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IMPROVING THOUGHPUT USING CHANNEL QUALITY INDICATOR IN LTE TECHNOLOGY

This article focusing on the downlink performance of LTE physical layer on MIMO antenna with Channel Quality Indicator (CQI) Feedback. The other parameter used in this article is Pedestrian A (PedA) channel and Pedestrian B (PedB) channel models for several transmission modes which is Transmit Diversity, Open Loop Spatial Multiplexing and Closed Loop Spatial Multiplexing. Multiple Input Multiple Output (MIMO) systems form an essential part of LTE in order to achieve the ambitious requirements for throughput and spectral efficiency [1]. Adaptive transmission schemes that adjust transmission parameters with respect to time-varying channels enable robust and spectrally efficient communications. In this paper we dealing how to develop the CQI by using feedback for the data transmitting, Open Loop Spatial Multiplexing and Closed Loop Spatial Multiplexing by using multiple antennas in the transmitter and receiver (MIMO).
Key words: *LTE, CQI, throughput improving.*

Introduction

The LTE base stations are called Evolved NodeBs (eNodeBs) which is the main component of the LTE radio access network (RAN) architecture. The mobile terminals are commonly referred to as user equipments (UEs). The functionalities of eNodeB and UEs are divided into different protocol layers. The Figure 1 shows a simplified diagram showing the different layers and the data flow for downlink transmission [1, 2].

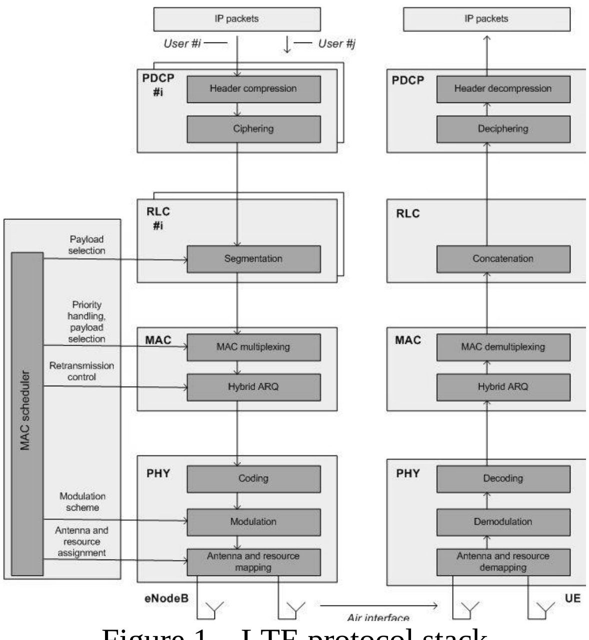


Figure 1 – LTE protocol stack

The IP packets enter the protocol stack at Packet Data Convergence Protocol (PDCP) layer and flows through the protocol stack down to the Physical layer before entering the radio interface.

In cellular communication systems, the quality of the signal received by a UE depends on the channel quality from the serving cell, the level of interference from other cells, and the noise level. To optimize system capacity and coverage for a given transmission power, the transmitter should try to match the information data rate for each user to the variations in the received signal [3]. This is commonly referred to as link adaptation and is typically based on Adaptive Modulation and Coding (AMC).

For the downlink data transmissions in LTE, the eNodeB typically selects the Modulation and Coding Scheme (MCS) depending on the Channel Quality Indicator (CQI) feedback transmitted by the UE in the uplink. In general, in response to the CQI feedback the eNodeB can select between QPSK, 16-QAM and 64-QAM schemes with a wide range of code rates. For the LTE uplink transmissions, the link adaptation process is similar to that for the downlink, with the selection of MCS also being under the control of the eNodeB. But the eNodeB can directly make its own estimate of the supportable uplink data rate by channel sounding. An identical channel coding structure is used for the uplink, while the modulation scheme may be selected between QPSK and 16QAM. The 64QAM is optional for the LTE UL. A simple method by which a UE can choose an appropriate CQI value could be based on a set of Block Error Rate (BLER) thresholds. The UE would report the CQI value corresponding to the MCS that ensures BLER $\leq$ 10% based on the measured received signal quality. The list of modulation schemes and code rates with CQI values supported by 3GPP LTE standards is shown in Table 1.

Table 1

CQI table for modulation schemes

CQI index	Modulation	Approximate code rate	Efficiency(information bits per symbol)
0	No transmission	—	—
1	QPSK	0,076	0,1523
2	QPSK	0,120	0,2344
3	QPSK	0,190	0,3770
4	QPSK	0,300	0,6016
5	QPSK	0,440	0,8770
6	QPSK	0,590	1,1758
7	QPSK	0,370	1,4766
8	16QAM	0,480	1,9141
9	16QAM	0,600	2,4063
10	16QAM	0,450	2,7305
11	64QAM	0,550	3,3223
12	64QAM	0,650	3,9023
13	64QAM	0,750	4,5234
14	64QAM	0,850	5,1152
15	64QAM	0,930	5,5547

Main part

In LTE, MIMO technologies have been widely used to improve downlink peak rate, cell coverage, as well as average cell throughput. To achieve this diverse set of objectives, LTE adopted various MIMO technologies including transmit diversity, single user (SU)-MIMO, multiuser (MU)-MIMO, closed-loop rank-1 precoding, and dedicated beamforming. The transmit diversity scheme is specified for the configuration with two or four transmit antennas in the downlink, and with two transmit antennas in the uplink. The closed-loop rank-1 precoding scheme is used to improve data coverage utilizing SU-MIMO technology based on the cell-specific common reference signal while introducing a control signal message that has lower overhead. The dedicated beamforming scheme is used for data coverage extension when the data demodulation based on dedicated reference signal is supported by the UE [4].

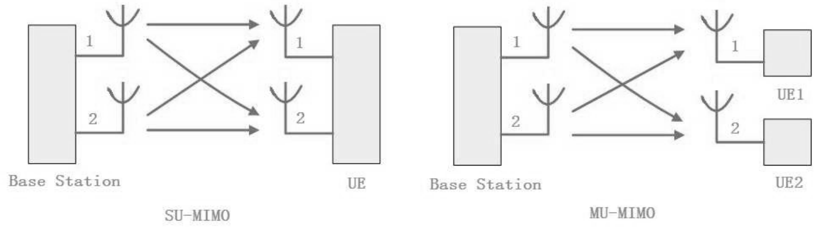


Figure 2 – SU-MIMO and MU-MIMO

a) *Transmit Diversity*

SFBC with two transmit antennas on downlink:

$$\begin{matrix} Antenna\_0 \\ Antenna\_1 \end{matrix} \overset{\xrightarrow{Subcarrier}}{\begin{bmatrix} S_0 & S_1 \\ -S_1^* & S_0^* \end{bmatrix}} \tag{1}$$

SFBC + FSTD with four transmit antennas on downlink:

$$\begin{matrix} Antenna\_0 \\ Antenna\_1 \\ Antenna\_2 \\ Antenna\_3 \end{matrix} \overset{\xrightarrow{Subcarrier}}{\begin{bmatrix} S_0 & S_1 & 0 & 0 \\ 0 & 0 & S_2 & S_3 \\ -s_1^* & s_0^* & 0 & 0 \\ 0 & 0 & -s_3^* & s_2^* \end{bmatrix}} \tag{2}$$

Modified SFBC + FSTD for PHICH with four transmit antennas on downlink:

$$Type\_1: \begin{matrix} Antenna\_0 \\ Antenna\_1 \\ Antenna\_2 \\ Antenna\_3 \end{matrix} \underbrace{\overset{\xrightarrow{Subcarrier}}{\begin{bmatrix} S_0 & S_1 & S_2 & S_3 \\ 0 & 0 & 0 & 0 \\ -S_1^* & S_0^* & -S_3^* & -S_2^* \\ 0 & 0 & 0 & 0 \end{bmatrix}}}_{1^{st}\ repetition} \cdot \underbrace{\begin{bmatrix} 0 & 0 & 0 & 0 \\ S_0 & S_1 & S_2 & S_3 \\ 0 & 0 & 0 & 0 \\ -S_1^* & S_0^* & -S_3^* & -S_2^* \end{bmatrix}}_{2^{nd}\ repetition} \cdot \underbrace{\begin{bmatrix} S_0 & S_1 & S_2 & S_3 \\ 0 & 0 & 0 & 0 \\ -S_1^* & S_0^* & -S_3^* & -S_2^* \\ 0 & 0 & 0 & 0 \end{bmatrix}}_{3^{rd}\ repetition}$$

$$Type\_2: \begin{matrix} Antenna\_0 \\ Antenna\_1 \\ Antenna\_2 \\ Antenna\_3 \end{matrix} \underbrace{\overset{\xrightarrow{Subcarrier}}{\begin{bmatrix} 0 & 0 & 0 & 0 \\ S_0 & S_1 & S_2 & S_3 \\ 0 & 0 & 0 & 0 \\ -S_1^* & S_0^* & -S_3^* & -S_2^* \end{bmatrix}}}_{1^{st}\ repetition} \cdot \underbrace{\begin{bmatrix} S_0 & S_1 & S_2 & S_3 \\ 0 & 0 & 0 & 0 \\ -S_1^* & S_0^* & -S_3^* & -S_2^* \\ 0 & 0 & 0 & 0 \end{bmatrix}}_{2^{nd}\ repetition} \cdot \underbrace{\begin{bmatrix} 0 & 0 & 0 & 0 \\ S_0 & S_1 & S_2 & S_3 \\ 0 & 0 & 0 & 0 \\ -S_1^* & S_0^* & -S_3^* & -S_2^* \end{bmatrix}}_{3^{rd}\ repetition} \tag{3}$$

Once the number of transmit antennas at eNodeB is detected, a specific transmit diversity scheme applicable to the other physical downlink channels is determined. Transmit diversity schemes defined for LTE downlinks are illustrated in (1) – (3). The space-frequency block code (SFBC) as shown in (1) is used if the eNodeB has two transmit antennas. For the eNodeB with four transmit antennas, a combination of the SFBC and the frequency switched transmit diversity (FSTD) as shown in (2) is used to provide robustness against the correlation between channels from different transmit antennas and for easier UE receiver implementation. The transmit diversity scheme shown in (2) can be used for all downlink channels other than PHICH. The transmit diversity scheme used for PHICH is shown in (3). When there are multiple PHICHs transmitted, using type 1 or type 2 alternatively for different PHICHs would be helpful to keep uniform power distribution over eNodeB transmit antennas [4].

b) *Open Loop Spatial Multiplexing*

The eNodeB sends the scheduled UE the information about what precoding matrix is used as a part of downlink control information, using a three-bit information field for two transmit antennas and a six-bit information field for four transmit antennas. This information field is denoted transmit precoding matrix indication (TPMI). To support frequency-selective precoding without excessive downlink signaling overhead, the TPMI can also indicate that the precoding matrices reported in the most recent PMI report from the scheduled UE are used for their corresponding frequency resources. Use of the transmit diversity is indicated by TPMI. The open-loop spatial multiplexing may be operated when reliable PMI feedback is not available at the eNodeB, for example, when the UE speed is not slow enough or when the feedback overhead on uplink is too high. The open-loop spatial multiplexing with M layers and N transmit antennas (*N*≥*M*) is illustrated in Figure 3. The feedback consists of the RI and the CQI in open-loop spatial multiplexing. In contrast to the closed-loop spatial multiplexing, the eNodeB only determines the transmission rank and a fixed set of precoding matrices are applied cyclically across all the scheduled subcarriers in the frequency domain [4].

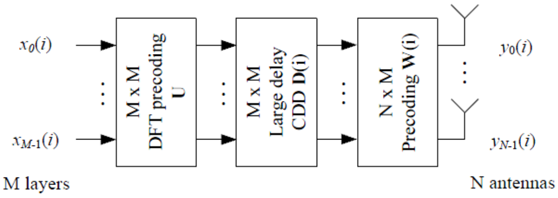


Figure 3 – Open-loop spatial multiplexing with N antennas and M layers

c) *Closed Loop Spatial Multiplexing*

The base station (also known as eNodeB) applies the spatial domain precoding on the transmitted signal taking into account the precoding matrix indicator (PMI) reported by the UE so that the transmitted signal matches with the spatial channel experienced by the UE. The closed-loop spatial multiplexing with *M* layers and *N* transmit antennas $(N \geq M)$ is illustrated in Figure 4. To support the closed-loop spatial multiplexing in the downlink, the UE needs to feedback the rank indicator (RI), the PMI, and the channel quality indicator (CQI) in the uplink. The CQI feedback indicates a combination of modulation scheme and channel coding rate that the eNodeB should use to ensure that the block error probability experienced at the UE will not exceed 10% [4].

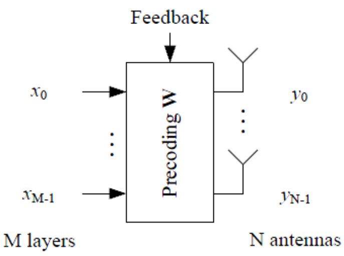


Figure 4 – Closed-loop spatial multiplexing with N antennas and M layers

In our article, both Pedestrian A and Pedestrian B channel models was used. The mobile speed considered to be 3km/h in each of these cases .The number of taps incase of Pedestrian A model is 4 while Pedestrian B has 6 taps. The average powers and relative delays for the taps of multipath channels based on ITU recommendations are given in table 2.

Table 2

ITU Pedestrian Channel Model

Tap	Channel A		Channel B	
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)
1	0	0	0	0
2	110	-9,7	200	-0,9
3	190	-19,2	800	-4,9
4	410	-22,8	1200	-8,0
5	—	—	2300	-7,8
6	—	—	3700	-23,9

In LTE downlink, the quality of channel is measured in the UE and sent to the eNodeB in the form of so-called CQIs (Channel Quality Indicator). The quality of the measured signal depends not only on the channel, the noise and the interference level but also on the quality of the receiver, e.g. on the noise figure of the analog front end and performance of the digital signal processing modules. That means a receiver with better front end or more powerfull signal processing algorithms delivers a higher CQI. The signal quality measurements are done using reference symbols. In Figure 5 the whole signal generation chain of the LTEs physical layer with Turbo coding and modulation modules can be seen, which are parts of the link adaptation system.

In the LTE physical layer, resources are managed with the so-called RM Modules (Resource Management), which assign incoming data blocks to resource blocks. One resource block consists of 12 sub-carriers and one time slot. The resource management in LTE can be seen in Figure 6 CQI values are used also to select the optimum resource block i.e. the optimum sub-carrier and the optimum time slot.

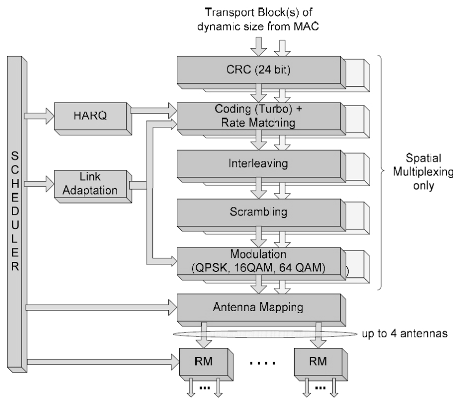


Figure 5 – Signal generation chain in LTE

There are two kinds of CQI reporting: periodic and aperiodic, where the PUCCH (Physical Uplink Control Channel) is used for periodic CQI reporting only and PUSCH (Physical Uplink Shared Channel) for aperiodic CQI reporting.

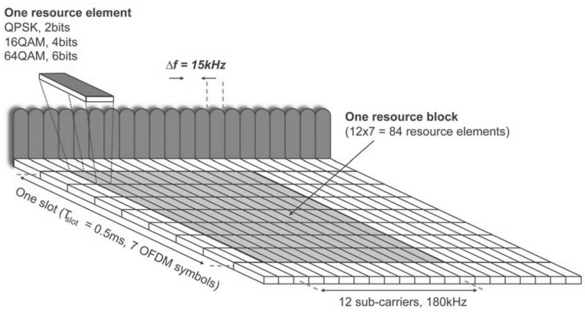


Figure 6 – Two dimensional resource management in LTE

Periodic CQIs are reported by the UE in periodic time intervals. If the eNodeB wishes channel quality information at a specific time, aperiodic CQIs are triggered. In order to define the frequency granularity of the CQI, the whole system bandwidth is divided into N sub-bands, each consisting of k contiguous Physical Resource Blocks (PRBs). The number of sub-bands is given by $N = N_{RB}^{DL}/k$ and determines the frequency granularity of the CQI reporting, where N_{RB}^{DL} is the number of resource blocks (RB) in the whole system bandwidth (DL stands for Downlink).

a) Periodic CQI reporting

The periodic reporting of the CQIs is done over the PUCCH. Periodic CQI can be either wideband or UE-selected sub-band feedback for all downlink transmission modes. The type of CQI is decided by the *e*NodeB. In the wideband mode, one CQI value is measured in the whole system bandwidth and sent to the eNodeB. In the UE-selected sub-band feedback the total number of sub-bands *N* in the whole system bandwidth is divided into *j* fractions called bandwidth parts. In each bandwidth part a particular sub-band is selected and the measured channel quality in this sub-band with its position in the bandwidth part is sent to *e*NodeB. In Table 3 sub-band size (*k*) and bandwidth parts (*J*) versus downlink system bandwidth N_{RB}^{DL} can be seen.

Normally periodic CQIs are used but if eNodeB needs channel quality information at times rather than time raster of the periodic CQI, it can also wish aperiodic transmission of the CQIs by the UE. Losses of synchronization or handover situations are also cases, where aperiodic CQIs are used. Aperiodic CQI reporting is done over the PUSCH and requested by the *e*NodeB by setting a CQI request bit on the Physical Downlink Control Channel (PDCCH).

The type of CQI is set by the eNodeB and can be one of the following modes:

1. Wideband feedback: in this mode as in the periodic reporting, the UE reports one CQI value for the whole system bandwidth.

2. eNodeB-configured sub-band feedback: there are two kinds of CQI reported in this mode, one for the whole system bandwidth and one for the sub-bands. In the calculation of sub-band CQIs, it is assumed that transmission takes place only in the relevant sub-band.

3. UE-selected sub-band feedback: as in the eNodeB-configured mode, two types of CQIs are used, one wideband CQI value for the whole system bandwidth and one for reporting the average measured CQI in *M* selected sub-bands each of the size *k*. The UE decides which sub-bands are selected. The UE sends also the position of the *M* selected sub-bands.

Table 3

Number of resource blocks in the whole system bandwidth (N_{RB}^{DL}), number of resource blocks in a sub-band (*k*) and bandwidth parts (*J*) in periodic CQI using UE-selected sub-bands

System Bandwidth N_{RB}^{DL}	Sub-band Size *k* (RBs)	Bandwidth Parts (*J*)
6-7	NA	NA
8-10	4	1
11-26	4	2
27-63	6	3
64-110	8	4

Number of resource blocks in the whole system bandwidth, number of resource blocks in a sub-band (*k*) and number of selected sub-bands (*M*) by the UE for the UE selected sub-band feedback CQI reports can be seen in Table 4.

Table 4

Parameters of the aperiodic CQI report for UE-selected sub-bands feedback

System Bandwidth (RBs)	Sub-band Size *k* (RBs)	Number of preferred sub-bands (*M*)
6-7	(Wideband CQI Only)	(Wideband CQI Only)
8-10	2	1
11-26	2	3
27-63	3	5
64-110	4	6

The throughput results are compared to the system capacity C of an AWGN channel calculated according to Shannon capacity:

$$C = FB\log_2(1+SNR) \tag{4}$$

Here, SNR is the Signal to Noise Ratio, B the bandwidth occupied by the data subcarriers as shown below, and F a correction factor. The bandwidth B is calculated as

$$B = \frac{N_{SC} \cdot N_S \cdot N_{rb}}{T_{sub}},$$

where N_{SC} = 12 is the number of subcarriers in one RB, N_S is the number of OFDM symbols in one sub-frame (usually equal to fourteen when the normal Cyclic Prefix (CP) is set), N_{rb} is the number of RBs that fit into the selected system bandwidth (for example 6 RBs within a 1.4MHz system bandwidth), and T_{sub} is the duration of one sub-frame equal to 1ms.

The transmission of an OFDM signal requires also the transmission of a CP to avoid inter-symbol interference and the reference symbols for channel estimation. Therefore, the well-known Shannon formula is adjusted in (4) by the factor F . This factor F as shown below, accounts thus for the inherent system losses and is calculated as

$$F = \underbrace{\frac{T_{frame} - T_{CP}}{T_{frame}}}_{CPloss} \cdot \underbrace{\frac{N_{SC} \cdot N_S/2 - 4}{N_{SC} \cdot N_S/2}}_{\text{reference symbol loss}},$$

where T_{frame} is the fixed frame duration equal to 10 ms and T_{CP} is the total CP time of all OFDM symbols within one frame [5].

Simulation Results

In our article we Simulate the BLER as shown in Figure 7, for example at BLER of 10^{-2}, PedB CQI 8 Transmit Diversity required SNR of 6 dB while PedA CQI 11 Closed Loop Spatial Multiplexing required SNR of 28 dB. It indicates that PedA CQI 11 Closed Loop Spatial Multiplexing required the highest SNR to achieve the same level of BLER of PedB CQI 8 Transmit Diversity. It can be conclude that, PedA CQI 8 required the less SNR than others and PedA CQI 11 Closed Loop Spatial Multiplexing required the highest SNR than other for BLER of (10^-2). Another example, with respect to SNR, at SNR of 8dB, PedB CQI 8 Transmit Diversity gave a lower BLER compared to others.

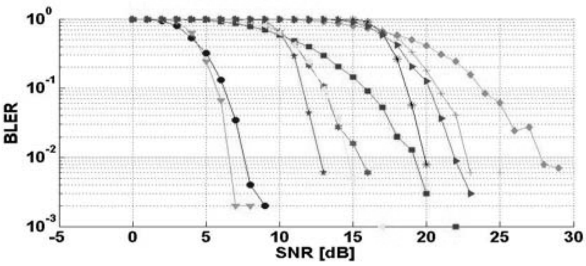
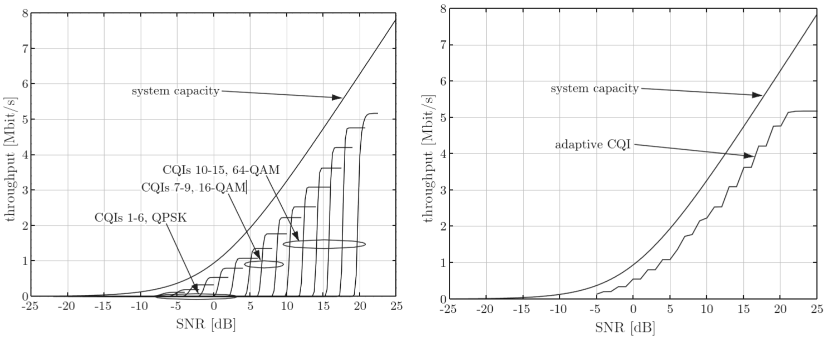


Figure 7 – Throughput for comparison CQI 8 and CQI 11 on Transmit Diversity, Open Loop Spatial Multiplexing, Closed Loop Spatial Multiplexing with PedA and PedB

In Figure 8, a, we Simulation the throughput curves are plotted for every CQI value. Here, HARQ is switched off and no retransmissions are performed. The SNR gap from the achievable capacity is around 2 dB for most of the CQI values. The distance from the capacity curve is increasing with increasing CQI value which is explained by the non-Gaussian QAM constellations. The throughput with AMC is depicted in Figure 8, b for one user that obtains all the available resources. Note that the performance in Figures 8, a and 8, b looks very similar, although a maximum number of three retransmissions are allowed for the simulation in Figure 8, b. The reason for the similar performance is that in an AWGN channel the switching between the modulation and coding schemes can be done perfectly and hardly any retransmissions are required (although allowed if necessary).



a b

Figure 8 – Throughput performance: without HARQ over an AWGN for individual CQIs (a); with AMC and HARQ over an AWGN (b)

In Figure 9, we Simulation the data throughput of SISO, 2x1 transmit diversity (TxD), 4x2 transmit diversity, and 4x2 Open Loop Spatial Multiplexing (OLSM) is compared when transmitting over an uncorrelated ITU Pedestrian B channel. In this simulation we set the CQI to a fixed value of seven and the maximum number of HARQ retransmissions to three. The maximum throughput values achieved by the different MIMO schemes in Figure 9 depends on the number of transmit antennas and on the number of data streams (layers). If more transmit antennas are utilized for the transmission, more pilot symbols are inserted in the OFDM frame and thus lower maximum throughput can be achieved. In the case of OLSM, two spatially separated data streams are transmitted thus leading to twice the maximum throughput of the 4x2 TxD system. Note that the results in Figure 9 were obtained without channel adaptive precoding. An additional gain of the TxD schemes can therefore be expected when the PCI is utilized.

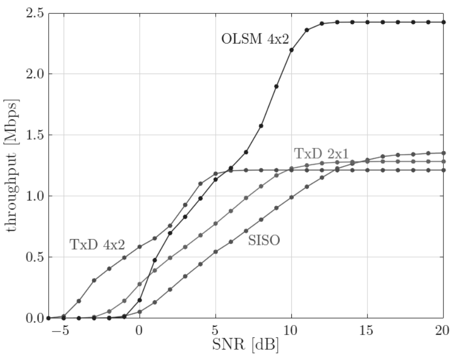


Figure 9 – Throughput in the OLSM 4x2, the TxD 4x2, the TxD 2x1, and the SISO system over an uncorrelated ITU Ped B channel

Conclusions

The data rate is determined by the chosen MCS and the error rate depends on the MCS and the prevailing channel quality. A higher order modulation scheme such as 64QAM or 16QAM would allow more bits per modulation symbol allowing a higher data rate and bandwidth efficiency, while at the same time requiring better SINR at the receiver for error-free demodulation. Similarly a high code rate will reduce redundancy at the cost of lower error correction capability. The feedback delay and the time variability of the channel are factors that need to be considered both in the design of a rate adaptive system and in the choice of MIMO and selection of the best scheme according to the channel conditions and feedback delay is determinant for receivers that are able to use different MIMO modes. For BLER, CQI 8 have the lowest BLER than CQI 11. CQI 11 required more higher

SNR to achieve the same BLER level of CQI 8. So that, even though the 64QAM have better throughput, but it need more higher SNR and produce higher BLER. For channel model, both PedA and PedB produce the same peak throughput. But, they have differences in SNR requirements and BLER produce. PedB seems have better performance than PedA. PedB required least SNR to achieve the peak throughput compared to PedA. PedB also produce the lower BLER than PedA. PedA required more higher SNR to achieve the same BLER level as PedB.

References

1. Rohde & Schwarz, (2010), "UMTS Long Term Evolution (LTE). Technologies Introduction", available at: http://pwrk.cachefly.net/rs/fileadmin/customer/downloads/PDF/ UMTS_Eng.pdf (Accessed March, 25, 2014).
2. Dahlman, E., Parkvall, S., Sköld, J., and Beming, P., (2008), *3G Evolution: HSPA and LTE for Mobile Broadband*, 2nd ed., Elsevier, Oxford, UK.
3. Sesia, Stefania, Toufik, Issam, and Baker, Matthew, (2011), *LTE – The UMTS Long Term Evolution: From Theory to Practice*, John Wiley and Sons, The Atrium, Southern Gate, Chichester, West Sussex, UK.
4. Lee, Juho, Han, Jin-Kyu, and Zhang, Jianzhong (Charlie), (2009), "MIMO Technologies in 3GPP LTE and LTE-Advanced", EURASIP Journal on Wireless Communications and Networking, Volume 2009, pp. 1-10.
5. Mehlführer, C., Caban, S., Wrulich, M., and Rupp, M., (2008), "Joint throughput optimized CQI and precoding weight calculation for MIMO HSDPA", 2008 42nd Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA, 26-29 Oct., 2008, pp. 1320-1325.

Список використаної літератури

1. UMTS Long Term Evolution (LTE). Technologies Introduction [Електронний ресурс] / Rohde & Schwarz. –2010 р. Доступно з: http://pwrk.cachefly.net/rs/fileadmin/customer/ downloads/PDF/UMTS_Eng.pdf.
2. Dahlman E. 3G Evolution: HSPA and LTE for Mobile Broadband: монографія / Dahlman E., Parkvall S., Sköld J., Beming P. – Oxford, UK, 2008. – 448 с.
3. Sesia S. The UMTS Long Term Evolution: From Theory to Practice: монографія / Sesia Stefania, Toufik Issam, Baker Matthew. – West Sussex, UK, 2011. – 752 с.
4. Lee Juho. MIMO Technologies in 3GPP LTE and LTE-Advanced / Lee Juho, Han Jin-Kyu, Zhang Jianzhong (Charlie) // EURASIP Journal on Wireless Communications and Networking, Volume 2009. – С. 1-10.
5. Mehlführer, C. Joint throughput optimized CQI and precoding weight calculation for MIMO HSDPA / Mehlführer C., Caban S., Wrulich M., Rupp M. / 2008 42nd Asilomar Conference on Signals, Systems and Computers: матеріали конференції, Pacific Grove, CA, 26-29 Oct., 2008, С. 1320-1325.

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Підвищення пропускної здатності системи LTE з використанням показника якості каналу. *У статті запропоновано дослідження ефективності використання ресурсів системи LTE у процесі розподілу пропускної здатності між абонентами. На основі використання показника якості каналу (ПЯК) досягнуто більш плавне завантаження системної ємності. Досліджено вплив систем модуляції та кодування, а також антенних*

систем на пропускну здатність системи LTE. Результати дослідження підтверджено шляхом моделювання.
Ключові слова: *LTE, ПЯК, підвищення пропускної здатності.*

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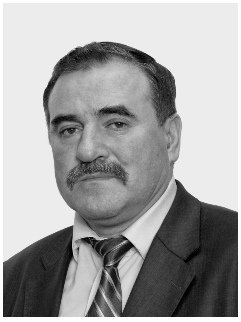
Повышение пропускной способности в системе LTE с использованием показателя качества канала. *В статье исследована производительность нисходящей линии физического уровня LTE с MIMO антеннами и обратной связью в виде индикатора качества канала (ИКК). В статье использованы модели канала пешеходов A и B для нескольких режимов передачи, которыми являются разнесение при передаче, пространственного мультиплексирования с открытой петлей и пространственного мультиплексирования с замкнутой петлей. MIMO системы являются существенной частью LTE для достижения требований к пропускной способности и спектральной эффективности. Адаптивные схемы передачи, которые регулируют параметры передачи по отношению к нестационарным каналам, обеспечивают надежные и спектрально эффективные коммуникации. В этой статье исследован ИКК с использованием для передачи данных обратной связи; рассмотрены системы пространственного мультиплексирования с открытой петлей и замкнутой петлей с использованием MIMO.*
Ключевые слова: *LTE, ИКК, повышение пропускной способности.*



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