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Effective Radio Resource Management for Multimedia Broadcast/Multicast Services in UMTS Networks

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Broadcast and multicast offer a significant improvement of spectrum utilization, and become particularly important where information channels are shared among several users. Mobile cellular environments are expected to evolve with the technological approaches necessary to facilitate the deployment of multimedia services, such as streaming, file download, and carousel services. The perspective that video streaming in wireless networks services is an attractive service to end-users has spurred the research in this area. To provide for a video delivery platform in UMTS, the third generation partnership project (3GPP) addressed this problem with the introduction of the multimedia broadcast and multicast services (MBMS) in 3GPP Release 6. In this document we analyse several effective radio resource management techniques to provide MBMS, namely, use of nonuniform QAM constellations, multicode, and macrodiversity to guarantee the optimal distribution of QoS depending on the location of mobiles.

1. INTRODUCTION

In a mobile cellular network it is often necessary to transmit the same information to all the users (broadcast transmission) or to a selected group of users (multicast transmission). Depending on the communication link conditions some receivers will have better signal-to-noise ratios (SNR) than others and thus the capacity of the communication link for these users is higher. Cover [1] showed that in broadcast transmissions it is possible to exchange some of the capacity of the good communication links to the poor ones and the tradeoff can be worthwhile. A possible method to improve the efficiency of the network is to use nonuniform signal constellations (also called hierarchical constellations) which are able to provide unequal bit error protection. In this type of constellations there are two or more classes of bits with different error protection, to which different streams of information can be mapped. Depending on the channel conditions, a given user can attempt to demodulate only the more protected bits or also the other bits that carry the additional information. An application of these techniques is in the transmission of coded voice or video signals. Several papers have studied the use of nonuniform constellations for this purpose [1, 2]. Nonuniform 16-QAM and 64-QAM constellations are already incorporated in the DVB-T (digital video broadcasting-terrestrial) standard [3].

Multimedia broadcast and multicast services (MBMS) introduced by 3GPP in Release 6 are intended to efficiently use network/radio resources (by transmitting data over a common radio channel), both in the core network but most importantly in the air interface of UMTS terrestrial radio access network (UTRAN), where the bottleneck is placed to a large group of users. However, it should take additional account of these network/radio resources. MBMS is targeting high (variable) bit rate services over a common channel.

One of the most important properties of MBMS is resource sharing among several user equipments (UEs), meaning that these users should be able to listen to the same MBMS channel at the same time. Sufficient amount of power should be allocated to these MBMS channels so that arbitrary UEs in the cell can receive the MBMS service.

One of the key issues in multicast transmission is the management of radio resources. The main requirement is to make an efficient overall usage of the radio resources. This makes the use of a common channel the favourite choice, since many users can access the same resource at the same time, but this depends also on the number of users belonging to the multicast group, the type of service provided, and the QoS that it can guarantee.

In this paper we will analyse several effective radio resource management techniques to provide MBMS, namely, the use of non-uniform QAM constellations, multicode, and macrodiversity. The objective is to guarantee the optimal distribution of QoS depending on the location of the mobiles.

In Section 2 the multicode packet scheduling model is presented, Section 3 describes non-uniform QAM constellations, macrodiversity combining techniques are detailed in Section 4, and in Section 5 simulation results are presented. Finally some conclusions are drawn in Section 6.

2. MULTICODE PACKET SCHEDULING (TWO QOS REGIONS)

Up to today no special transport channel has been specified for the purpose of multicast, but some proposal and preliminary studies have been provided. Therefore the driving concept to support multicast on the UTRAN is to use the existing transport channels, with minor modifications.

A flexible common channel suitable for point-to-multipoint (PtM) transmissions is already available, namely, the forward access channel (FACH), which is mapped onto the secondary common control physical channel (S-CCPCH).

In [4], it was shown that about 40% of the sector total power has to be allocated to a single 64 kbps MBMS if full cell coverage is required. This makes MBMS too expensive since the overall system capacity is limited by the power resource.

To make MBMS affordable for the UMTS system, its power consumptions have to be reduced. If MBMS is carried on S-CCPCH, there is no inner-loop power control. Extra power budget has to be allocated to compensate for the receiving power fluctuations.

Since MBMS video streaming is scalable, one way to improve the power efficiency of MBMS carried over S-CCPCH is to split the MBMS video streaming into several streams with a different quality of service (QoS). The basic video layer is coded by itself to provide the basic video quality and the enhancement video layer is coded to enhance the basic layer. The enhancement layer when added back to the basic layer regenerates a higher quality reproduction of the input video. 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 amount of power or coding protection and only the users who have better channel conditions are able to receive that additional information to enhance the video quality. 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.

Two possible MBMS multicode schemes will be considered. The first one uses a single rate stream (single spreading code), which is carried on a single 256 kbps channel and sent to the whole area in the cell. The second one uses a double streaming transmission, that is, two data streams (two spreading codes), each of 128 kbps where basic information for basic QoS is transmitted with the power level needed to cover the whole cell, and a second stream conveys additional information to users near the Node B (base station). This way, Node B power can be saved trading off with QoS of UEs at cell borders.

2.1. System model

According to the proposed transmission method UEs will receive the service accordingly to their geographic position. The RNC accounting for the differences in Node Bs radio resource availability divides MBMS data by its priorities and transmits them in a fashion that suits each Node B. In Figure 1 this approach is shown, where we can see the information scalability in two separate physical channels for one MBMS service (256 kbps). This corresponds to the transmission of two data streams, each of 128 kbps, where basic information providing the basic QoS is transmitted with the power level needed to cover the whole cell, and the second stream conveys additional information to users near the Node B.

The model consists of two QoS regions, where the first region receives all information while the second region receives the most important data. The QoS regions are associated with the geometry factor that reflects the distance of the UE from the base station antenna. The geometry factor G is defined as the ratio of interference generated in the own cell to the interference generated in the other cells plus thermal noise, that is,

$$G = \frac{I_{\text{own}}}{I_{\text{others}} + P_N}. \quad (1)$$

Table 1 shows the G values chosen. For the first region the geometry factor is $G = 0$ dB and for the second region $G = -6$ dB.

UE1 will receive the most important data (transmitted at 128 kbps) to get a basic video quality service, whereas UE2 will receive all the data to provide a higher quality reproduction of the input video.

3. NONUNIFORM QAM CONSTELLATIONS

Another transmission method which is based on the same philosophy of the multi-code transmission method just described is the use of nonuniform constellations. In this study we consider the use of 16-QAM non-uniform modulations for the transmission of broadcast and multicast services in WCDMA systems. For 16-QAM two classes of bits are used. Some modifications to the physical layer of the UMTS-(universal-mobile-telecommunications-systems-) based system to incorporate these modulations were already proposed in [5, 6].

3.1. 16-QAM

These constellations are constructed using a main QPSK constellation where each symbol is in fact another QPSK constellation, as shown Figure 2.

The bits used for selecting the symbols inside the small inner constellations are called weak bits and the bits corresponding to the selection of the small QPSK constellation are called stronger bits. The idea is that the constellation can be viewed as a 16-QAM constellation if the channel conditions are good or as a QPSK constellation otherwise. In the latter situation the received bit rate is reduced to half. The main

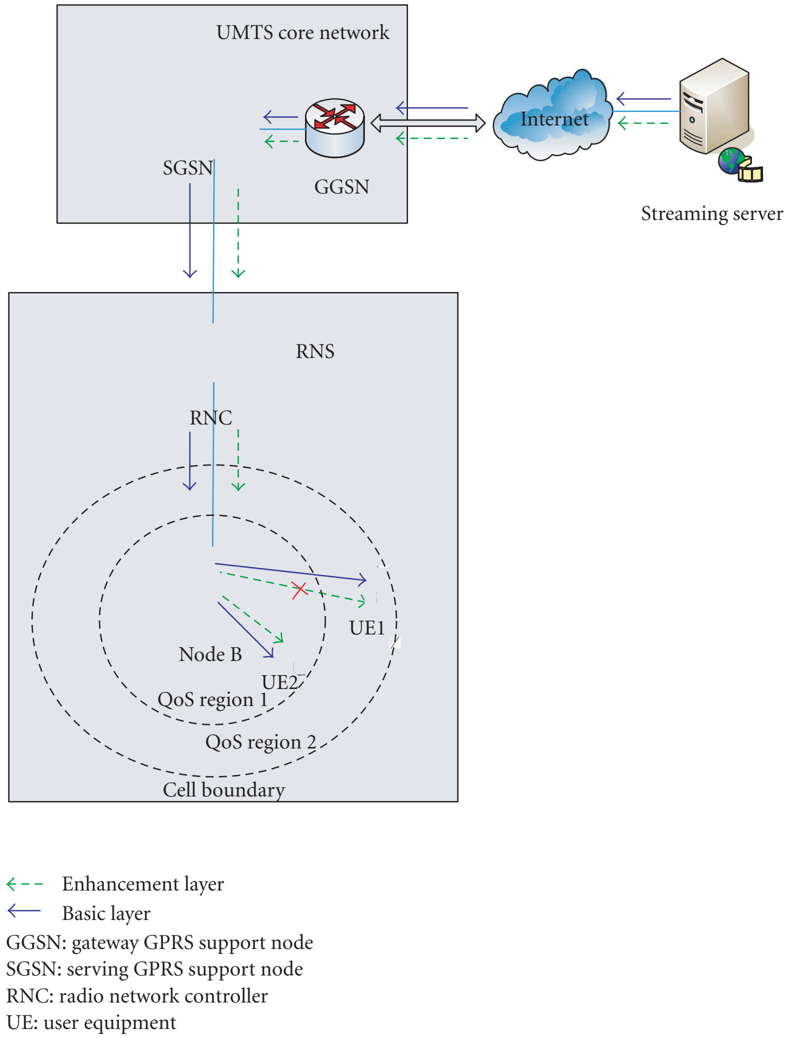

FIGURE 1: Two QoS regions packet scheduling model.

TABLE 1: QoS regions parameters.

QoS region	EU capacity	Maximum bit rate	G (dB)
1	UE1	256 kbps	0
2	UE2	128 kbps	−6

parameter for defining one of these constellations is the ratio between d_1 and d_2 as shown in Figure 2:

$$\frac{d_1}{d_2} = k, \quad \text{where } 0 < k \leq 0.5. \tag{2}$$

Each symbol s of the constellation can be written as

$$s = \left(\pm\frac{d_2}{2} \pm \frac{d_1}{2}\right) + \left(\pm\frac{d_2}{2} \pm \frac{d_1}{2}\right)j. \tag{3}$$

If $k = 0.5$, the resulting constellation is a uniform 16-QAM. When k is lower than 0.5, the bit error rate (BER) of the stronger bits improves but since the BER of the weaker symbols decreases, the overall BER also decreases.

Figure 3 shows a simplified transmission chain incorporating 16-QAM non-uniform constellations. In this scheme there are 2 parallel processing chains, one for the basic information stream and the other for the enhancement information.

4. MACRODIVERSITY COMBINING

Macrodiversity combining (MDC) is proposed as an enhancement to the UMTS 3GPP Release 6 MBMS. In a point-to-multipoint (PtM) MBMS service the transmitted content is expected to be network specific rather than cell specific, that is, the same content is expected to be multicasted/broadcasted through the entire network or through most of it. Therefore, a natural way of improving the physical layer performance is to take advantage of macrodiversity. On the network side, this means ensuring sufficient time synchronization of identical MBMS transmissions in different cells; on the mobile station side, this means the capability to

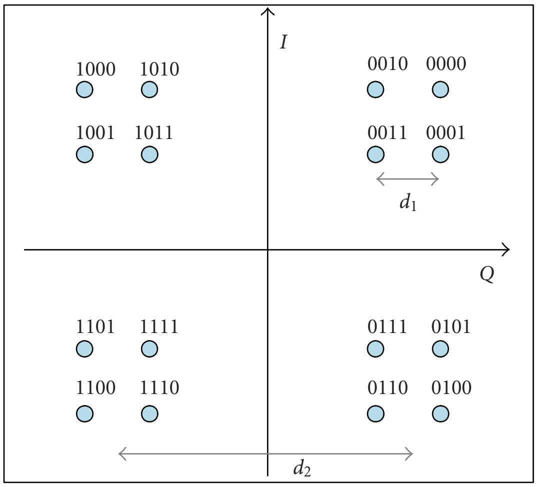

Figure 2: Signal constellation for 16-QAM nonuniform modulation.

receive and decode the same content from multiple transmitters simultaneously.

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 SNR.

In macro diversity the received signals from different paths have to be processed using some sort of combining algorithm. In this study two different combining procedures are considered, namely, selective combining (SC) and maximal ratio combining (MRC).

4.1. Selective combining

Figure 4 shows a scheme of how selective combining operates at the receiver side. With SC the path/branch yielding the highest SNR is always selected. In order to guarantee that the receiver uses the path with the best quality a simultaneous and continuous monitoring of all diversity paths is required.

The output of the diversity combiner will be

$$y(t) = g_k \cdot s_m(t) + n_k(t), \quad \text{with } g_k = \max\{|g_1|, \ldots, |g_N|\}, \tag{4}$$

where g_k is the maximum amplitude of the fading coefficients, and $n_k(t)$ is the additive Gaussian white noise (AGWN) which is independent from branch to branch.

4.2. Maximal ratio combining

The maximal ratio combining (Figure 5), although being the most complex combining technique presented, is the optimum way to combine the information from the different paths/branches. The receiver corrects the phase rotation caused by a fading channel and then combines the received signals of different paths proportionally to the strength of each path. Since each path undergoes different attenuations, combining them with different weights yields an optimum solution under an AWGN channel.

The output of the receiver can be represented as

$$y(t) = \sum_{j=1}^{N} |g_j|^2 s_m(t) + n_j(t). \tag{5}$$

5. SIMULATION RESULTS

Typically, radio network simulations can be classified as either link level (radio link between the base station and the user terminal) or radio network subsystem system level. A single approach would be preferable, but the complexity of such simulator—including everything from transmitted waveforms to multicell network—is far too high for the required simulation resolutions and simulation time. Therefore, separate link and system level approaches are needed.

Link level simulations are necessary for building a receiver model in the system simulator that can predict the receiver block error rate (BLER) and BER performance, taking into account channel estimation, interleaving, and decoding. The system level simulator is needed to model a system with a large number of mobiles and base stations, and algorithms operating in such a system.

Table 2 presents some link level parameters which will be used in the following sections. The channel estimation is performed using the common pilot channel (CPICH) which is transmitted in parallel to the data channels, using an orthogonal reserved code. At the receiver, the modulation is removed from the CPICH by multiplying it by its conjugate, which results in a sequence of noisy channel estimates. These noisy channel estimates are then passed through a moving average filter and the filtered sequence can be interpolated (or decimated) to match the rate of the data channels. 3GPP [4] refers to Vehicular A and Pedestrian B channel models as representative for the macrocellular environment and therefore results will be presented along this study for these two models. The velocities of 3 and 30 km/h were presented in 3GPP [4] for the Vehicular A channel, where 3 km/h has provided worst performance results.

Table 3 shows the system level assumptions used for the simulations.

The link performance results are used as an input by the system level simulator where several estimates for coverage and throughput purposes can be made by populating the scenario topology uniformly and giving users a random mobility. The estimates are made for every transmission time interval (TTI) being the packets that are received with a BLER below 1% considered to be well received. The estimates for coverage purposes are made for an average of five consecutive received packets; if the average received BLER of these packets is below the 1% BLER, the mobile user is considered as being in coverage. For the throughput calculation the estimation is made based on each individual packet received with a BLER lower than 1%.

Figure 6 shows the geometry CDF function values obtained for the macrocellular environment. The geometry factor was previously defined in Section 2.1; a lower geometry

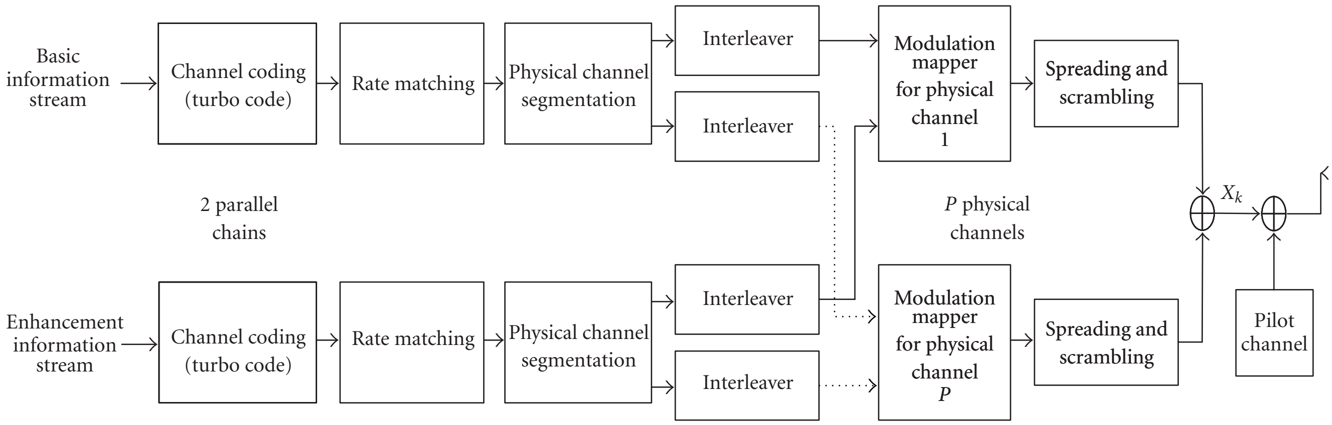

Figure 3: Proposed transmitter chain.

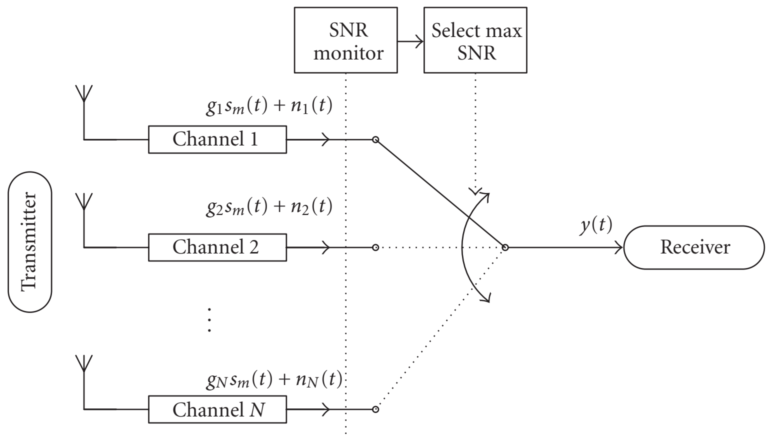

Figure 4: Selective combining.

factor is expected when user is located at the cell edge (the case where the interference received from the neighbouring cells is higher than the interference experienced in its own cell).

The cumulative distribution function (CDF) of geometry can be obtained through uniformly distributing a large number of mobile users over the topology and calculating the G at each position.

From Figure 6 it is possible to notice that for the studied scenario about 95% of the users experience a geometry factor of −6 dB or better, 80% experience a geometry of −3 dB or better, and about 62% of the users experience a geometry of 0 dB or better.

Figure 7 presents the first results obtained with the link level simulator. The results are presented in terms of Ec/Ior (dB) representing the fraction of cell transmit power necessary to achieve the corresponding BLER performance graduated on the vertical axis. For the reference BLER $= 10^{-2}$ and bit rate of 256 kbps (use of a single spreading code with spreading factor SF = 8) we need to have a geometry factor of 0 dB in order to achieve Ec/Ior less than 80% (−1 dB) considering the VehA propagation channel. This means that we can only offer such a high bit rate for users located in the middle of the cell, not near the border. By using a multicode transmission (2 spreading codes with SF = 16) with two different transmission powers, each assuring a bit rate of 128 kbps, offering different QoS that depend on the location of the UEs, higher throughput is achieved with lower total transmission power from the Node B.

In Figures 8–10, the QPSK 1% BLER coverage versus MBMS channel power (Node-B Tx Ec/Ior) is shown with selective combining or maximal ratio combining over 1 and 2 radio links (RLs), respectively, for the studied path models and TTI of 40 ms and 80 ms. Due to the better operation of the turbo decoder with increasing TTI (increasing encoded block sizes) we observe a decrease in the required transmitted power from the Node B when we use TTI = 80 ms instead of 40 ms. However, due to the limiting transport block size of 5114 bits per block of the turbo encoder specified in 3GPP, the bit rate of 256 kbps does not allow an increase in the encoded block size for TTI = 80 ms. As expected, the average coverage of maximal ratio combining is always better than

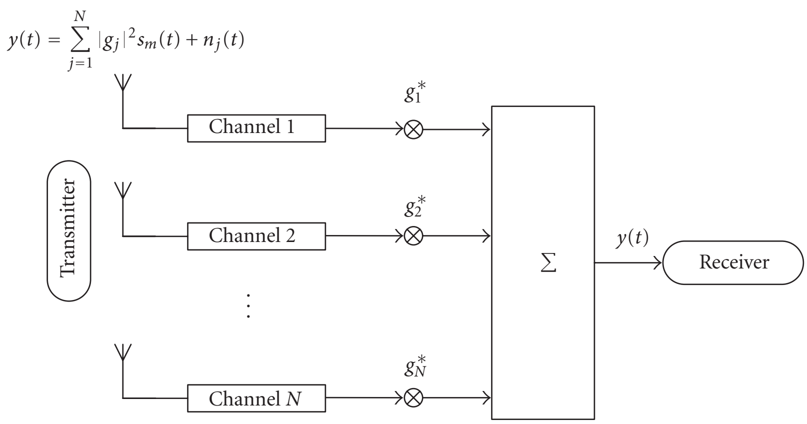

Figure 5: Maximal ratio combining.

Table 2: Link level simulation parameters.

Parameter	Value
S-CCPCH slot format	12 (128 kbps)
Transport block size & number of transport blocks per TTI	Varied according to information bit rate (128 or 256 kbps) and TTI value
CRC	16 bits
Transmission time interval (TTI)	20 ms
CPICH Ec/Ior	−10 dB (10%)
P-SCH (primary-synchronization channel) Ec/Ior	−15 dB (3%)
S-SCH (secondary-synchronization channel) Ec/Ior	−15 dB (3%)
Tx Ec/Ior	Varied
OCNS (orthogonal channel noise simulation)	Used to sum the total Tx Ec/Ior to 0 dB (100%)
Channel estimation	Enabled
Power control	Disabled
Channels	Pedestrian B, 3 km/h, Vehicular A, 3 km/h

selective combining and increasing the number of received radio links provides reduction in the transmitted power independently of the combining technique.

In Figure 8, for the reference average coverage of 90% the required Ec/Ior is about 60%–65% (PedB-VehA) for 128 kbps. For 256 kbps the same values of Ec/Ior allow average coverage around 52%–55%. There is the need of multicode or macrodiversity combining to allow an increase of bit rate and average coverage and/or a reduction in transmitted power. With multi-code the bit rate of 256 kbps is achievable with two streams of 128 kbps, one of them requiring $\text{Ec/Ior}_1 = 30\%$ (62% coverage in PedB environments) and the other $\text{Ec/Ior}_2 = 50\%$ (85% coverage in PedB).

However, macrodiversity offers better coverage and reduction of transmitted power than multicode. Tables 4 and 5 illustrate the required Ec/Ior for the reference BLER $= 1\%$ using macrodiversity with Vehicular A and Pedestrian B propagation channels, respectively. The performance of the former is always a little bit worse. According to the results of Tables 4 and 5 up to two MBMS channels with 256 kbps could be transmitted at the same time if MRC with 2RL were employed and considering that the maximum total available $\text{Ec/Ior} \le 83\%$.

Table 3: System level assumptions.

Parameter	Value
Cellular layout	Hexagonal
Sectorization	Yes, 3 sector/cell
Site-to-site distance	1000 m
Number of base stations	18
Base station antenna gain	17.5 dBi
Antenna beamwidth, −3 dB	70 degrees
Antenna front-to-back ratio	20 dB
Propagation model	Okamura-Hata
Base station total Tx power (sector)	43 dBm
Thermal noise DL	−103.3 dBm
Orthogonally factor	0.4
Std of shadow fading	10 dB
Cable losses	3 dB

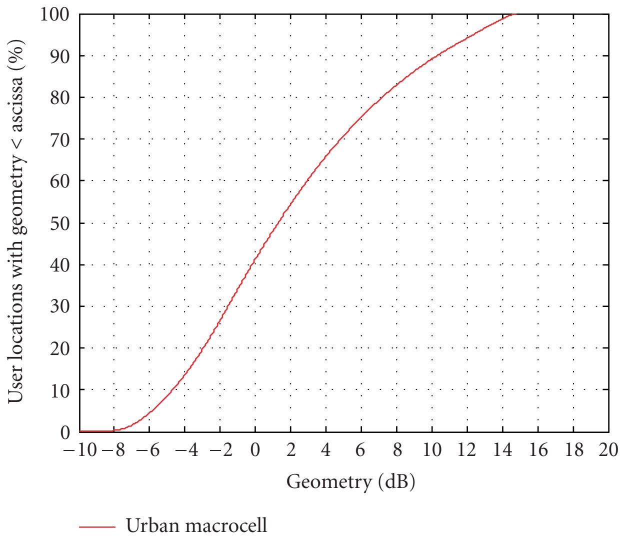

Figure 6: Geometry CDF, urban macrocell scenario.

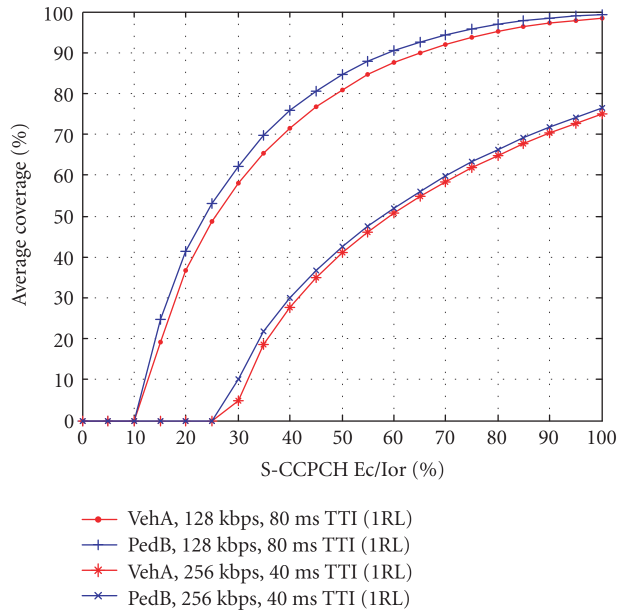

Figure 8: QPSK average coverage versus Tx power (1RL).

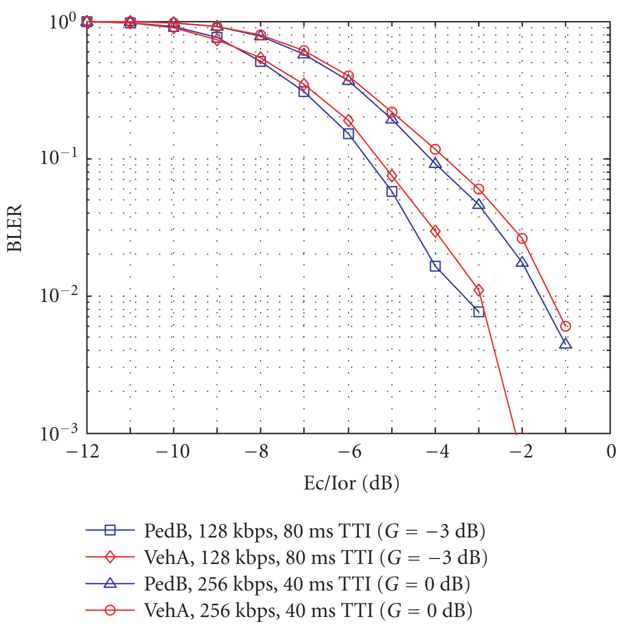

Figure 7: BLER versus Tx power for QPSK, different bit rates and geometries (V = 3 km/h).

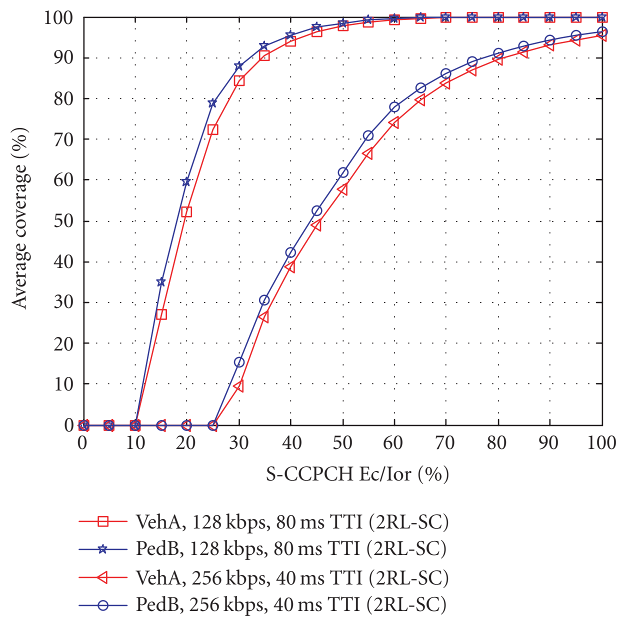

Figure 9: QPSK average coverage versus Tx power (2RL-SC).

Figure 11 presents an alternative way of offering the bit rate of 256 kbps using nonuniform 16-QAM modulation and a single spreading code with SF = 16 for $G = 0$ dB. This case is more spectral efficient than the previous one presented in Figure 7 because it uses a higher SF but there is the disadvantage of requiring a more complex receiver. An iterative receiver based on the one described in [5] is employed for decoding both blocks of bits. For the reference value of BLER $= 10^{-2}$ the difference of total transmitted power between the strong and the weak blocks is about 5.5 dB for either Vehicular A or Pedestrian B. Notice that in this study we are only considering $k = 0.5$ (uniform 16-QAM constellation).

Figure 12 corresponds to Figure 11 with SF = 32 and geometry $G = -3$ dB. In this case the maximum achievable bit rate is 128 kbps. For BLER $= 10^{-2}$ the difference of total transmitted power between the strong and the weak blocks also is 5.5 dB for either Vehicular A or Pedestrian B. The comparison between Figures 11 and 12 indicates that we can decrease the bit rate (increase of spreading factor) by decreasing the geometry (increasing of other cells interference). It

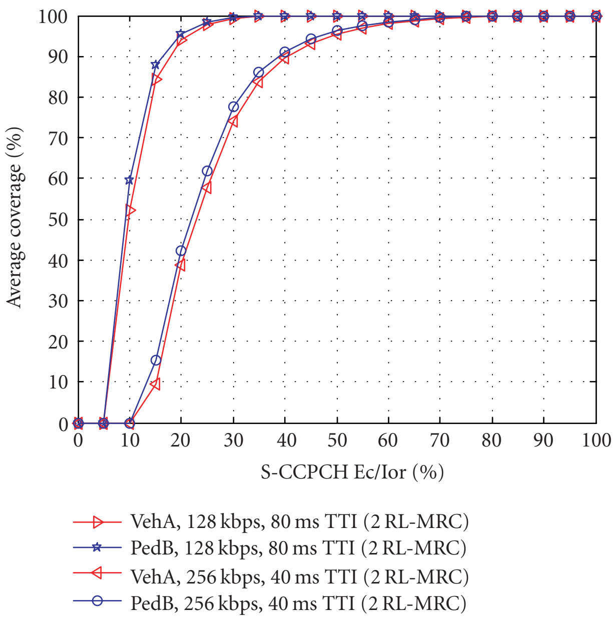

FIGURE 10: QPSK average coverage versus Tx power (2RL-MRC).

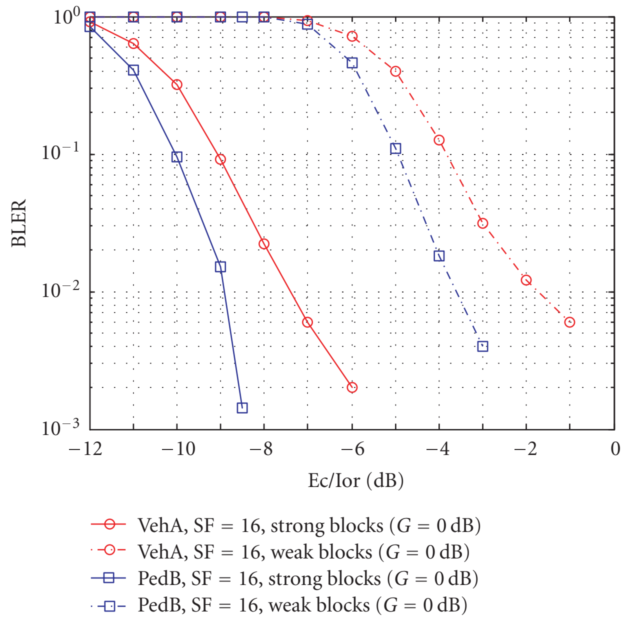

FIGURE 11: BLER versus Tx power for 16-QAM strong and weak blocks of bits (SF = 16), $k = 0.5$.

TABLE 4: Vehicular A, 3 km/h, 90% coverage, 1% BLER.

Bit rate	TTI length	1RL	SC (2RL)	MRC (2RL)
128 kbps	80 ms	−1.87 dB 64.9%	−4.61 dB 34.6%	−7.59 dB 17.4%
256 kbps	40 ms	— —	— —	−3.89 dB 40.75%

TABLE 5: Pedestrian B, 3 km/h, 90% coverage, 1% BLER.

Bit rate	TTI length	1RL	SC (2RL)	MRC (2RL)
128 kbps	80 ms	−2.39 dB 57.6%	−4.92 dB 32.2%	−8.09 dB 15.5%
256 kbps	40 ms	— —	— —	−4.10 dB 38.9%

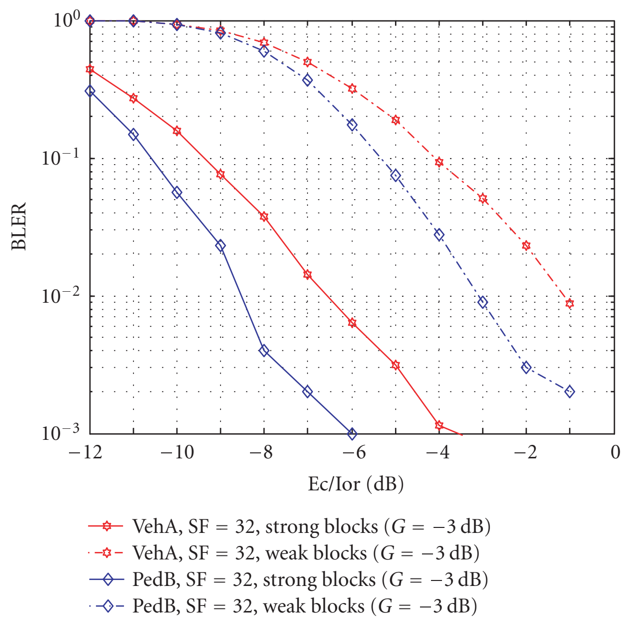

FIGURE 12: BLER versus Tx power for 16-QAM strong and weak blocks of bits (SF = 32), $k = 0.5$.

means that we must decrease the bit rate if we intend to allow an increase of coverage. This is true independently of the site-to-site distance between base stations (Node Bs).

In Figures 13–15, the 16-QAM 1% BLER coverage versus MBMS transmitted channel power (Node-B Tx Ec/Ior) is shown with selective and maximal ratio combining over 1 and 2 radio links (RLs), for the studied path models and a TTI of 40 ms.

In Figure 13, the performance of the conventional 1 radio link (RL) reception is illustrated for comparison with reception using macrodiversity combining. For the reference average coverage of 90% and 1RL the difference of required Ec/Ior between strong blocks and weak ones is about 70% (PedB) and even higher percentage of Ec/Ior is required for VehA (actually the 90% coverage for weak bocks is not achievable for the later propagation channel with a single radio link). As expected the average coverage of the strong blocks is always much better than weak blocks. However, this difference tends to decrease as the number of radio links increases; for instance, in the 90% average coverage with 2RL and MRC, the difference of required Ec/Ior is only 15% for PedB (see Figure 15).

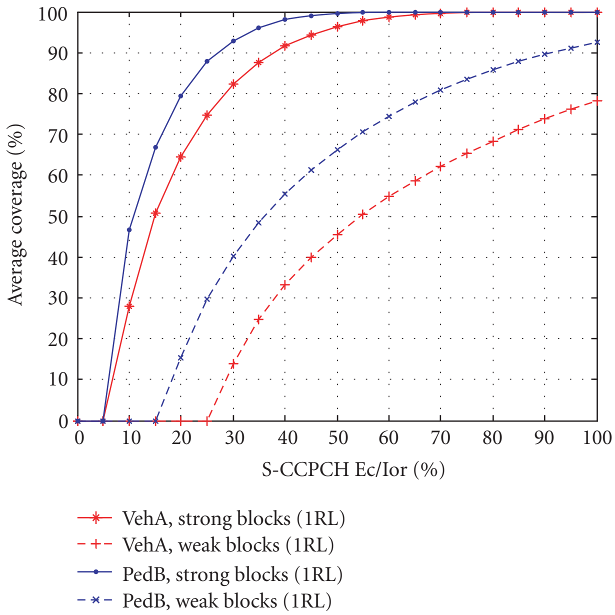

FIGURE 13: 16-QAM average coverage versus Tx power (1RL).

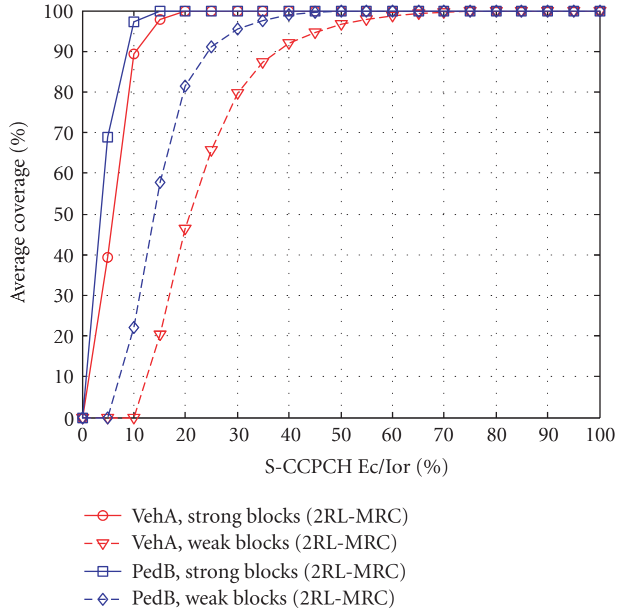

FIGURE 15: 16-QAM average coverage versus Tx power (2RL-MRC).

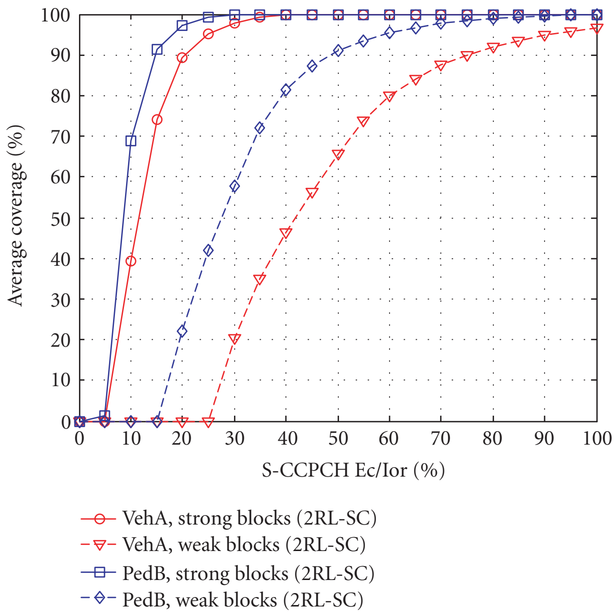

FIGURE 14: 16-QAM average coverage versus Tx power (2RL-SC).

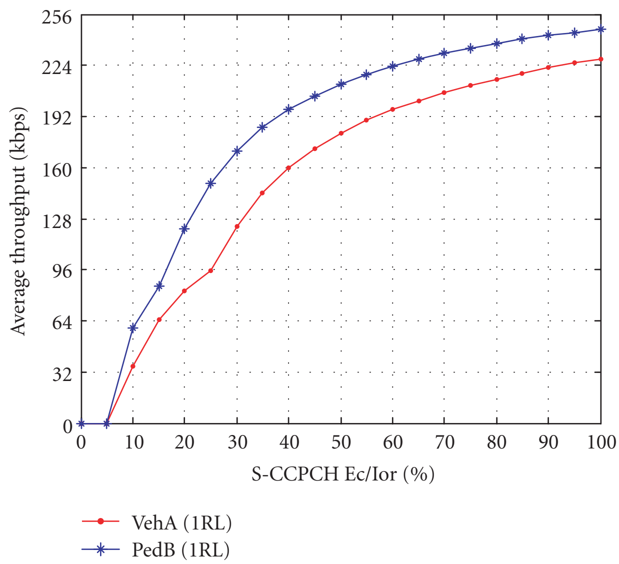

FIGURE 16: 16-QAM average throughput versus Tx power (1RL).

Figures 16 and 17 show the 1% BLER throughput versus MBMS transmitted channel power (Node-B Tx Ec/Ior) with selective combining and maximal ratio combining over 1 and 2 radio links (RLs) for various channel models and TTI = 40 ms. In Figure 16, the performance of the conventional 1 radio link (RL) reception is illustrated for comparison. The maximum throughput of 256 kbps is not achievable with 1RL, for both propagation channels, due to the low coverage of weak blocks. To achieve the reference throughput between 95% and 99% of the maximum bit rate, which is 256 kbps, we need macrodiversity combining. With 2RL-SC (Figure 17) we can observe a smooth step in the throughput between 96 and 128 kbps, especially for the VehA channel due to the way SC operates and the difference of required Ec/Ior between weak and strong blocks. We recall that for 128 kbps only the strong blocks are correctly received. With 2RL-MRC there is no such behaviour around 128 kbps because of the way this diversity combining operates. As expected, the reference throughput is achieved with less Ec/Ior for MRC compared to SC.

In Figures 18–20, the 1% BLER throughput versus MBMS channel power (Node-B Tx Ec/Ior) is shown with

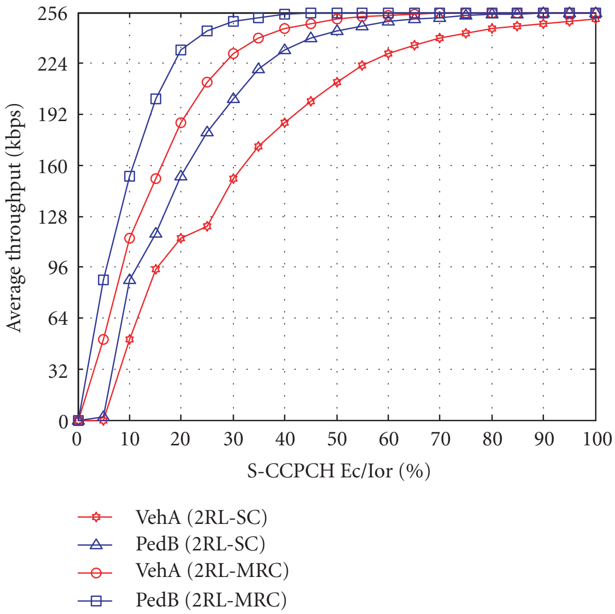

Figure 17: 16-QAM average throughput versus Tx power (SC/MRC).

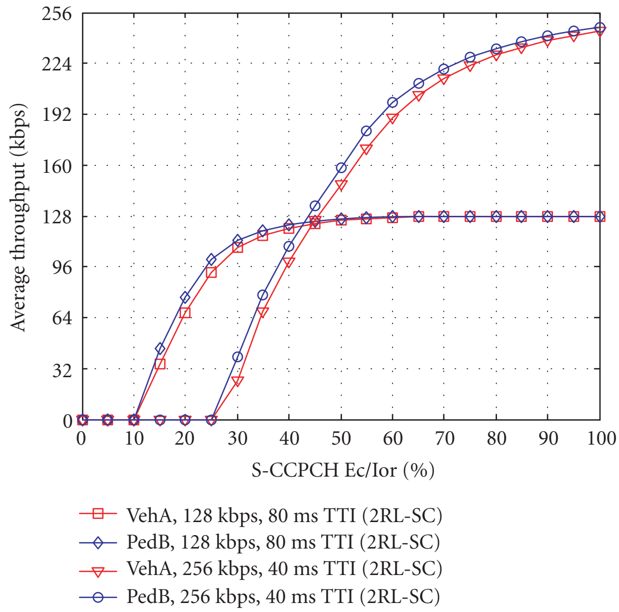

Figure 19: QPSK average throughput versus Tx power (2RL-SC).

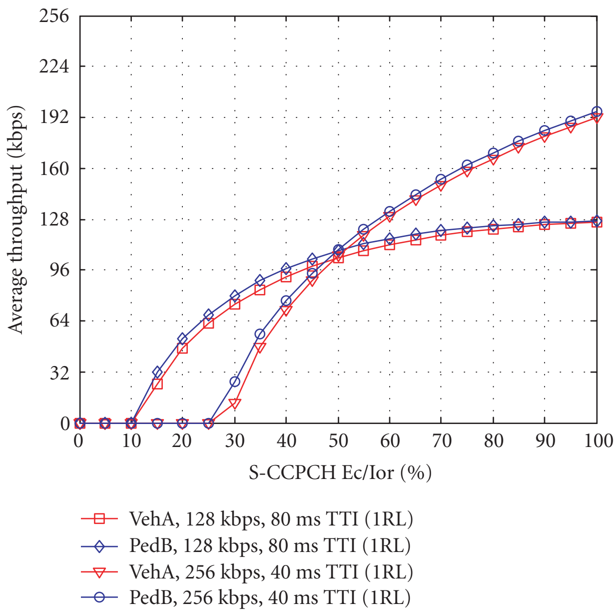

Figure 18: QPSK average throughput versus Tx power (1RL).

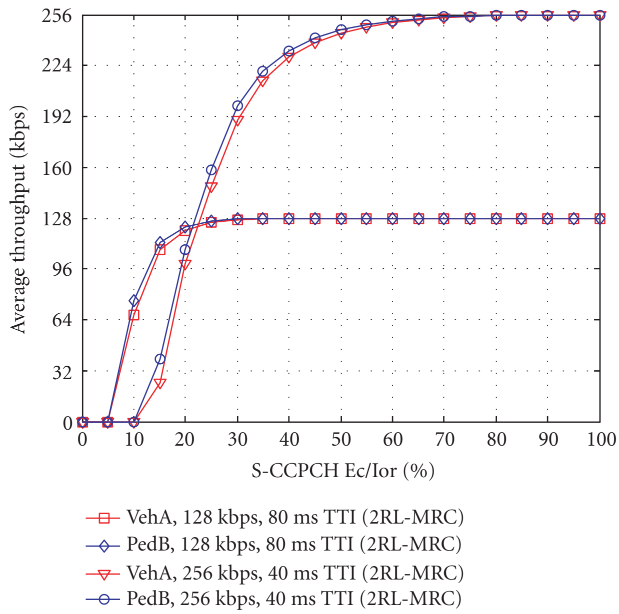

Figure 20: QPSK average throughput versus Tx power (2RL-MRC).

maximal ratio combining and selective combining over 1 and 2 radio links, for the various channel models, TTI lengths, and spreading factors based on Release 6 results [4] (named QPSK in the caption). The performance of these R6 throughput results is illustrated for comparison, with the corresponding average throughput illustrated in Figures 16 and 17.

In Figure 18 we can check that for a 256 kbps bit rate over 1RL the performance of QPSK is clearly worse than the 16-QAM performance results presented in Figure 16. However, this difference tends to decrease as the number of radio links increases. This means that the benefits of using macrodiversity combining are higher for QPSK than 16-QAM.

Considering the reference bit rate of 256 kbps and reference coverage of 95% with macrodiversity by maximal ratio combining 2 radio links (2RL-MRC), the capacity gain of using nonuniform16-QAM is 0.2 dB + 3 dB = 3.2 dB. The 0.2 dB comes from the comparison of Figures 17 and 20 for the Vehicular A channel, and the last 3 dB is due to the use of SF = 16 instead of SF = 8, which allows for using the double of the channels.

6. CONCLUSIONS

In this paper we have analysed several effective radio resource management techniques to provide MBMS, namely, use of nonuniform QAM constellations, multicode, and macrodiversity to guarantee the optimal distribution of QoS depending on the location of mobiles. In this study we have also presented the expected capacity gains that multicode and nonuniform 16-QAM modulations with more complex receivers can provide to reduce the PtM MBMS channel power. The latter receivers are more power efficient than current receivers based on QPSK modulation. We have shown that macrodiversity combining offers better capacity gains than multi-code for broadcast/multicast services. The use of both techniques at the same time is suggested. Non-uniform 16-QAM receivers should be built in the near future with or without the macrodiversity combining already specified by 3GPP, as an effective mean to increase not only the throughput, but also the number of simultaneous simulcast services.

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