Study of OTA Throughput of 4G LTE Wireless Terminals for Different System Bandwidths and Coherence Bandwidths in Rich Isotropic Multipath

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***Abstract*—The paper shows experimental and theoretical study of over-the-air (OTA) throughput of LTE wireless devices for different system bandwidths and coherence bandwidths in rich isotropic multipath (RIMP) environment. The theory models the effect of the frequency diversity obtained in OFDM system and shows good agreement with the measurements for the different system bandwidths and coherence bandwidths.**

Index Terms—OTA; LTE; OFDM; throughput; coherence bandwidth;delay spread

I. INTRODUCTION

The 3rd Generation Partnership Project (3GPP) has provided successful reports and specifications for Long Term Evolution (LTE) [1]. The LTE standard is the latest communication technology standard today which is extensively adopted by the industry to satisfy the demands of their customers with high speed internet and low latency. The major differences between LTE and its predecessor telecommunication standards WCDMA and GSM are Orthogonal Frequency Division Multiplexing (OFDM), Multiple-Input Multiple-Output (MIMO), and scalable bandwidth which provide improved receiver sensitivity, higher throughput data-rates, and flexibility. However, LTE also increases cost and system complexity, and therefore it puts strict requirements to ensure as high spectral efficiency as possible. To successfully deploy LTE with improved user-experience, it is of importance to be able to measure, quantify, and compare the over-the-air (OTA) performance of LTE devices. This paper presents an experimental study of the effect on the throughput of different system bandwidths when the environment has different coherence bandwidths, for a 2x2 MIMO transmit-diversity case. The results are compared with a theoretical model that includes the receiver sensitivity in the form of an ideal threshold receiver as defined in [2].

Both conducted-tests and OTA-tests are performed. The conducted test-environment can be represented by an ideal Line-Of-Sight (LOS) channel (i.e. no fading) with Additive White Gaussian Noise (AWGN), referred to as an AWGN channel.

The OTA test-environment is a Rich Isotropic Multipath (RIMP), i.e. a Rayleigh fading environment with no LOS. This environment is emulated experimentally by a reverberation chamber, and it was initially used to test small multi-port antennas for wireless terminals [3][4], and the last years the testing has been extended to active devices [5]. The uncertainty of the tests are controllable by basic theories [6], and known to be lower than standard deviation of 0.5 dB, above 1 GHz even approaching 0.1 dB.

In the present paper the Device-Under-Test (DUT) is tested both by connecting a cable directly to an LTE base station simulator referred to as conducted-tests, and in the reverberation chamber referred to as OTA-tests. Our previous related work was about conducted and OTA throughput modeling for SISO and SIMO in [2]; for different coherence bandwidths in [7]; and for 2×2 MIMO multiplexing in [8]. The purpose of the present paper is to study measured throughput for different system bandwidths and see how well the OFDM model works for all these, and to investigate how the threshold level change with the system bandwidth.

II. THE SIMPLE THROUGHPUT MODEL & RECEIVER SENSITIVITY

The simple throughput model introduced in [2] explains the LTE measurements very well. The model is based on simple threshold receiver concept. The advanced forward error correcting (FEC) codes correct the errors in the corrupted received data. The errors occur due to noise, interference, and multipath scattering. The errors are corrected by error correcting blocks in the advanced digital receiver chain until a certain specific received power level that we define as threshold power level. The threshold level is dependent on many different parameters that include modulation scheme, coding rate, system bandwidth, etc. In other words, a combination of different system parameters provides us an effective threshold power that represents the power level at which the ideal digital receiver breaks down from 0% to 100% BLock Error Rate (BLER) in an AWGN channel. Not only these system parameters define the threshold power but also hardware components in the wireless terminal such as LNA, mixer, and antenna also play an important role in determining the threshold power level. In this study we investigate the effects of system bandwidths (B_s) and coherence bandwidths (B_c) on threshold, throughput, and diversity gain of a given DUT. From [2], the simple throughput model is as follows:

$$T = R \times (1-\varepsilon) = CCDF\left(P_t / P_{av}\right) \qquad (1)$$

where T is throughput, R is the maximum achievable data-rate, ε is the error-rate, $CCDF$ is the complementary cumulative distribution function, P_t is the receiver threshold power, and P_{av} is the average received power. To calculate the number of equivalent frequency diversity channels N_{fd}, we use:

$$N_{fd} = B_s / B_c \qquad (2)$$

We generate a total of $N_{fd} \times N_t \times N_r$ channels in our simulation and calculate the CCDF of these channels. At the receiver, these channels are combined using maximal-ratio combining (MRC) scheme, which gives the diversity performance of the receiver.

III. Measurement Setup and System Configuration

Both conductive and OTA measurement setups are shown in Fig. 1. In conductive measurements, the DUT is connected simply via the external antenna ports to the LTE base station simulator with the help of cables. The DUT is placed in a shielded box to avoid external noise and interferences, and to make sure only external antenna ports contribute to the measurement results. As mentioned earlier, the conducted measurements are performed to observe the DUT's threshold power level for a particular fixed system configuration. The OTA measurements are performed in a reverberation chamber, which emulates the RIMP environment [9]. We use a self-grounded four-port bow-tie antenna [10] connected to the base station as a fixed antenna, and we use two identical high efficiency disk-cone reference antennas as DUT antennas.

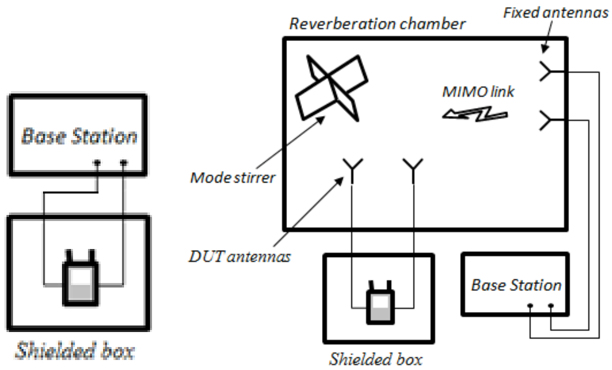

Figure 1: Conductive (left) and OTA Measurement Setup (right)

The DUT we choose for these measurements is a commercially available LTE device of category 3 with OFDM and MIMO capability and supporting modulation schemes up to QAM-64.The system configuration is different for different measurements but some of the parameters are fixed e.g. LTE band 7 i.e. 2655 MHz downlink frequency, MCS index 19 referring to QAM-64 modulation scheme, TBS index 17 referring to transport block size of 36696, 2×2 MIMO antenna configuration with transmit diversity. The measurements were done for system bandwidths B_s of 20 MHz, 15 MHz, 10 MHz, and 5 MHz (corresponding to 100, 75, 50, and 25 resource blocks respectively), and for coherence bandwidths B_c of 10 MHz, 5 MHz, and 2.5 MHz (corresponding to 55ns, 105ns, and 225ns channel delay spreads respectively). The relationship of coherence bandwidth B_c and delay spread σ measured inside reverberation chamber is explained in [11], but the final equation has an error so we present the correct equation here:

$$B_c = \sqrt{3} / \pi\sigma \qquad (3)$$

For each power-level the measured throughput is the result of averaging 50 throughtput measurements inside the reverberation chamber.

IV. Conducted & OTA LTE Throughput Measurements and Simulation Results

Fig. 2 shows SISO conducted throughput measurements and simulations in AWGN channel for different systems bandwidths i.e. 20 MHz, 15 MHz, 10 MHz, and 5 MHz.

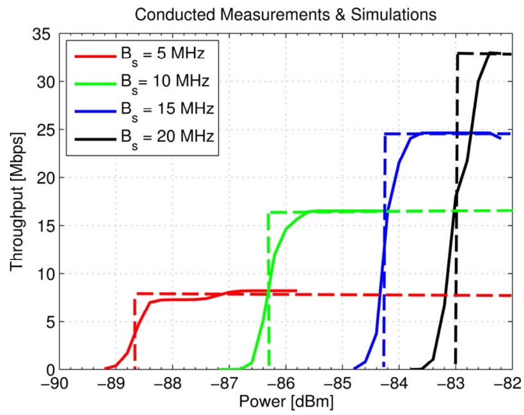

Figure 2: Conducted measurements (solid lines) & simulations (dashed lines) of SISO LTE throughput in AWGN for system bandwidths of 20, 15, 10, and 5 MHz.

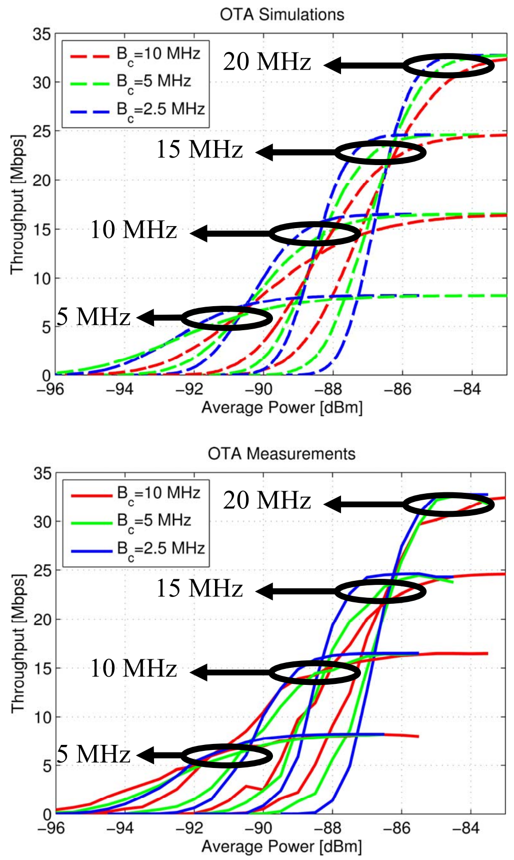

Figure 3: OTA Simulations (top) & OTA measurements (bottom) of 2×2 MIMO LTE throughput in RIMP for system bandwidths of 20, 15, 10, and 5 MHz, and for coherence bandwidths of 10, 5, and 2.5 MHz.

Fig. 3 shows OTA simulated and measured results for LTE device with OFDM and 2×2 MIMO using transmit diversity. Fig. 3 (top) shows "best-fit" simulated results while Fig. 3 (bottom) shows the measured data for different system bandwidths and coherence bandwidths. The "best-fit" simulated curves are explained in the next section with reference to Tables I and II.

V. Discussion & Conclusions

The Fig. 3 (top) and Fig. 3 (bottom) are showing a quite good agreement between simulation and measurement results of the throughput curves for different B_s and B_c plotted against received power level. The simple throughput model has in principle the same shapes as the measured curves. The results from the curves are summarized in the table below. The best-fit OTA values shown in Table I and Table II are the values of N_{fd} and P_t that make the theoretical curves fit best to the measured curves. The discrepancy between the threshold values for the conducted and best-fit OTA cases is also shown.

TABLE I. Modelling Frequency Diversity

B_s [MHz]	**B_c [MHz]**	**N_{fd}**	
		B_s / B_c	***Best-fit OTA***
20	10, 5, 2.5	2, 4, 8	2, 4, 8
15	10, 5, 2.5	1.5, 3, 6	2, 4, 8
10	10, 5, 2.5	1, 2, 4	1, 2, 4
5	10, 5, 2.5	0.5, 1, 2	1, 1, 2

TABLE II. Modelling Threshold Power

B_s [MHz]	**P_t [dBm]**		**Discrepancy [dB]**
	Conducted	***Best-fit OTA***	
20	-83.0	-84.0	-1.0
15	-84.3	-85.6	-1.3
10	-86.3	-87.4	-1.1
5	-88.7	-89.6	-1.1

From results it is clear that when the system bandwidth is larger than the coherence bandwidth of the environment, we will gain a lot from frequency diversity in an OFDM system. However, by increasing the system bandwidth we need more power because the threshold level increases proportional to the system bandwidth. It can be seen from Table I that in practice we get a diversity gain of 2 already when $B_s = 1.5\ B_c$. This will be investigated further. The threshold power measured for the conducted case and the best-fit threshold power in the theoretical OTA model are given in Table II. There is a discrepancy of about -1 dB. This is too large and systematic to be explained by measurement accuracy, because we have calibrated cable losses very carefully. Therefore, this also needs further investigation.

Acknowledgements

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