MAC Layer Performance of Different Channel Estimation Techniques in UTRAN LTE Downlink

David Martín-Sacristán, Jorge Cabrejas, Daniel Calabuig and Jose F. Monserrat
iTEAM, Institute of Telecommunications and Multimedia Applications
{damargan,jorcabpe,dacaso,jomondel}@iteam.upv.es

Abstract—**Long Term Evolution (LTE) is the new standard proposed by the 3GPP to evolve towards 4G. Evolved UTRAN (E-UTRAN) specifications are currently completed and research groups are studying the performance of the last Release 8. Nevertheless, these studies lack of a full modeling of the MAC layer because they either leave out retransmissions and turbo coding or assume ideal channel estimation. This paper uses an accurate LTE MAC layer simulator to perform a complete downlink LTE performance study. Results compare different channel estimation techniques showing significant difference among them, most of all regarding the robustness of the estimator against errors. Finally, LTE system performance assessment is presented employing a realistic channel estimator.**

Keywords: LTE, Channel Estimation, Link Level Simulation

I. INTRODUCTION

Mobile communications with improved transmission capabilities are important economical and social drivers generating growth. The UTRAN Long Term Evolution (LTE) is an ongoing task to build up a framework for the evolution of the 3rd Generation Partnership Project (3GPP) radio technologies towards 4G. In March 2008, 3GPP approved the specifications of the Evolved UTRAN (E-UTRAN) and research community is currently assessing the performance of the definitive Release 8 standard.

E-UTRAN is based on the Orthogonal Frequency Division Multiplexing (OFDM) technique, especially suited for combating multipath fading, offering higher spectral efficiency than previous 3GPP technologies. Accurate channel estimation in OFDM systems, and hence in LTE, allows coherent demodulation and improves system performance. Although several channel estimators have been proposed in the literature, minimum mean-square-error (MMSE) estimators, also referred to as Wiener-based estimators, have been proven to be the optimal linear estimators [1]. MMSE channel estimators use frequency-domain and time-domain correlation functions to filter a set of available estimates obtained with the help of reference signals. Nevertheless, this correlation functions are a priori unknown and must be estimated. MMSE and other simpler channel estimation schemes have been extensively studied in the literature but without considering the specific features and requirements of LTE.

Actually, several papers deal with the performance evaluation of LTE. However, up to date this assessment has been partially done because of one of these two reasons. First, some of these works only focused on the physical layer, leaving out the retransmission processes and turbo coding [2]-[4]. System level analysis need MAC layer performance information and cannot be carried out with only a physical layer characterization. Second, other papers assessing the performance of LTE radio access network assumed ideal channel estimation, which results in an optimistic estimation of LTE capacity [5]-[7].

This paper evaluates LTE link level performance considering a transmission chain fully compliant with LTE Release 8 and including realistic HARQ and turbo-decoding. Besides, a number of channel estimation methods apart from the well-known ideal have been compared, including the simplest linear method and those based on Wiener filtering. Special attention has been paid to robustness of Wiener-based channel estimation methods against failures in their assumptions, being this issue not yet assessed in the literature.

The rest of the paper is organized as follows. Section II explains the main radio interface features of LTE. The fundamentals of the implemented channel estimators are presented in section III. Simulation environment is detailed in section IV, whereas simulation results concerning robustness of estimators and global LTE performance are presented and discussed in section V. Finally the main conclusions of the assessment are drawn.

II. LTE RELEASE 8 MAIN FEATURES

3GPP LTE is the name given to the new standard developed by 3GPP to cope with the future market requirements identified by ITU. To meet these requirements, a combination of new system architecture together with an enhanced radio access technology was incorporated in the specifications.

The most important technologies included in the new radio access network are OFDM, MIMO, turbo coding and hybrid ARQ with soft combining. These technologies are shortly explained in the following paragraphs.

A. OFDM

OFDM provides a high robustness against frequency selective fading and offers spectrum flexibility which facilitates

---

a smooth evolution from already existing radio access technologies to LTE. Besides, OFDMA, the multiple access technique derived from OFDM, offers a high degree of freedom to the scheduler. OFDM resources can be represented as a time-frequency grid. Fig.1 depicts the smallest resource unit, the Resource Block (RB). In time domain, one RB corresponds with one subframe of 1ms, which is divided into 2 time slots each of 7 OFDM symbols. In the frequency domain, each RB consists of 12 subcarriers.

B. *MIMO*

One of the most important means to achieve the high data rate objectives for LTE is multiple antenna support. LTE supports one, two or four antennas in the transmitter and/or the receiver. Multiple antennas can be used in two different ways: to obtain additional transmit/receive diversity or to get spatial multiplexing by creating several parallel channels. Processes to implement transmit diversity and spatial multiplexing are specifically included in the LTE transmitter specifications [8].

C. *Turbo coding*

In order to correct bit errors, introduced by channel variations and noise, channel coding is utilized. In case of the LTE downlink shared channel (DL-SCH), the channel studied in this paper, a turbo encoder with rate 1/3 is used, followed by puncturing to increase the coding rate to the desired level.

D. *Hybrid ARQ with soft combining*

Hybrid Automatic Repeat reQuest (ARQ) with soft combining is a technique that deals with the retransmission of data in case of errors. It consists of a combination of Forward Error Correction (FEC) and ARQ. With soft combining, the erroneously received packet is stored in a buffer and later combined with the retransmission(s) to obtain a single packet that is more reliable than its constituents. In LTE full Incremental Redundancy (IR) is applied, which means that the retransmitted packets are typically not identical with the first transmission but carry complementary information.

III. CHANNEL ESTIMATION METHODS

In a mobile communication system, when the channel is fully known by the receiver the Shannon limit can be approached. However, in real systems, channel is unknown and therefore it has to be estimated. Channel estimation is a difficult task, especially in wideband mobile channels due to their frequency selectivity and time varying nature In LTE a pilot-assisted channel estimation is done, since reference signals are used by the receiver to estimate attenuation and phase change suffered by the signal in the frequency domain. Relying on channel estimates frequency domain equalization (FDE) can be performed which is a simple method to correct changes introduced by the channel in the transmitted data.

A. *Reference signals*

In LTE there exist three downlink reference signals: cell specific, Multicast Broadcast Single Frequency Network (MBSFN) and User Equipment (UE) specific reference signals [8]. Cell specific reference signals are used for the channel estimation and are transmitted on one or several antennas. Their exact position depends on the slot number within a radio frame (10 subframes), the OFDM symbol number within the slot and the type of cyclic prefix. A pseudo-random sequence is used for the reference signal generation.

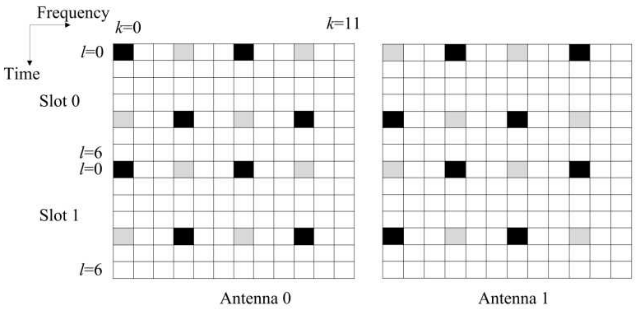

Figure 1. Mapping of the reference signals (normal cyclic prefix)

The resource elements used for the reference signal transmission in any of the antennas will not be used for any transmission on any other antennas in the same slot.

Fig. 1 illustrates the resource elements selected for the transmission of pilot symbols within one RB and considering two antennas and normal cyclic prefix.

B. *Channel estimation methods implemented*

Let $H(l,k)$ be the complex value of channel estimate in the l-th OFDMA symbol and the k-th subcarrier of a RB. In the pilot symbols, $\widetilde{H}(l,k)$ is calculated by dividing the received signal, $Y(l,k)$, by the transmitted symbols, $X(l,k)$, which are known:

$$\widetilde{H}(l,k) = Y(l,k)/X(l,k). \tag{1}$$

The remaining complex channel values are obtained from methods which are based on either polynomial or Wiener interpolation (MMSE estimator) or mixed polynomial-Wiener methods. A noticeable characteristic of mobile wireless channels is that their response variation can be assumed to be independent in time and frequency domains. Thus, the correlation of the channel frequency response at different times and frequencies can be calculated as the multiplication of the time and frequency correlation functions. This fact allows a separate time and frequency domain channel estimation instead of the more complex joint time-frequency domain estimation. For this paper, all channel estimation methods are applied first in the frequency domain and then in the time direction. Moreover, a quasi ideal method of channel estimation has been implemented.

1) *Polynomial interpolation*

The polynomial interpolation calculates channel complex symbols between reference signals through a linear or a second-order interpolation [9]. In this paper a completely linear interpolator in frequency and time domain (Linear) has been analyzed.

2) *Wiener interpolation*

In the OFDM systems the optimal linear estimator in the mean-square error sense is a 2D (both time and frequency) Wiener filter. However, the complexity of this estimator is usually too big to be implemented in practice. The use of separable filters is a common method to reduce complexity with a slight error in performance (W2x1D). The final estimation of the channel attenuations, $\widetilde{H}(l,k)$, are linear combinations of the estimates obtained for the pilot symbols.

First in the frequency domain, all estimated reference signals within one OFDM symbol are arranged in a vector p. The channel response for a given time and for all subcarriers is a vector, $\tilde{H}_f(l)$, that can be estimated as:

$$\tilde{H}_f(l) = \left(\left(R_{pp} + \sigma^2 I\right)^{-1} R\right)^H p, \qquad (2)$$

where R_{pp} is the autocorrelation matrix of the true channel response, at pilot positions, R is the cross-correlation matrix of the channel reponse and itself at pilot positions, σ^2 is the noise power, H is the hermitical operation, and I is the identity matrix. Once calculated the channel estimates for all subcarriers, in the time domain and for each subcarrier, a similar procedure is followed. In this case, p comprises four estimates taken from those symbols containing reference signals (in Fig. 1 l=0 and l=4 for Slot 0 and 1). $\tilde{H}_t(k)$ is calculated as in ec. (2). In both cases, matrix R_{pp} and R are calculated from the frequency and time correlation functions of the channel. The frequency correlation is determined by applying an FFT of the power delay profile, whereas the time correlation fits the zero order Bessel function:

$$R_h(\tau) = J_0(2\pi\tau v/\lambda), \qquad (3)$$

where v is the receiver velocity and λ is the wave length and τ represents the delay. Note that the Wiener interpolation estimator requires a previous knowledge of the frequency and time correlation and the noise power of every resource.

C. *Mixed polynomial-Wiener methods*

In this case a linear estimation in the time direction is used instead of the Wiener interpolation (WFD-LTD). Reduction in the computation complexity is remarkable although it comes at the cost of an error made in the estimation. Additionally, vector p can contain all pilot symbols in an OFDM symbol or just the nearest ones. Both methods are compared in this paper. In the latter, called Winner low complexity (Wlc), the nearest six pilot symbols are used. This method reduces complexity in exchange for a slight reduction in performance.

D. *Quasi ideal estimation*

Quasi-ideal estimation (Qideal) has been implemented for the sake of comparison with the best possible results. This method obtains the frequency channel response applying the FFT over the mean value of the channel time samples for each tap every OFDM symbol time interval. This method would be ideal if the channel remained unchanged during the whole OFDM symbol.

IV. SIMULATION ENVIRONMENT

In this assessment, a number of simulations were conducted with a LTE link level simulator fully compliant with the released specifications [8][10]. Next, the main simulator features and simulation assumptions are commented.

A. *Frame structure*

Every subframe presents the same structure. It is assumed that the first two OFDM symbols in each subframe are occupied by control channels. Besides, the transmission of reference signals wastes resources, as shown in Fig 1, what has been also considered. The remaining resources are filled with useful data.

TABLE I. MAIN SIMULATION PARAMETERS

Transmission BW	10 MHz (50 Resource Blocks)
Duplexing mode	FDD
FFT size	1024
OFDM symbols per subframe	7
CP length (samples)	72 first symbol of subframe 80 rest of symbols
Carrier frequency	2 GHz
Modulation and coding, Transport block size	QPSK 1/3, TBS=4.576 bits 16QAM 1/2, TBS=13.704 bits 64QAM3/4, TBS=30.882 bits
MIMO schemes	SIMO 1x2 (1trx, 2 rx) with MRC
Turbo-decoder	Max-log-MAP 8 iterations
HARQ with soft combining	6 processes, up to 3 retransmissions
Correlation among channels	low (uncorrelated)

B. *Channel model*

Data transmission and channel effect has been modeled in time domain. Received signal is obtained as a linear combination of the transmitted samples filtered with the channel response plus white gaussian noise.

The time-varying multipath channel is modeled in the link level simulator whose impulse response is:

$$h(t,\tau) = \sum_{l=1}^{L} h_l(t)\delta(t - t_l), \qquad (4)$$

where $h_l(t)$ and t_l are the complex value and delay of the time-varying multipath components, respectively. Concerning the values of $h(t,\tau)$, two wideband tapped delay-line profiles defined by 3GPP are employed in the simulations: Extended Pedestrian A (EPA) and Extended Vehicular A models (EVA) [11]. The first model shows lower frequency variability than the latter. Concerning time variation, it is assumed that the channel changed sample by sample (fast fading assumption), while in other papers it remains unchanged during the OFDM symbols or LTE subframes (slow fading assumption). This accurate modeling is necessary to account for inter carrier interference (ICI) produced in OFDM systems with time-varying channels. ICI can degrade the performance of FDE methods, such as those employed in this paper. Thus, it is necessary to accomplish such an exhaustive performance study.

Additionally, the correlation among channels has a severe impact on MIMO performance. In the link level simulator, matrices representing correlation among antennas are separately defined for the transmitter and the receiver according to [11]. Channel correlation matrix is obtained as the Kronecker product of the transmitter and receiver matrices. Next, this correlation is introduced in the simulations following the process described in [12].

C. *Turbodecoding, Hybrid ARQ and MIMO*

LTE specifications show clearly how data processing must be done in the transmitter. However, operation in the receiver is not specified. Thus, different receiver implementations are allowed and encouraged by 3GPP. In the link level simulator, classical solutions are adopted in the key processes at the receiver. A detailed description of the receiver features is provided in Table I. Although neither spatial multiplexing nor transmit diversity have been simulated, the conclusions of this assessment are also valid for these antenna configurations.

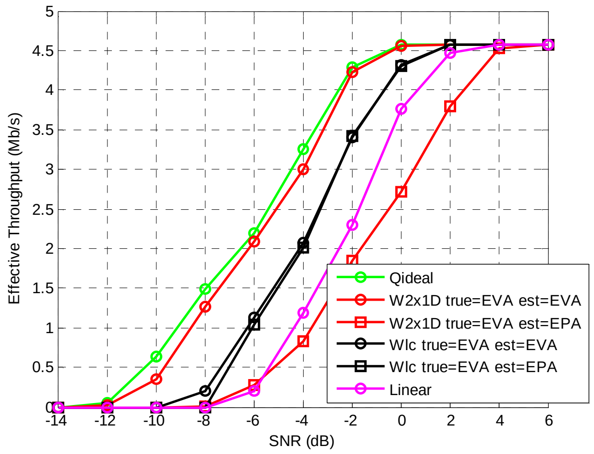

Figure 2. Effect of PDP estimation errors

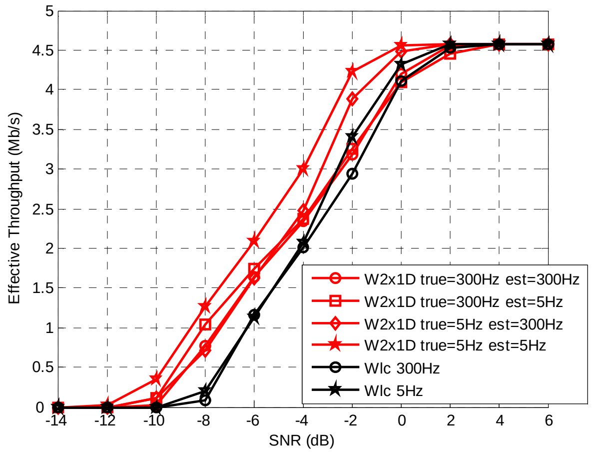

Figure 3. Effect of Doppler frequency estimation errors

D. *Transmitter impairments*

Modulation inaccuracy at the transmitter is modeled through the introduction of a 6% Error Vector Magnitude [11].

V. RESULTS AND DISCUSSION

In this section simulation results are presented and discussed. Firstly, robustness of channel estimators is evaluated, highlighting the performance of the realistic estimator (Wlc method). Secondly, LTE system performance is presented employing the realistic channel estimator.

A. *Evaluation of channel estimators robustness*

Section III presented several pilot assisted channel estimation methods. Some of those methods assume that channel statistics are known 'a priori'. Those methods performing Wiener filtering in frequency domain assume a perfect knowledge of the frequency domain correlation (or equivalently, of the channel Power Delay Profile, PDP) and the noise power (ore equivalently, of the Signal to Noise Ratio, SNR), whereas those methods performing Wiener filtering in time domain assume the knowledge of the frequency domain correlation of the channel (or equivalently, of the Doppler frequency). Unfortunately, information about the channel statistics is not available at the receiver, although it can be estimated. Next, performance of channel estimators in presence of errors in the channel statistics estimation is presented.

First, it is evaluated how frequency domain correlation estimation error affects system performance. Reference curves have been obtained based on simulations conducted with EVA and EPA PDPs without any PDP estimation error. The error is emulated using a wrong frequency correlation function in the Wiener filtering. When the true channel is EVA, EPA has been used and vice versa.

In all simulations EVA channel has been used, Doppler frequency has been fixed to 5Hz and modulation and coding was QPSK 1/3. Results in Fig. 2 show that, in absence of errors, W2x1D outperforms Wlc method. Nevertheless, PDP estimation error is highly harmful for the W2x1D but its effect on the system performance is negligible when using Wlc. For the sake of simplicity in Fig. 2 only the results for channel W2x1D and Wlc methods are presented but similar conclusion can be drawn comparing Wlc and WFD-LTD, although in absence of errors their performances are closer (1.5dB of difference). In general, Qideal presents obviously the best results while Linear method behaves the worst. If the true channel is an EPA channel, results are similar although an important difference is observed: estimation error produces a negligible effect whatever the estimation method.

According to these results, it is concluded that full Wienner interpolation is more recommended in pedestrian scenarios, whereas in vehicular scenarios, more robust estimators as Wlc are preferred. Anyway, Wlc represents in general a good tradeoff between complexity and performance.

Another assumption in Wiener estimators is the knowledge of the time correlation function or of the Doppler frequency (see ec. (3)). Simulations have been carried out over EVA channels with two possible Doppler frequencies: 5Hz and 300Hz. Since the only method using time domain correlation information is W2x1D, errors have been only introduced in this estimator making calculations with a wrong Doppler frequency. According to the obtained results, Qideal method is the best one, followed by W2x1D, WFD-LTD, Wlc and finally Linear. Therefore, the more information is used by the estimator, the better performance is achieved. For the sake of simplicity only the main results are shown in Fig.3. Wlc performance is not affected by Doppler estimation errors because not estimation is made. Conversely, W2x1D reduces its performance if the estimation is not accurate. Behavior of W2x1D is better than Wlc, but it is worth noting that perfect frequency estimation is assumed and that performance improvement comes at the cost of higher complexity.

The last assumption made by the Wiener estimators is the knowledge of the SNR. If not any error in the estimation of the SNR is taken into account, for each simulation point the estimated SNR coincides with the real one. In this last study, simulations cover the same SNR range as before but in all cases a fixed SNR estimate is assumed. Three different values are used as constant estimations, representing low, medium and high SNR values. Since LTE SNR operating range is from -14dB to 26dB, low SNR value is defined as -7.33dB, medium SNR as 6dB and high SNR as 19.33dB.

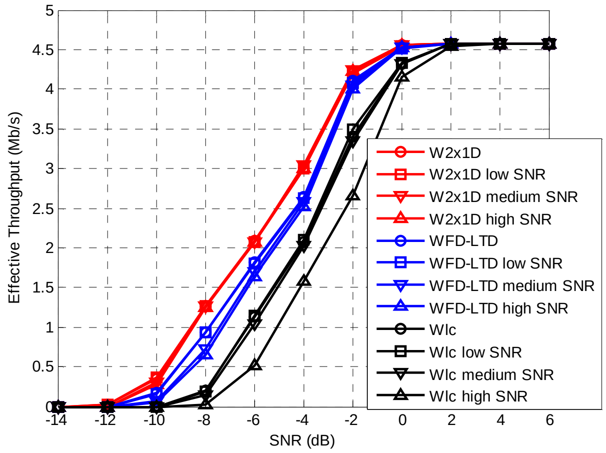

Figure 4. Effect of SNR estimation errors

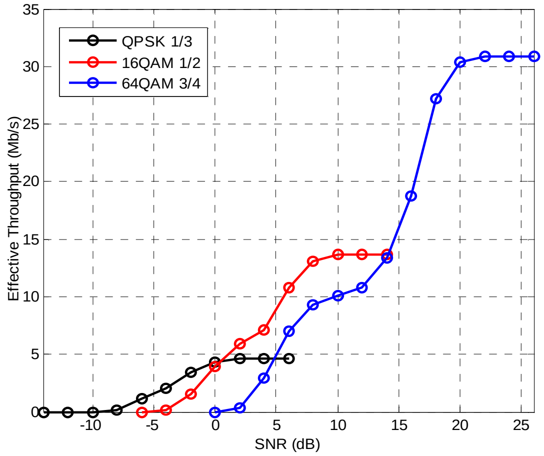

Figure 5. LTE throughput for a EVA channel with Doppler frequency 5Hz

Fig. 4 shows the performance of W2x1D, WFD-LTD and Wlc estimator, i.e., those using SNR estimation. SNR estimation error produces a negligible effect on W2x1D performance, and the effect is small for WFD-LTD. Conversely, if the Wlc estimation is used, the high SNR assumption has an important impact on system performance. Therefore, a fixed medium SNR assumption seems to be a practical rule for maximizing Wiener-based estimators.

B. *LTE performance evaluation*

In order to reduce receiver complexity and memory requirements and given that previous results demonstrate its robustness, the realistic Wlc estimator is a firm candidate to be implemented in real LTE equipments. Next, a more complete LTE performance evaluation is depicted in Fig. 5 where the full LTE SNR dynamic margin is covered using QPSK, 16QAM and 64QAM modulations. Note that the maximum system throughput is around 65Mb/s because spatial multiplexing was not taken into account. If that was the case, then this throughput could be increased theoretically up to 130Mb/s for a pedestrian scenario.

VI. CONCLUSIONS

In this paper a complete LTE Release 8 link level simulator has been presented together with several performance results. Specifically, some channel estimators of different level of complexity have been compared, assessing their behavior in realistic scenarios where the receiver lacks a perfect knowledge of channel statistics. It has been demonstrated that the performance of Wiener-based estimators can be hardly affected by failures on the frequency and time correlation function estimation. These failures and the need of reducing the receiver complexity have motivated the design of a simpler and more robust channel estimator. This estimator uses only the six nearest pilot symbols to apply a Wiener filter in frequency and, afterwards, a simple linear interpolation. The good performance of this estimator and, most of all, the fact that it withstands failures in frequency estimation, support the relevance of this proposal.

ACKNOWLEDGMENT

Part of this work has been performed in the framework of the CELTIC project CP5-026 WINNER+. This work was supported by the Research Program of the Generalitat Valenciana No. GVPRE/2008/247.

REFERENCES

[1] Ye Li, L. J. Cimini and N. R. Sollenberger, " Robust Channel Estimation for OFDM Systems with Rapid Dispersive Fading Channels," IEEE Transactions on Communications, vol. 46, no. 7, pp. 902-915, July 1998.

[2] J.J Sanchez, D. Morales-Jimenez, G. Gomez and J.T. Enbrambasaguas, "Physical Layer Performance of Long Term Evolution Cellular Technology," in proc. 16th IST Mobile and Wireless Communications Summit, pp. 1-5, July 2007.

[3] A. Osman and A. Mohammed, "Performance Evaluation of a Low-Complexity OFDM UMTS-LTE System," in proc IEEE Vehicular Technology Conference Spring, pp. 2142-2146, May 2008.

[4] K. Manolakis, A. Ibing and V. Jungnickel, "Performance evaluation of a 3GPP LTE terminal receiver," in proc. 14th European Wireless Conference, pp. 1-5, June 2008.

[5] C. Spiegel, J. Berkmann, Zijian Bai, T. Scholand and C Drewes, "MIMO Schemes in UTRA LTE, A Comparison," in proc. IEEE Vehicular Technology Conference Spring, pp. 2228-2232, May 2008.

[6] Na Wei et al., "Baseline E-UTRA Downlink Spectral Efficiency Evaluation," in proc. IEEE 64th Vehicular Technology Conference Fall, pp. 1-5, Sept. 2006.

[7] P. Mogensen et al., "LTE Capacity Compared to the Shannon Bound," in proc. IEEE 65th Vehicular Technology Conference Spring, pp. 1234-1238, April 2007.

[8] 3GPP TS 36.211 v.8.3.0, “Physical Channels and Modulation,” 2008.

[9] S. Sampei and T. Sunaga, ”Rayleigh fading compensation for QAM in land mobile radio communications,” IEEE Transactions on Vehicular Technology, vol.42, no.2, pp.137-147, May 1993.

[10] 3GPP TS 36.212 v.8.3.0, “Multiplexing and Channel Coding,” 2008.

[11] 3GPP TR 36.803 v.1.1.0, “UE radio transmission and reception,” 2008.

[12] 3GPP R4-070141, “Radio propagation modelling for E-UTRA performance requirement definition, ” Nokia, February 2007.