Multi-resolution with Hierarchical Modulations for Long Term Evolution of UMTS

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***Abstract* - In the Long Term Evolution (LTE) of UMTS the Interactive Mobile TV scenario is expected to be a popular service. By using multi-resolution with hierarchical modulations this service is expected to be broadcasted to larger groups achieving significant reduction in power transmission or increasing the average throughput. In this paper system level simulations of multi-cellular networks considering broadcast and multicast transmissions using the OFDM/OFDMA based LTE technology are presented to evaluate the capacity, in terms of number of TV channels with given bit rates or total spectral efficiency and coverage. Multi-resolution with hierarchical modulations is presented to evaluate the achievable throughput gain compared to single resolution systems of Multimedia Broadcast/Multicast Service (MBMS) standardised in Release 6.**

I. INTRODUCTION

3GPP has launched the study item Evolved UTRA and UTRAN, the aim of which was to study means to achieve further substantial leaps in terms of service provisioning and cost reduction. The overall target of this long-term evolution (LTE) of 3G was to arrive at an evolved radio access technology that can provide service performance on parity with current fixed line access. At this point it is important to emphasize that this evolved RAN is an evolution of the current 3G networks, building on already made investments. 3GPP community has been working on LTE and various contributions were made to implement MBMS in LTE [1].

Orthogonal frequency division multiplexing/orthogonal frequency division multiple access OFDM/OFDMA [2], used in the physical layer (downlink connection) of LTE, is an attractive choice to meet requirements for high data rates, with correspondingly large transmission bandwidths and flexible spectrum allocation. OFDM also allows for a smooth migration from earlier radio access technologies and is known for high performance in frequency-selective channels. It further enables frequency-domain adaptation, provides benefits in broadcast scenarios and is well suited for multiple-input multiple-output (MIMO) processing.

For MBMS support within a certain cell coverage area for a given coverage target, the MCS (Modulation and Coding Scheme) of the MBMS transport channel typically has to be designed under worst-case assumptions. Apart from cell-edge users experiencing large inter-cell-interference, users with better channel conditions (closer to the base station) could receive the same service with a better quality (e.g., video resolution), as their receiving SNR would allow usage of a higher-rate MCS. Hierarchical modulation, which has been specified for broadcast systems like DVB-T (Digital Video Broadcast Terrestrial) or MediaFLO, is one way of accounting for unequal receiving conditions. Here, a signal constellation like 16QAM, with each symbol being represented by four bits, is interpreted in a sense that the two first bits belong to an underlying QPSK alphabet. This enables the use of two independent data streams with different sensitivity requirements. In the example above, the so-called high priority stream employs QPSK modulation and is designed to cover the whole service area. The low priority stream requires the constellation to be demodulated as 16QAM, and provides an additional or refined service via the two additional bits. These may transport an additional MBMS channel with a different type of service, or an enhancement stream that, for example, leads to enhancing the resolution of the base stream. A design parameter that determines the constellation layout allows the control of the amount of distortion that the enhancements symbols add to the baseline constellation, and can be used to control the ratio of coverage areas or service data rates. Theoretical evaluation of this type of modulations where it is explicitly shown the dependence of the individual bit streams performance on the constellation design parameter has been previously presented.

Hierarchical constellations [3] and MIMO (spatial multiplexing) are methods to offer multi-resolution. In OFDMA based networks, the transmission of different fractions of the total set of sub-carriers (chunks) depending on the position of the mobiles is another way to offer multi-resolution. Any of these methods is able to provide unequal bit error protection. In any case there are two or more classes of bits with different error protection, to which different streams of information can be mapped. Regardless of the channel conditions, a given user always attempts to demodulate both the more protected bits and the other bits that carry the additional resolution. Depending on its position inside the cell more or less blocks with additional resolution will be correctly received by the mobile user.

However, the basic quality will be always correctly received independently of the position of any user, within the 95% coverage target. In this paper section 2 presents the evaluation methodology and simulation assumptions are presented. In section 3 the system level results are presented. In section 4 the conclusion are presented.

II. EVALUATION METHODOLOGY AND SIMULATION ASSUMPTIONS

Typically, radio network simulations can be classified as either link level (radio link between the base station and the user terminal) or system level (several base stations with large number of mobile users). A single approach would be preferable, but the complexity of such simulator (including everything from transmitted waveforms to multi-cell network) is far too high for the required simulation resolutions and simulation time. Therefore, separate but interconnected link and system level approaches are needed.

The link level simulator is needed for the system simulator to build a receiver model that can predict the receiver BLER/BER (Block Error Rate/Bit Error Rate) performance, taking into account channel estimation, interleaving, modulation, receiver structure 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.

As the simulation is divided in two parts, an approach of linking between the two simulators must be defined. Conventionally, the information obtained from the link level simulator is inserted in the system level simulator through the utilization of a specific performance parameter (BLER) corresponding to a determined signal to interference plus noise ratio (SNR) estimated in the terminal or base station. In Figure 1 is shown the simulators interaction.

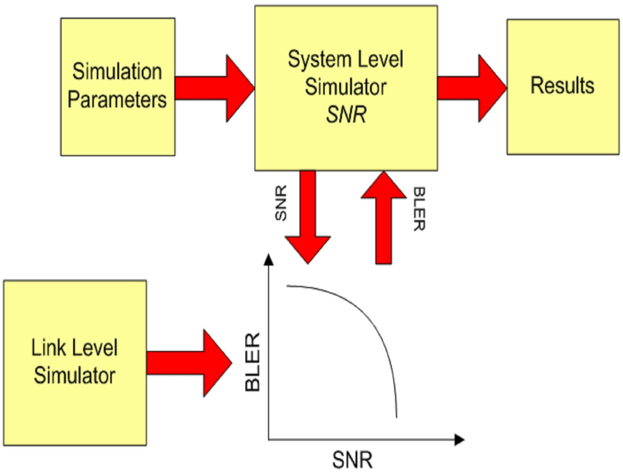

Figure 1. Interaction between Link Level Simulator and System Level Simulator.

A. Radio Access Network System Level Simulator

For the purpose of validating the work presented in this section, it was developed a system level simulator in Java, using a discrete event based philosophy, which captures the dynamic behaviour of the Radio Access Network System. This dynamic behaviour includes the user (e.g. mobility and variable traffic demands), radio interface and RAN (Radio Access Network) with some level of abstraction.

The system level simulator (SLS) works at Transmission Time Interval (TTI) rate and typical time interval of each simulation is 600 seconds. Table I shows the simulation parameters. It presents the parameters used in the link and system level simulations based on 3GPP documents.

Transmission bandwidth	10 MHz
Cyclic prefix size	72
FFT Size	1024
Carriers space (kHz)	15
Available bandwidth	9 MHz
Sample time (ns)	130
Max Tx Power (dBm)/sector	46
Number of used sub-carriers/sector	200
Number of used sub-carriers/cell	600
Freq. Reuse	1/3
Sub-frame duration (ms)	0.5
Interfering cells transmit with % of Max Power	90
Cell Radius (m)	750
Inter-Site Distance (m)	1500
Cellular layout	Hexagonal
Sectors	3 sectors/cell
Number of cell sites	19
Antenna gain of the base station	17.5 dBi
Propagation Model	Okumura-Hata
Downlink thermal noise	-100 dBm

Table I. Link and System Level Simulation parameters for Urban Macro cellular scenario.

The channel model used in the system level simulator considers three types of losses: distance loss, shadowing loss and multi-path fading loss (one value per TTI). The model parameters depend on the environment. For the distance loss the Okumura-Hata Model from the COST 231 project was used. Shadowing is due to the existence of large obstacles like buildings and the movement of UEs in and out of the shadows. This is modelled through a process with a lognormal distribution and a correlation distance. The multi-path fading in the system level simulator corresponds to the 3GPP channel model, where the ITU Vehicular A environment was chosen as reference.

Figure 2 illustrates the cellular layout (trisectorial antenna pattern) indicating the fractional frequency reuse of 1/3 considered in the system level simulations. 1/3 of the available bandwidth was used in each sector to reduce the multi-cell interference. As indicated in Figure 2, the identification of the sources of multi-cell interference, i.e., use of the same adjacent sub-carriers (named physical resource blocks or chunks), is given by the sectors with the same color/number, namely, red/one, green/two or yellow/three.

For 16-QAM hierarchical constellations two classes of bits with different error protection are used. The blue color around the antennas only indicates the approximate coverage of the weak bits blocks, while the other colors indicate the coverage of the strong bits blocks.

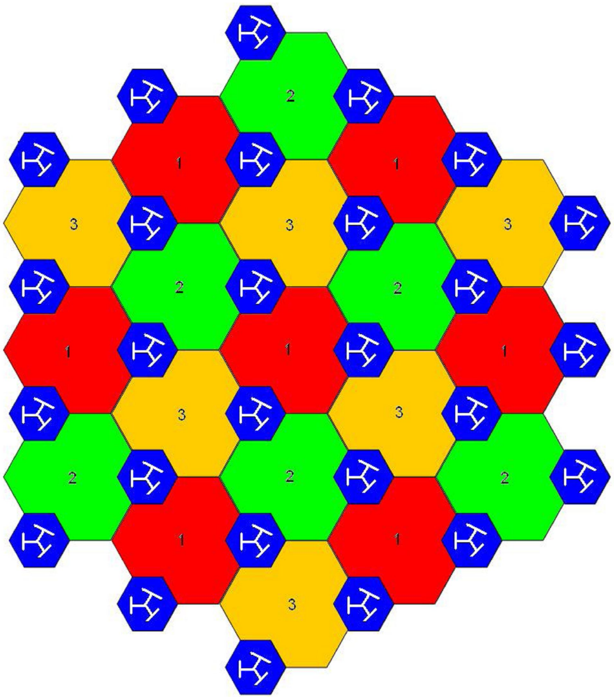

Figure 2. Cellular layout including the frequency reuse of 1/3.

III. SYSTEM-LEVEL PERFORMANCE RESULTS

Each information stream was encoded with a block size of 2560 bits per sub-frame duration of 0.5ms. One third of the total physical resource blocks (PRB) are transmitted in each sector. This corresponds to an instantly occupied bandwidth of 3MHz, where we have considered 20 PRBs each with 150kHz of adjacent bandwidth (corresponding to 10 sub-carriers with frequency spacing of 15kHz). We have considered that three different coding rates are used, namely,1/2, 2/3 and 3/4 This leads to total transmitted information bit rates per cell sector of 5120 kbps, 6825 kbps and 7680 kbps, respectively. Considering that each PRB carries a different TV program channel this corresponds to channel bit rates of 256 kbps, 341 kbps and 384 kbps, respectively. We have evaluated in the link level simulations the hierarchical 16-QAM with $k=0.5$ for these three channel bit rates.

Figure 3 presents the coverage vs. the fraction of the total transmitted power (Ec/Ior), for the multi-cell interference scenario where there is interference only from one third of the sectors due to the frequency reuse of 1/3 (see Figure 2). The cell radius is 750m, and we have separated strong blocks (H1) from weak blocks (H2) without including macro-diversity combining. The multi-cell interference is 90% of the maximum transmitted power in each site. For Ec/Ior=50% and channel bit rate 256kbps the coverage of H1 is 95% and for H2 is 85%. For the same Ec/Ior but 384kbps data rate, the coverage values of H1 and H2 are 39% and 30%, respectively. In both cases there is a difference of about 10% between the coverage of H1 and H2.

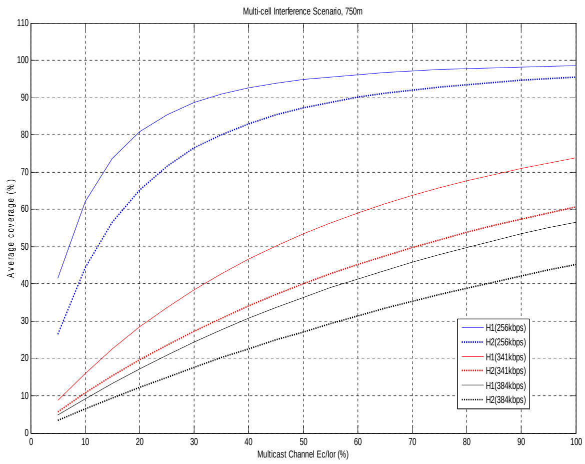

Figure 3. Average coverage (%) vs. Ec/Ior, 1 Radio Link

Figure 4 presents the coverage vs. Ec/Ior separating strong blocks (H1) from weak blocks (H2) with macro-diversity combining of the best two radio links. For Ec/Ior=20% regardless of the channel bit rate and the type of blocks the coverage is always above 95%. However, for 384 kbps the coverage values of H1 and H2 are different from each other. Only for Ec/Ior=50% the coverage of strong blocks is above or equal to 95% for 384 kbps. But for 256 kbps the coverage value for strong blocks is above 95% for Ec/Ior=5%. This indicates that as long as there is macro-diversity combining of the two best links it is possible to increase the channel bit rate or increase the number of transmitted channels keeping the same bit rate.

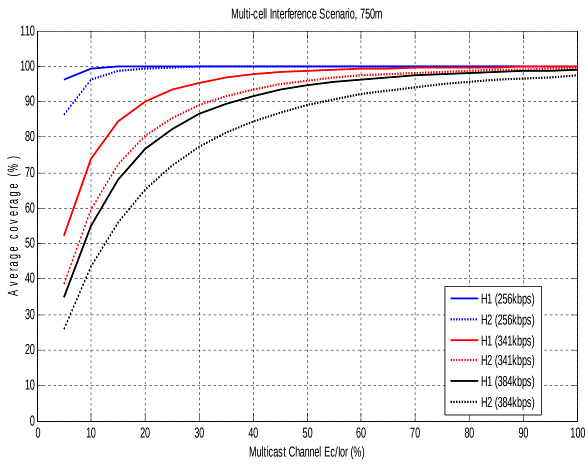

Figure 4. Average coverage (%) vs. Ec/Ior, 2 Radio Links

Figure 5 considers the throughput distribution as function of the Ec/Ior for multi-cellular network with and without macro-diversity. We observe a considerable gain in throughput when macro-diversity (2RL) is considered compared to the single radio link case. This is particularly true for the high bit rate 384 kbps. For the low bit rate the macro-diversity gain is not as substantial as the throughput performance is already good for a single radio link.

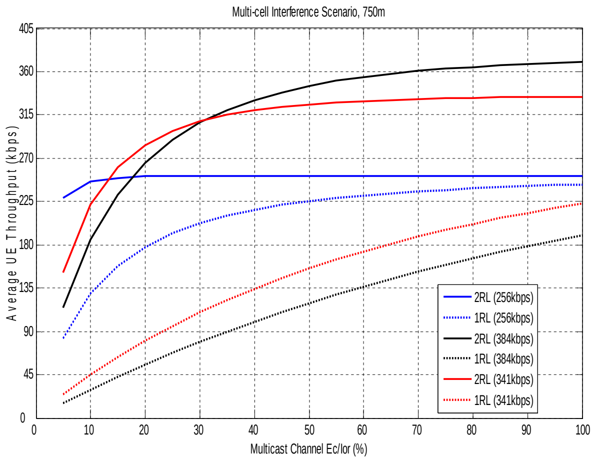

Figure 5. Throughput vs. Ec/Ior, R=750m, k=0.5.

Figure 6 considers the throughput distribution as function of the distance between UEs and BS for the Ec/Ior=90%, with and without macro-diversity. For the chosen Ec/Ior, macro-diversity (2RL) assure almost the maximum throughput for 256 kbps, however it is more obvious the decrease in throughput for 384 kbps and mobile users at the cell borders. It is obvious that without macro-diversity (1RL case), only for the 256 kbps channel, the throughput is almost the maximum regardless of the distance. For the high bit rate 384 kbps a single radio link only offers high throughput for users close to the base station.

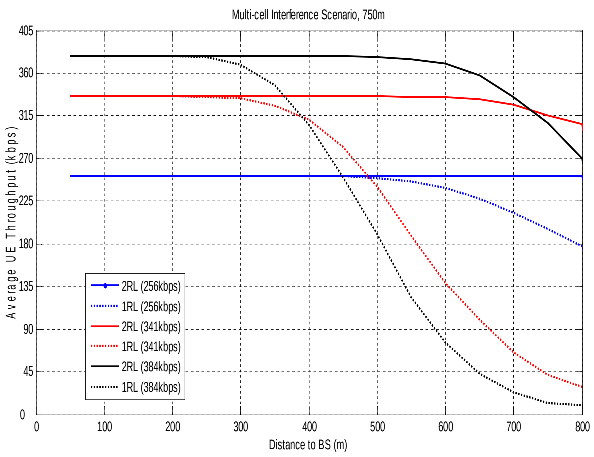

Figure 6. Throughput vs. distance between UEs and BS, k=0.5.

IV. CONCLUSION

The main conclusion of this work is: for the cellular network LTE based and the high channel bit rate 384 kbps, the spectral efficiency achieved per cell sector considering that 20 TV channels are transmitted simultaneously in the total bandwidth of 10 MHz is 0.768 bps/Hz/cell. This value of spectral efficiency is valid for users at the cell border. The inter-site-distance (ISD) associated to this spectral efficiency is 1500m. Alternatively, 30 TV channels with 256 kbps could be transmitted at the same time as indicated in Table II. There is a gain of two compared to the MBMS of Release 6 [4].

QoS	#channels	Efficiency	ISD	Bandwidth
256 kbps	30	0.768 bps/Hz/cell	1500 m	10 MHz
384 kbps	20	0.768 bps/Hz/cell	1500m	10 MHz

Table II. Capacity values for 16QAM hierarchical multi-resolution OFDMA.

V. REFERENCES

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