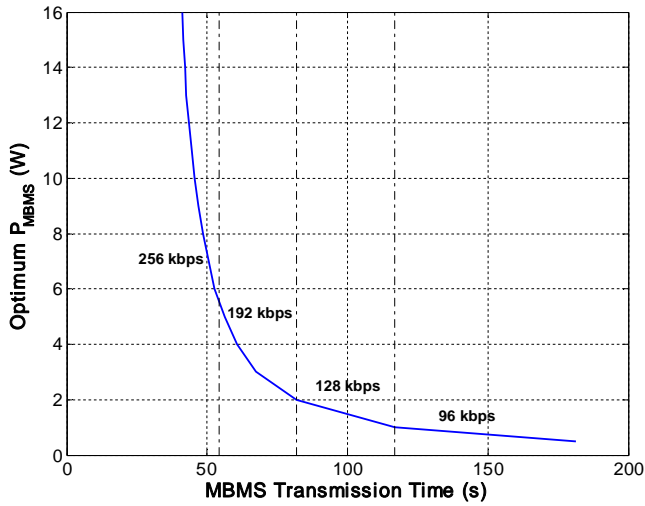


Fig. 4: Optimum MBMS transmit power (W) vs. Transmission time (s). No selective combining.

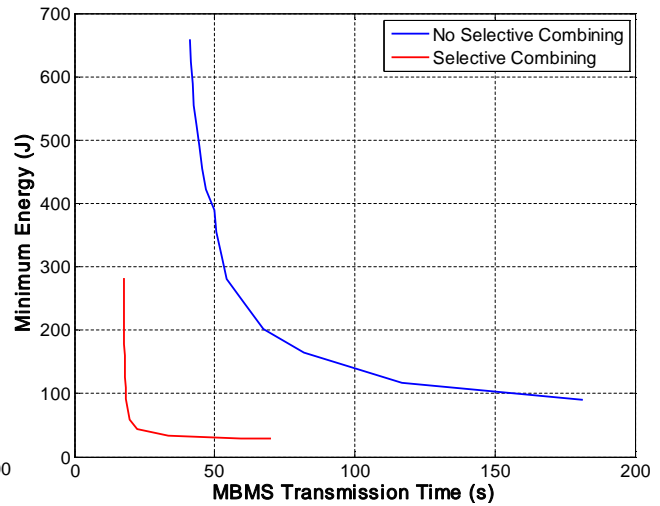


Fig. 5: Minimum MBMS energy (J) vs. transmission time (s).

B. File Delivery Results with HSDPA

In our HSDPA simulations we compute the time instant when each user receives the file and the total HSDPA transmission time employed at that time. With HSDPA when all remaining users are in outage (i.e., there are no users in covered areas), there is no transmission. Note that this differs from MBMS, where the transmission remains constant even if all users have received the file successfully, or if all remaining users are in outage. With HSDPA no resources are consumed unless there is at least one user in a covered area.

Fig. 6 shows the energy required to achieve a 95% file acquisition probability with HSDPA as a function of the number of users for different transmit powers. Fig. 7 shows the service time as a function of the number of users for the same transmit power values shown in Fig. 6. As expected the energy grows with an increasing number of users, but we can note that, as in the case of MBMS, the optimum transmission configuration is the minimum transmit power, which is the configuration that provides the largest service time. Therefore, there is again a trade-off between resource consumption and transmission time.

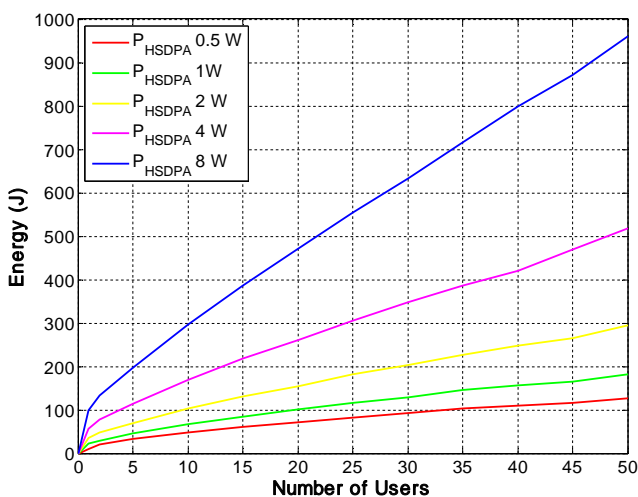


Fig. 6: HSDPA energy (J) vs. Number of users.

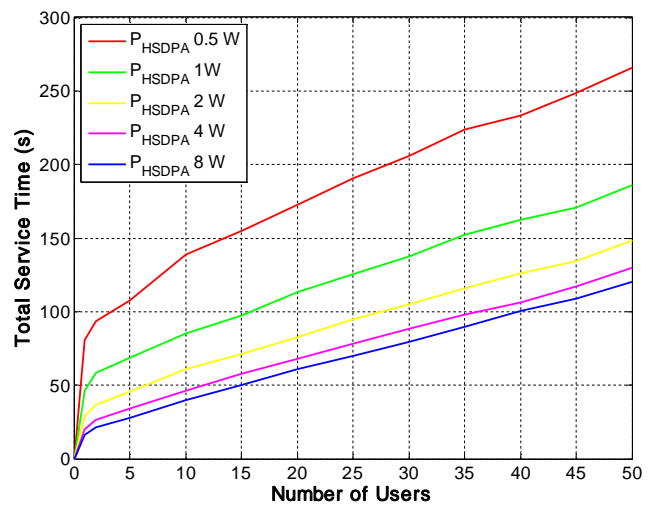


Fig. 7: HSDPA service time (s) vs. Number of users.

Fig. 7 compares the minimum energy that can be achieved with HSDPA as a function of the number of users per cell with the minimum energy provided with MBMS (with and without selective combining). We can see that, if there is no time constraint to deliver the service, it is more efficient to employ HSDPA if there are up to 29 users in the cell than MBMS without selective combining. However the threshold goes down to only 4 users in case selective combining is implemented.

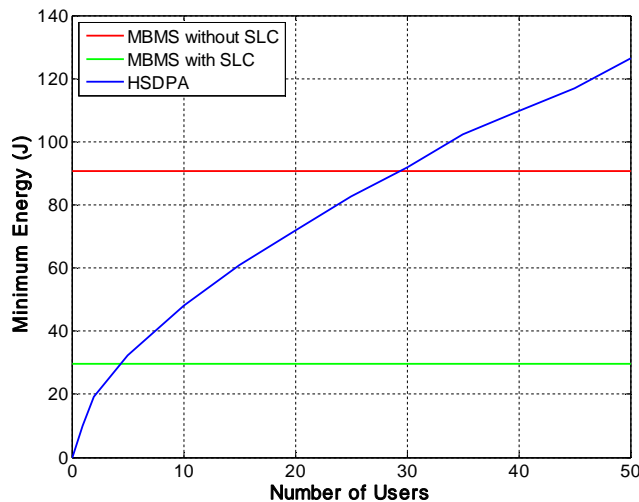


Fig. 8: Comparison minimum energy MBMS and HSDPA (J) vs. Number of users per cell.

In case there is a maximum time to deliver the service, the optimum HSDPA transmit power will be the minimum value that transmits the file in due time. For example, if we consider a constraint equal to 181 s (time needed to achieve with MBMS a 95% acquisition probability with 0.5 W without selective combining), we would need to increase the HSDPA power from 0.5 W to 1 W for more than 23 users. And for a constraint of 70 s (time needed to achieve a 95% acquisition probability with MBMS for 0.5 W with selective combining), it would not be even possible to employ 0.5 W with HSDPA for one single user in the cell.

C. File Delivery Results with MBMS and HSDPA

In our hybrid MBMS and HSDPA simulations, we first perform the MBMS transmission to achieve a certain file acquisition probability, and then we serve the remaining users with HSDPA. We have only considered the reference case without any macro diversity combining technique for MBMS. We have assumed that there are no congestion problems in the network during the error repair phase with HSDPA, and hence the radio link becomes the bottleneck. Moreover the back-off window is set to zero, in order to make a fair comparison with the results obtained when using only MBMS.

To investigate the potential efficiency improvement of the hybrid unicast-multicast delivery, we compute the energy required to achieve a target file acquisition probability as a function of the number of users per cell and the acquisition probability after the initial MBMS transmission. We do not consider any time constraint to deliver the service, and thus the transmit power value employed for both MBMS and HSDPA is 0.5 W.

Fig. 9 shows the CDF of the amount of repair data needed to complete the reception of the file after the MBMS transmission for different acquisition probabilities with MBMS. We can note that there will be always some users that need a considerable amount of repair data. We can see that the worst 1% of users needs at least 334, 421, and 490 KB of repair data for acquisition probabilities after the MBMS transmission of 86%, 91%, and 95% respectively. These users are ones located in bad reception locations that move at low speeds, and they cannot be served regardless how much parity data is transmitted in MBMS if very low transmit powers are employed.

As a consequence, it becomes increasingly more costly to serve the final percentage of users using only MBMS. We can see this effect in Fig. 10, which shows the minimum MBMS energy as a function of the target acquisition probability (in the figure the ranges where each data rate is optimum is also pictured). The final percentage of users could be served more efficiently with HSDPA, if the cost of doing this is acceptable. Therefore, larger gains can be expected for very high file acquisition probabilities.

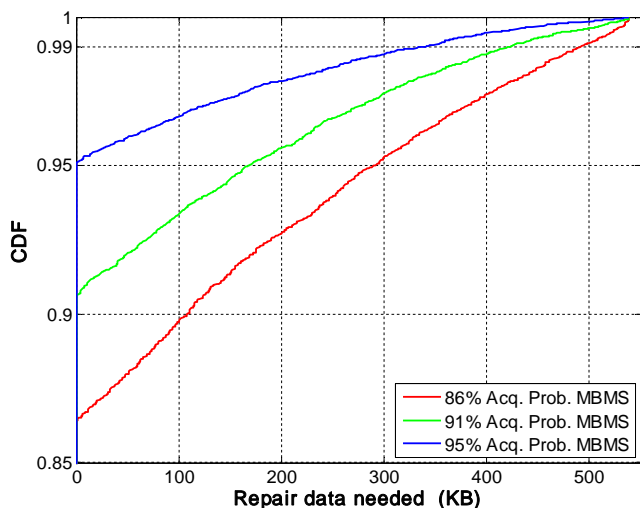


Fig. 9: CDF repair data needed (KB) after the MBMS transmission.

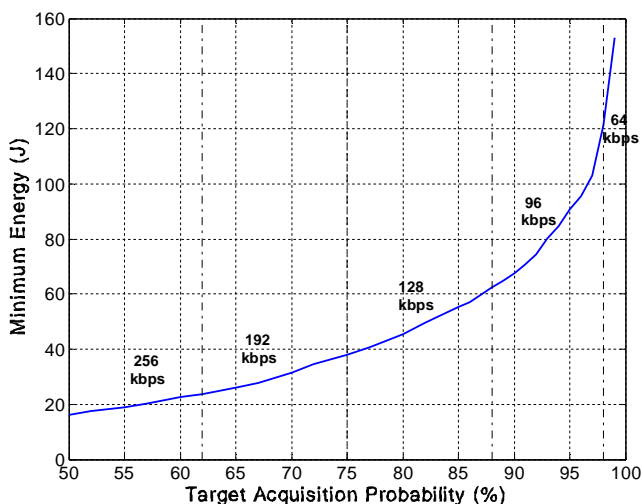


Fig. 10: Minimum MBMS energy (s) vs. Target file acquisition probability (%).

Finally in Fig. 11 we compare the minimum energy achieved with the hybrid approach for two file acquisition probabilities (95% and 99%) with the minimum achieved using only MBMS. The optimum MBMS acquisition probability depends on both the number of users and target acquisition probability, and it increases with both parameters. As expected the gain obtained with the hybrid delivery mode is larger for small number of users and for higher file acquisition probabilities. A quite significant gain can be noticed for a 99% acquisition probability. In this case not even with 500 users per cell the option of using only MBMS is more efficient. On the other side, for a 95% acquisition probability, if there are more than 200 users in the cell, there is no significant gain in using HSDPA for error repair.

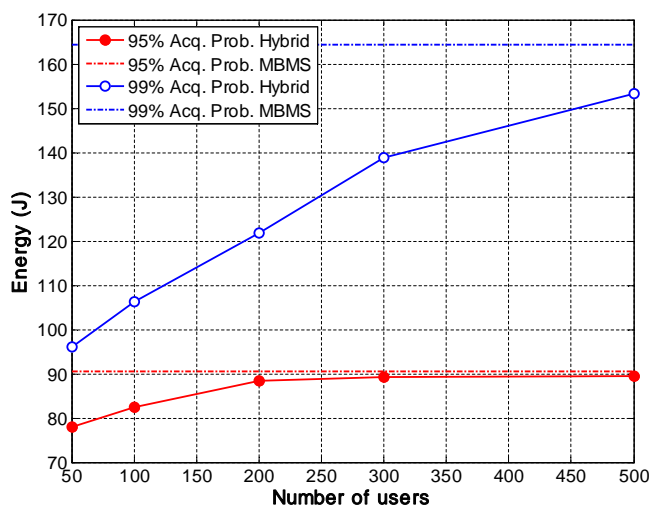


Fig. 11: Minimum energy (J) with only MBMS and with MBMS and HSDPA vs. Number of users per cell.

VI. CONCLUSIONS

In this paper we have reviewed the main technical issues for multicast file delivery in E3G mobile networks with HSDPA and MBMS. We have shown that for background services without time constraints, the optimum transmission configurations for both HSDPA and MBMS correspond to the lowest transmit power values. For time-constrained services, the optimum configuration is the minimum power that transmits the file in due time. The optimum MBMS bearer data rate depends on the transmit power, requiring higher bearer data rates for larger powers.

We have shown the need of implementing macro diversity techniques in MBMS, such as selective combining considered in this paper, as they considerably improve its performance. In our numerical evaluations, when considering selective combining the minimum energy to achieve a 95% acquisition probability of a 512 KB file is reduced down to a third, the minimum transmission time is reduced to less than half, and the minimum number of average users needed in the cell is reduced from 30 down to 4.

Moreover, in the paper we have also shown the potential efficiency improvement of a hybrid unicast-multicast delivery that can be obtained by employing HSDPA to repair the files not received correctly after the MBMS transmission. This gain is larger for very high file acquisition probability targets and for small numbers of users per cell.

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