Enhancing 3GPP LTE Downlink Transmission

A study to the downlink transmission of an LTE system with respect to different antenna array polarization

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Abstract— **Long Term Evolution (LTE) is developed by the 3GPP as a long term perspective for the UMTS/3G standard by providing higher peak data rates, reduced round trip latency and improved system capacity. Since success of UMTS is based on the uptake of mobile data services and the demand for such services is increasing exponentially, enhancements such as improved data rates and latency are to be considered. This paper aims to investigate performance of the 3GPP LTE downlink transmission with respect to different antenna array polarization for the purpose of enhancing achievable downlink throughput. In this paper, performance of Open Loop Spatial Multiplexing (OLSM) and Closed Loop Spatial Multiplexing (CLSM); two different LTE downlink Multiple Input Multiple Output (MIMO) transmission modes, are tested using Uniform Linear Antenna Arrays (ULA) and Cross Polarized Antenna Arrays (XPA) with respect to two different transmit antenna element spacing. This investigation is supported by performance analysis based on simulation results. With reference to the simulation results, it is shown that the use of cross polarized antenna arrays provides better performance in terms of achieving higher downlink throughput for small transmit antenna element spacing.**

Keywords-Long term evolution (LTE); multiple input multiple output (MIMO);open loop spatial multiplexing (OLSM); closed loop spatial multiplexing (CLSM); uniform linear antenna array (ULA); cross polarized antenna Array (XPA)

I. INTRODUCTION

Long-Term Evolution (LTE) was introduced by the Third Generation Partnership Project (3GPP) to ensure competitiveness of the 3GPP UMTS for a longer time frame. Hence, some requirements were set by the 3GPP for this new technology. These requirements included a peak data rate of 100 Mbps (5 bps/Hz) to be achieved in the downlink; assuming two receive antennas, and 50 Mbps (2.5 bps/Hz) to be achieved in the uplink; assuming one transmit antenna at the mobile terminal, for 20 MHz spectrum allocation [1]. By the use of multiple-input multiple-output (MIMO) technology, LTE did not only meet these requirements but also surpassed them. Therefore, MIMO can be viewed as an important factor in data rate enhancements.

MIMO as a technology supports a number of transmission modes. In LTE, seven different downlink transmission modes are supported [2]. Each transmission mode is used to provide different means of system improvement, e.g., transmission mode three, i.e., open-loop spatial multiplexing (OLSM), and transmission mode four, i.e., closed-loop spatial-multiplexing (CLSM), are used to achieve higher peak downlink data rate in contrast to other transmission modes that are used to improve system capacity and coverage. In addition to the individual system enhancement provided by these modes, each mode requires certain antenna configuration for specific environment settings and certain channel conditions. Therefore, to achieve optimum performance and further downlink data rate enhancement, this paper investigates the performance of the OLSM and CLSM with respect to different antenna array polarization and antenna element spacing.

In this paper, performance in terms of downlink throughput of a 4×4 OLSM and CLSM is tested using uniform linear antenna array (ULA), i.e., four vertical polarized spatially spaced antenna elements, and cross-polarized antenna array (XPA), i.e., two spatially spaced pairs of dual-polarized antennas, at both, the transmitter and receiver sides. This is performed to exploit the advantages of spatial and polarization diversity on the performance of spatial multiplexing. This study is based on simulation results that are carried out using the “LTE-A Link Level MATLAB Simulator” [5].

This paper proceeds as follow; Section 2 provides a brief review of the two LTE MIMO modes, i.e., OLSM and CLSM. Section 3 provides an overview of the LTE downlink signal generation chain, with a focus drawn on the main MIMO processing components, i.e., Layer mapping and precoding, at which CLSM or OLSM is achieved. In Section 4, simulations of the two MIMO modes at certain antenna configurations are presented and comparison of the different configurations is stated. Finally, in Section 5, conclusions drawn from this paper are previewed.

II. LTE MIMO - OLSM AND CLSM

In LTE, OLSM and CLSM are used to achieve higher downlink data rates by dividing the data into different streams (layers) that are transmitted over the same radio resources, i.e., using the same resource blocks but different transmit antenna elements. For these MIMO modes, the use of multiple antennas at the transmitter side and at the receiver side is mandatory, which leads to a 2×2 base line antenna configuration, i.e., two antennas at the eNodeB and two antennas at the terminal are to be supported in the first LTE release system with a maximum of up to four transmit (Tx) and receive (Rx) antennas.

These modes are used in a known, good quality channel condition, i.e., when the channel quality is known at the eNodeB and a high SINR is achieved [9]. They also require low correlated antenna elements to exploit multipath or diversity gains [8]. This low correlation can either be achieved by employing spatial or polarization diversity. Although both MIMO modes are used for the same purpose and require same antenna configuration, each can be used only under specific conditions and provides different level of throughput enhancement.

For both MIMO modes, the eNodeB requires some feedback information from the user equipment (UE) regarding the channel quality. In brief, the UE measures the downlink reference signals transmitted by the eNodeB on different antenna ports and transmits a Channel Quality Indicator (CQI), which represents the channel quality for the current transmission mode, and a Rank Indicator (RI), which represents the transmission rank, i.e., the number of useful layers that can be supported under the current channel conditions and modulation scheme. In addition to this feedback information, in the case of CLSM, the UE reports the precoding matrix that provides optimum performance in terms of achieving the maximum SINR under the current channel conditions by transmitting a Precoding Matrix Indicator (PMI). With reference to the UE’s Channel State Information (CSI): CQI, RI and PMI, the eNodeB allocates the radio resources and assigns a transmission scheme to each UE every single Transmission Time Interval (TTI). In the case of missing channel information or rapid changing channel due to a fast moving UE, OLSM is to be used [9]. On the other hand, in the case of low mobility scenarios where the UE reports detailed channel feedback information that closely matches the existing channel conditions, CLSM achieves better performance and hence is the choice to be made by the eNodeB [9].

When comparing between the performance of CLSM and OLSM, CLSM is said to provide better performance in terms of achieving the maximal system throughput, since it closely relates things to the real channel situation enabling the eNodeB to make the right decisions. But it can only be used when the channel conditions and the UE capabilities allow for it.

III. LTE- DOWNLINK MIMO SIGNAL GENERATION CHAIN (PRECODING AND LAYER MAPPING)

Fig. 1 shows the LTE physical downlink signal generation chain for multiple transmit/receive antenna element system. Note that, this is a general structure of the LTE baseband signal processing that is not applicable to all of the downlink physical channels. In this paper, we refer to the Physical Downlink Shared Channel (PDSCH) [3]. As shown in Fig. 1, each codeword, which corresponds to a coded transport block, is first scrambled using a cell-specific sequence based on the UE's C-RNTI (Cell Radio Network Temporary Identifier) and the cell's Physical Cell Identity (PCI) for the purpose of inter-cell interference rejection [3]. These scrambled bits are then grouped and converted into complex-valued modulation symbols using QPSK, 16 QAM or 64 QAM. After that, the resulting modulation symbols are input into a layer mapper followed by a precoder. We will look closely at these two components since they are defined independently for the different MIMO modes.

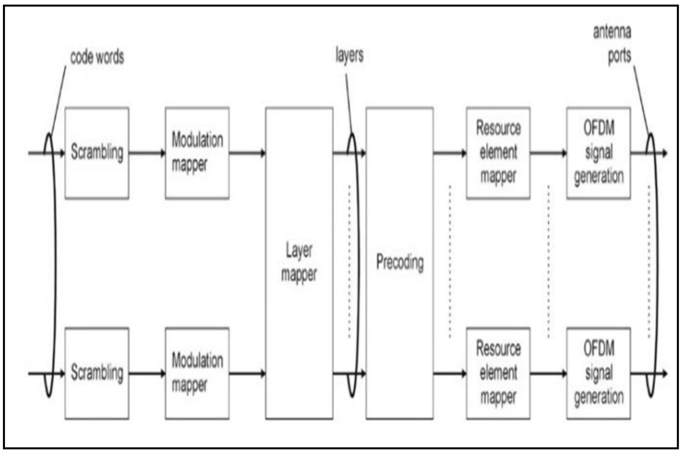

Figure 1. LTE-Physical Downlink Signal Generation Chain [3]

A. Layer Mapping

In this stage, the complex-valued modulation symbols are mapped into one or several transmission layers, i.e., the data is split into a number of layers. In LTE, layer mapping is defined for three different transmission schemes; transmission on a single antenna port, transmit diversity, and spatial multiplexing [3]. For spatial multiplexing (SM), the complex-valued modulation symbols are mapped in a round robin fashion into one, two, three or four layers. Table 1 shows the available layer mapping configurations for spatial multiplexing where; $d^{(q)}(i)$ represents the modulation symbol *(i)* per codeword *(q)*, $x^{(v)}(i)$ represents the modulation symbol *(i)* per layer *(v)*, and $M_{\mathrm{symb}}^{\mathrm{layer}}$ represents the number of modulation symbols per layer, which is equal for all layers in all configurations[3].

In the case of SM, the transmission rank is less than or equal to the number of antenna ports *(P)* and the maximum number of layers that can be supported, known as the channel rank, is equal to the minimum number of transmit and receive antennas. Note that the transmission rank reported by the UE can be less than the channel rank, e.g. in case of four transmit antennas and two receive antennas the channel rank is equal to two and the transmission rank can be one or two. In addition to this, a maximum of two codewords can be assigned for UE transmission per TTI [8]. In the case of one codeword assignment, the transmission mode serves to enhance the transmission robustness instead of enhancing the downlink data rates.

Therefore, in LTE transmission mode three and four; OLSM and CLSM, two codewords are mapped to two layers that are precoded and transmitted over two antenna elements in case of 2×2 MIMO. And in case of 4×4 MIMO, the two codewords are mapped to two, three or four layers that are precoded and transmitted over four antenna elements. The number of layers used for transmission is defined by the transmission rank that depends on the channel quality.

Table 1. Spatial Multiplexing Layer Mapping [3]

Number of Layers ***(v)***	**Number of codewords** ***(q)***	**Codeword-to-layer mapping i=0,1,…, $M_{\text{symb}}^{\text{layer}}$-1)**
1	1	$x^{(0)}(i)=d^{(0)}(i)$
2	2	$x^{(0)}(i)=d^{(0)}(i)$ $x^{(1)}(i)=d^{(1)}(i)$
2	1	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$
3	2	$x^{(0)}(i)=d^{(0)}(i)$ $x^{(1)}(i)=d^{(1)}(2i)$ $x^{(2)}(i)=d^{(1)}(2i+1)$
4	2	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$ $x^{(2)}(i)=d^{(1)}(2i)$ $x^{(3)}(i)=d^{(1)}(2i+1)$

B. *Precoding*

In the precoding stage, the layers are multiplexed before they are mapped to the radio resources for transmission on different antenna ports, *P*, to normalize the signal transmission across the different antenna elements to get the optimal signal reception with respect to the radio channel condition. As for layer mapping, precoding is defined for three different transmission schemes; Transmission on a single antenna port, transmit diversity and spatial multiplexing [3]. For spatial multiplexing, two precoding schemes are defined; precoding with large delay cyclic delay diversity (CDD), defined for OLSM and precoding without CDD, defined for CLSM [3]. Both precoding schemes are defined for a 2×2 and 4×4 antenna configuration.

For CLSM (precoding without CDD), the different number of layers, *v*, are multiplexed to a number of output signals that are equal to the number of antenna ports used for transmission, *P*, according to (1) [3];

$$\begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(P-1)}(i) \end{bmatrix} = W(i) \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(\upsilon-1)}(i) \end{bmatrix}. \qquad (1)$$

where $x^{(v)}(i)$ represents the modulation symbol per layer *v*, $y^{(p)}(i)$ represents the modulation symbol per port *P* and *W(i)* represents the precoding matrix *(P×v)* selected from a predefined codebook configured at both the eNodeB and the UE. The codebook is defined for transmission on two antenna ports and four antenna ports [3]. For two antenna ports, the codebook contains four precoding matrices defined for one and two layer transmission, whereas for four antenna ports, the codebook contains sixteen precoding matrices defined for one, two, three and four layer transmission [3]. For CLSM, the precoding matrix is selected with respect to the UE's feedback and from a defined set [2], i.e., not all precoding matrices are a valid choice for CLSM, for the purpose of minimizing signaling overhead and feedback delay.

For OLSM (precoding with large CDD), a CDD is applied in addition to the precoding matrix to improve robustness of system's performance by introducing artificial multipath that increases the diversity in the channel. Equation (2) represents the precoding for OLSM, where $x^{(v)}(i)$ represents the modulation symbol per layer *v*, $y^{(p)}(i)$ represents modulation symbol per port *P*, *W(i)* represents the precoding matrix *(P×v)* selected from the predefined codebook configured at both the eNodeB and the UE, and the combination of D(i) (*v*×*v* matrix) and U (diagonal *v*×*v* matrix) represents the cyclic delay diversity that is defined for two, three and four layer transmission [3]. Note that, matrix U and matrix D(i) are applied first, then precoding W(i). In OLSM, the precoding matrix is not based on UE feedback, instead is predetermined and is set by the eNodeB [2].

$$\begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(P-1)}(i) \end{bmatrix} = W(i)D(i)U \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(\upsilon-1)}(i) \end{bmatrix}. \qquad (2)$$

C. *Antenna mapping*

After the layers have been precoded, the output signals are mapped to resource blocks assigned for their transmission on different antenna ports. Note that in LTE, we refer to antenna ports and not physical antennas. An antenna port is defined by the presence of antenna port specific reference signals that are distributed within a resource block. There are six antenna ports defined in LTE release 8 [3]. These antenna ports are mapped to one, two or four physical antennas. For both OLSM and CLSM, antenna ports{0,1} are mapped to two transmit antenna elements in case of 2×2 MIMO, and antenna ports{0,1,2,3} are mapped to four transmit antenna elements in case of 4×4 MIMO [3].

IV. SIMULATION- OLSM AND CLSM PHYSICAL ANTENNA CONFIGURATION

This section studies performance of 4×4 OLSM, LTE transmission mode three, and CLSM, LTE transmission mode four, with respect to different antenna array polarization at two different transmit antenna element spacing. In this paper, two testing scenarios are considered. In the first scenario, uniform linear antenna array 'ULA', consisting of four vertically polarized, horizontally spaced, isotropic antenna elements is employed at both; the eNodeB and the UE sides. In the other scenario, uniform cross polarized antenna array 'XPA', consisting of two, horizontally spaced, pairs of dual-polarized (cross-polarized) antennas is employed at both the eNodeB and the UE sides. In the XPA, each pair consists of ±45° slanted isotropic antenna elements. These scenarios are simulated with respect to two different transmit inter-antenna distances; 0.5λ and 4λ, with the UE inter-antenna distance set to 0.5λ. Note that in the case of XPA, inter-antenna distance refers to the distance between the two antenna pairs and not the antenna elements. Fig. 2 shows the antenna configuration for the 'XPA' and 'ULA'.

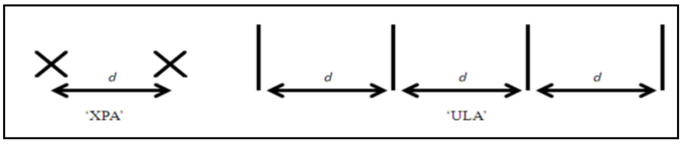

Figure 2. 'XPA' and 'ULA'

The simulation of the two testing scenarios is carried out using the "LTE-A Link Level (v1.1)" MATLAB simulator [5], with the use of the WINNER Phase II channel Model [6]. The WINNER Phase II channel Model is used to generate the radio channel realization for the link level simulator, and for the antenna array creation. Table 2 shows the common set of configured parameters for both scenarios.

Table 2. SIMULATION PARAMETERS

Parameter	Value
Propagation Condition	Typical Urban macro-cell, NLOS
Center Frequency	2.6 GHz
Channel Bandwidth	1.4 MHz
Number of UEs	1
User Speed	0 m/s
Receiver Type	Zero Forcing

In this simulation, a typical urban macro-cell with a non-line of sight condition is considered, where the eNodeB is mounted on rooftop and the UE is located at street level [7]. Due to this configuration the angular spread at the eNodeB is considered to be quite low and at the UE quite high. Therefore, an inter-antenna distance of 0.5λ is considered to be large at the UE and small at the eNodeB. In contrast, an inter-antenna distance of 4λ is considered to be large at the eNodeB.

Fig. 3 and Fig. 4 show simulation results for testing scenario 1 and scenario 2, using small transmit inter-antenna distance (0.5λ). Where Fig. 5 and Fig. 6 show the simulation results for both scenarios but using large transmit inter-antenna distance (4λ). It can be observed that, by the use of OLSM or CLSM, LTE surpasses the required downlink throughput (7Mbps for 1.4MHz).

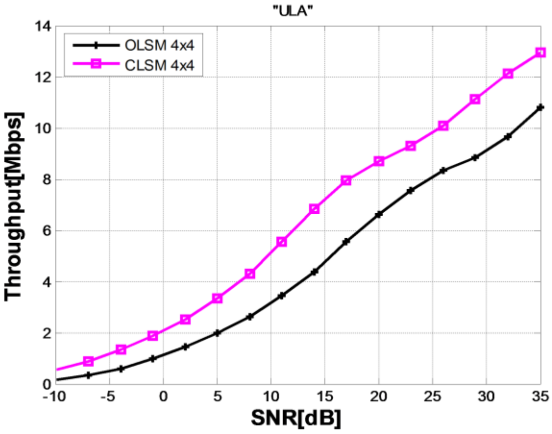

Figure 2. 'ULA' with 0.5λ transmit inter-antenna distance

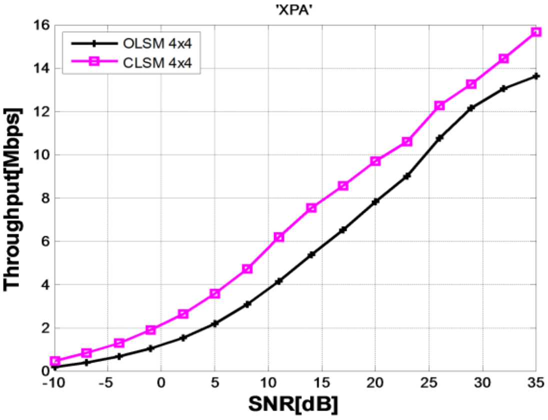

Figure 3. 'XPA' with 0.5λ transmit inter-antenna distance

It can be noted that CLSM provides better performance when compared to OLSM in all scenarios. It can also be noted that the performance of CLSM is more sensitive to antenna array polarization and inter-antenna distance when compared to OLSM. In addition, it can be observed that for both antenna configurations, performance of both transmission modes improves as the inter-antenna distance at the transmitter side increase.

For transmit inter-antenna distance of 0.5λ, it is observed that by using 'XPA' at both the transmitter and the receiver sides, OLSM and CLSM achieve higher downlink data rates. This leads to the conclusion that for small inter-antenna distance, exploiting polarization diversity provides better performance than exploiting the spatial diversity.

For transmit-antenna distance of 4λ, it is observed that OLSM provides the same downlink data rate for both antenna arrays, while CLSM performs slightly better for 'ULA'. This leads to the conclusion that, in the case where large inter-antenna distance is possible and according to our testing scenarios, exploiting spatial or polarization diversity doesn't result in a comparable performance with a priority given to exploit spatial diversity by employing 'ULA' for the slight better performance it provides.

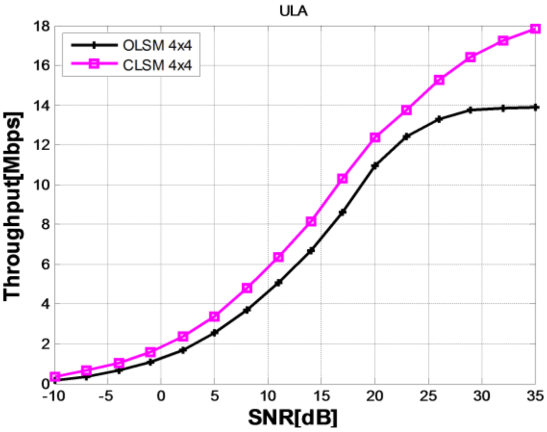

Figure 4. 'ULA' with 4λ transmit inter-antenna distance

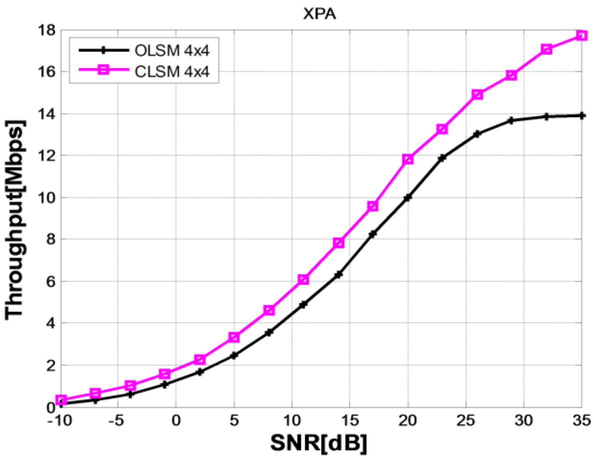

Figure 5. ‘XPA’ with 4λ transmit inter-antenna distance

V. CONCLUSION

In this paper, it is shown that with use of CLSM and OLSM, LTE is able to surpass the downlink requirements set by the 3GPP. It is also shown, through signal processing and simulation, that CLSM outperforms OLSM in terms of providing higher downlink throughput for all antenna configurations. It is also shown, through simulation, that performance of the OLSM, and CLSM, in terms of throughput, is dependent on antenna polarization and inter-antenna distance at the transmitter side. From simulation results, it is concluded that, for both OLSM and CLSM, exploiting polarization diversity at small transmit inter-antenna distance provides better throughput when compared to exploiting spatial diversity.

Therefore, as a final conclusion, to provide higher downlink data rate, in case of small impact devices and deployment scenarios where large implementation space is not permitted, cross polarized antenna arrays are to be used, whereas for deployment scenarios where large implementation space is available, both antenna array configurations can be used, since both provide almost the same downlink throughput.

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