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Performance Analysis of LTE Downlink Transmission

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Abstract: Mobile networks have triggered advances and changes in telecommunications world over the last two decades. In addition to the voice communication, the data usage has grown day by day. The recent increase of the data usage in mobile networks and appearance of new applications such as online gaming, mobile TV, streaming contents have greatly motivated the 3rd Generation Partnership Project (3GPP) to work on the Long Term Evolution (LTE). 3GPP LTE is the evolution of the Universal Mobile Telecommunications System (UMTS) which will make possible to deliver high quality multimedia services according to the users' expectations. LTE offers many significant improvements over previous technologies such as UMTS and High-speed packet access (HSPA). Higher downlink and uplink speeds, lower latency and simpler network architecture are among the new and important features that are provided in LTE. In this paper, the simulations for the performance analysis of LTE are presented. The effects of different parameters and other factors are investigated. The performance analysis results are shown in terms of Block Error Ratio (BLER) and Throughput versus Signal-to-Noise Ratio (SNR).

Keywords: LTE, BLER, SNR, downlink, throughput

1. 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 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.

2. BACKGROUND KNOWLEDGE

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.

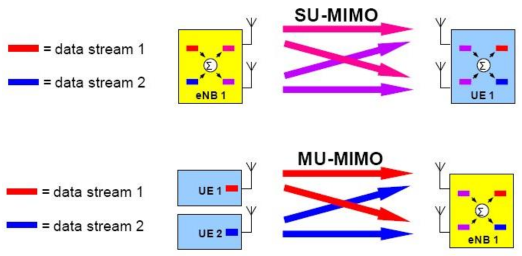

Figure. 1 SU-MIMO and MU-MIMO

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].

2.1 Transmit Diversity

SFBC with two transmit antennas on downlink:

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

SFBC + FSTD with 4 transmit antennas on downlink:

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

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

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

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

(Subcarrier →)

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. The space-frequency block code (SFBC) as indicated in the first equation 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 in the second equation 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 second equation can be used for all downlink channels other than PHICH. The transmit diversity scheme used for PHICH is in the third equation. 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].

2.2 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 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].

2.3 Channel Quality

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 powerful signal processing algorithms delivers a higher CQI. The signal quality measurements are done using reference symbols.

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 Fig. 2 CQI values are used also to select the optimum resource block i.e. the optimum sub-carrier and the optimum time slot.

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.

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).

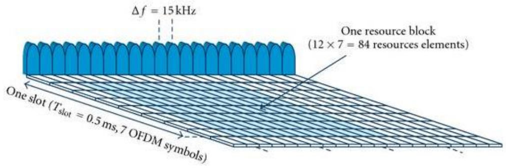

Figure. 2 Two Dimensional Resource Management in LTE

2.4 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 eNodeB. 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 subbands 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 eNodeB. In Table 1 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 eNodeB 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.

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

$$C = FB\log_2(1+SNR)$$

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, S N 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 intersymbol interference and the reference symbols for channel estimation. Therefore, the well-known Shannon formula is adjusted in $C = FB\log_2(1+SNR)$ 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].

3. PERFORMANCE ANALYSIS AND SIMULATION RESULTS

In LTE, one of the main features that provide transmission robustness is hybrid-ARQ (HARQ), which in LTE provides physical layer retransmission using incremental redundancy and soft combining. A transmission scheme based on H-ARQ combines detection and Forward Error Correction (FEC) plus a retransmission of the erroneous packet. LTE additionally uses soft combining, in which a given received packet is combined with the previously received packets and the resulting more powerful FEC code is then decoded. Hence, for each H-ARQ retransmission that the LTE system can employ, an improvement of the Block Error Rate (BLER) or throughput is expected.

From Figure 3 and Figure 4, the LTE simulations for the HARQ evaluation process were performed for a single-user scenario corresponding to the simulation parameters shown on figures' titles in 5MHz BW and when there is no HARQ, while Figure 5 and Figure 6 with the same parameters when there are 3 retransmissions. Even there is no much difference on high SNR values, the difference on the throughput and BLER can easily be observed that in lower SNR values such as -5 to 5 dB, there is significant improvement thanks to HARQ.

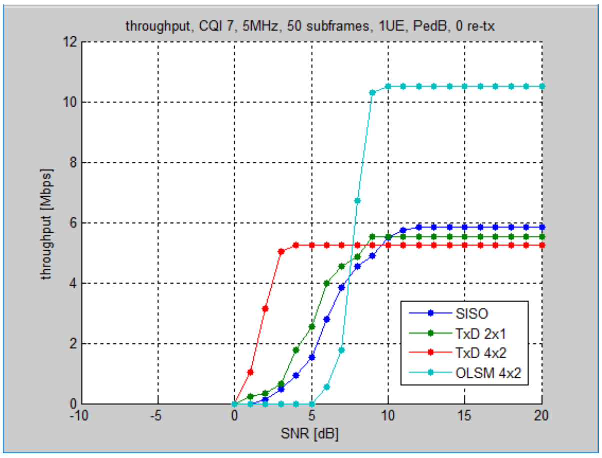

Figure. 3 Throughput Performance of the SISO, MIMO and OLSM in 5MHz with No HARQ

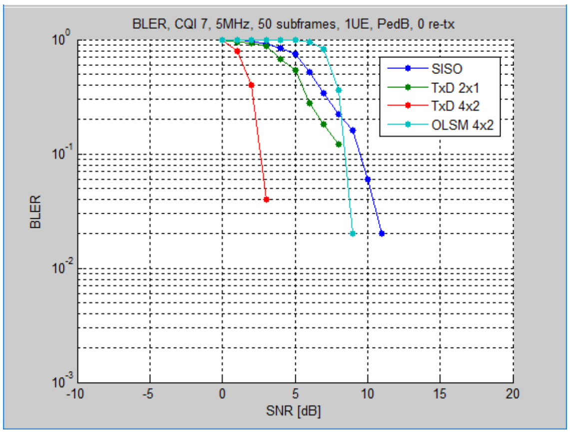

Figure. 4 BLER Performance of SISO,MIMO and OLSM in 5MHz with No HARQ

In addition to HARQ, the effects of MIMO are also investigated in figures from 3 to 6. In these four figures, the throughput of SISO, 2×1 (MISO) transmit diversity (T×D), 4×2 transmit diversity (MIMO), and 4×2 Open Loop Spatial Multiplexing (OLSM) is compared when transmitting over Pedestrian B (PedB) channel type over 5MHz channel BW. Again in these simulations the CQI value is set to 7.

The maximum throughput values achieved by the different MIMO schemes in Figures depends on the number of transmit antennas and on the number of data streams. 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 Open-Loop Spatial Multiplexing (OLSM), spatial multiplexing forms multiple independent links (on same channel) between transmitter and receiver to communicate at higher total data rates (Increases data rates by transmitting parallel data streams). Two spatially separated data streams are transmitted, thus leading to twice the maximum throughput of the 4×2 T×D systems.

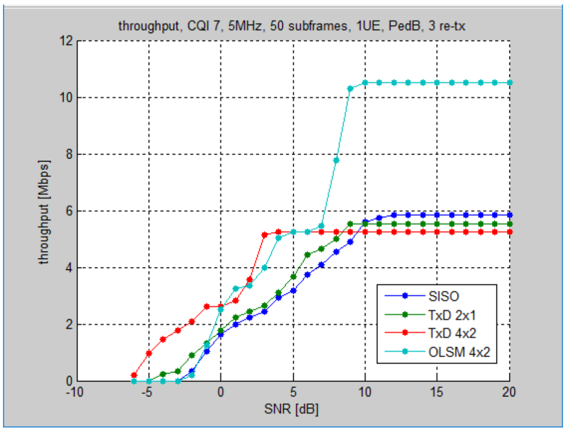

Figure. 5 Throughput Performance of the SISO, MIMO and OLSM in 5MHz with Retransmissions

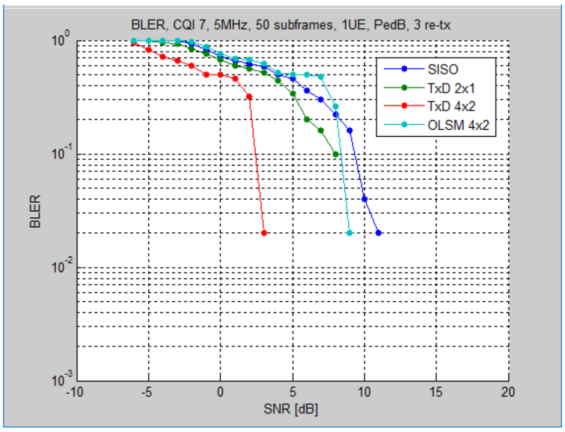

Figure. 6 BLER Performance of the SISO, MIMO and OLSM in 5MHz with Retransmissions

In Figure 7 and Figure 8, under the same simulation settings and parameters of Figure 3 and Figure 4 (No-HARQ), the performance of LTE is investigated for 10MHz BW. As expected, both BLER and throughput results are improved with respect to (w.r.t.) 5MHz. Throughput value is about 22 Mbps for 10 MHz while the throughput results are about 11 Mbps for 5MHz respectively. It shows that there is a linear improvement in the throughput results with respect to BW. But there is no big improvement with respect to the BLER results.

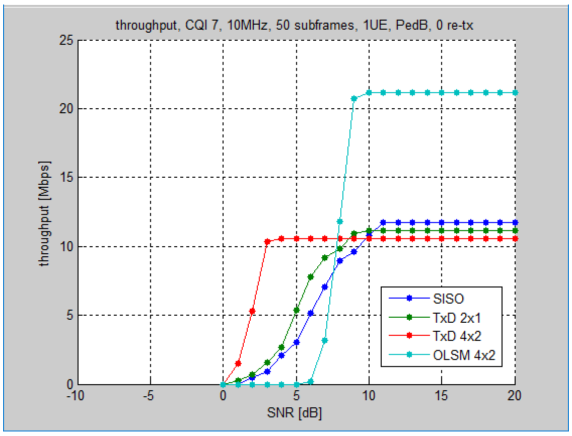

Figure. 7 Throughput Performance of the SISO, MIMO and OLSM in 10MHz with No HARQ

Maximum throughput is achieved with OLSM since spatial multiplexing works by creating separate data streams on multiple antennas. In spatial multiplexing, the eNodeB divides the data to be sent to a given UE on a given sub-channel into data streams, called layers. The number of layers is the same as the rank of the transmission. Transmission rank is determined according to channel conditions at the UE, as well as other considerations such as available resources at the eNodeB. Each layer reaches each Rx along a different path. The UE then reconstructs the layers using information from all antennas.

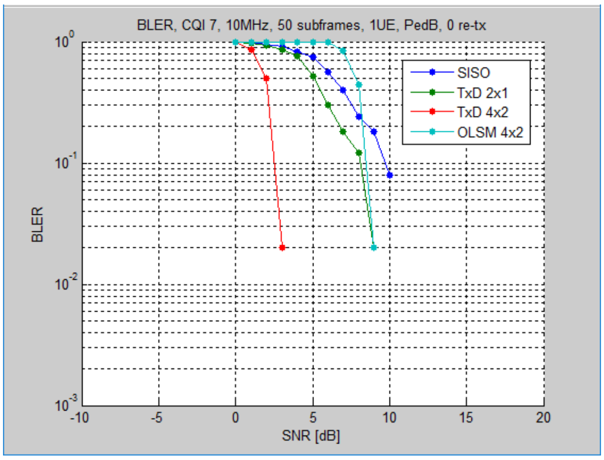

Figure. 8 BLER Performance of the SISO, MIMO and OLSM in 10MHz with No HARQ

In Figure 9 and Figure 10, the throughput and BLER results for different channel BWs are shown such as 1.4, 5 and 10MHz, again for PedB channel type and SISO system implementation. In 1.4MHz the saturated throughput is about 0.8Mbps, and 3.5Mbps and 7Mbps for 5MHz and 10MHz, respectively. Figure 9 shows that there is about 2x improvements in 10MHz w.r.t. 5MHz and more than 7x gain w.r.t. 1.4MHz channel BWs. These improvements show that there is a linear improvement in the throughput as the channel BW increases.

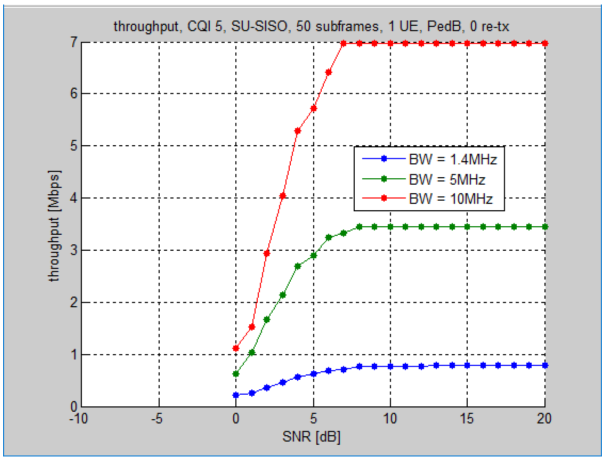

Figure. 9 Throughput Results for Different Channel Bandwidths

The effect of different channel types is shown in Figure 11 and Figure 12 including non-fading environment (AWGN). One can see that for the high and low SNR values all the channel types are reaches the same value (3.5Mbps at high SNR). However, for the medium SNR values there are some throughput differences for different channel models as shown.

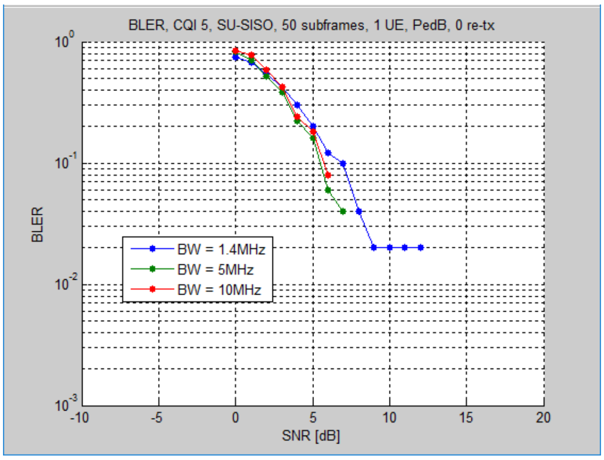

Figure. 10 BLER Results for Different Channel Bandwidths

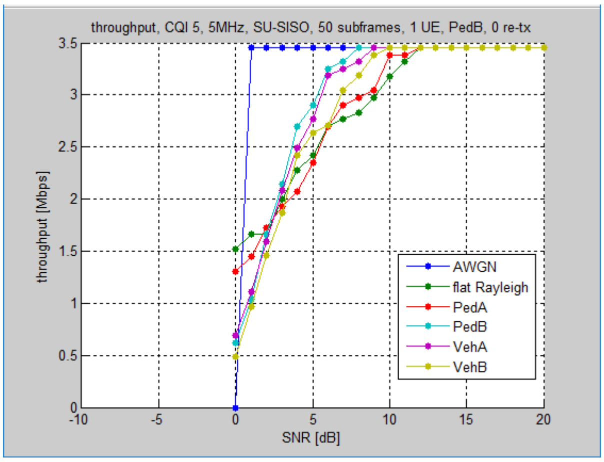

Figure. 11 Throughput Results for Different Channel Types

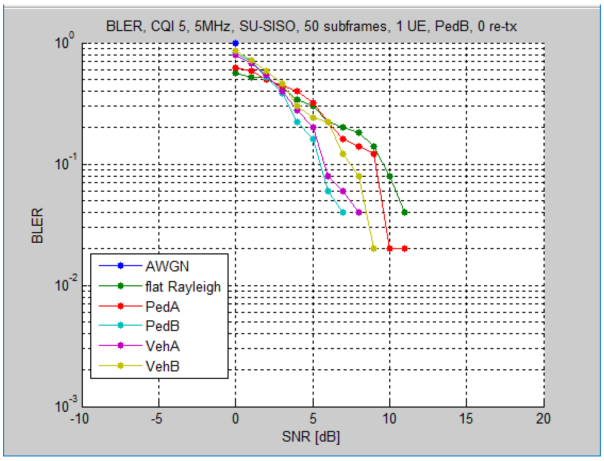

Figure. 12 BLER Results for Different Channel Types

4. CONCLUSION

In the light of the simulation results, it is observed that when the HARQ is used, even there is no much difference on high SNR values, the difference on the throughput and BLER can easily be observed that in lower SNR values such as -5 to 5 dB, there is significant improvement thanks to HARQ.

The maximum throughput values achieved by the different MIMO schemes depends on the number of transmit antennas and on the number of data streams. 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.

The effect of different channel types has been investigated including non-fading environment (AWGN). One can see that for the high and low SNR values all the channel types reach the same value. However, for the medium SNR values there are some throughput differences for different channel models.

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