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Impact of Modulation Techniques on Aggregated LTE-Advanced

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Abstract—**Carrier aggregation (CA) is one of the most important technologies to ensure the success of 4G technologies. This paper presents new Long Term Evolution-Advanced (LTE-Advanced) depending on CA technology; the new system has better performance than LTE. The system supports wider bandwidth up to 120 MHz and provides higher level of throughput. Aggregated LTE-Advanced is designed with 2x2 Multiple Input Multiple Output (MIMO) and different modulation techniques such as: Quadrature Phase Shift Keying (QPSK) and 64Quadrature amplitude modulation (64QAM). The results presentation and comparison prove that the maximum throughput is based on assuming 64QAM data modulation, maximum bandwidth 120 MHz and 5/6 code rates.**

Keywords- LTE-Advanced; Throughput; Modulation Techniques, MIMO.

I. INTRODUCTION

The Release 8 LTE carrier maximum bandwidth is 20 MHz. This is well-suited to the most of the frequency bands for LTE deployment as the continuous allocation per operator in a given frequency band rarely exceeds 20 MHz. When seeking to introduce the data rate with larger bandwidth, one could have considered larger bandwidths but a lack of continuous spectrum would have limited the usability to a few frequency bands only. The solution was to use carrier aggregation where multiple carriers of 20 MHz (or less) would be aggregated for the same user equipment (UE). The UE would be receiving carriers at the same time using of multiple frequency bands simultaneously. This kind of carrier aggregation where the carriers are on different frequency bands is considered inter-band carrier aggregation. Further motivation with the existing 20 MHz bandwidth was to maintain the backwards compatibility with the earlier LTE Releases. An existing Release 8 UE may access the network using a single carrier only; while a Release 10 carrier aggregation capable UE may then use more than one carrier without any impacts to the existing Release 8 or 9 terminals without carrier aggregation capability [1].

LTE-Advanced Release 10 provides several new enhancements which can both improve the performance and further boost the achievable peak data rates in the downlink direction. The following key new areas are introduced on top of the Release 8 and 9 MIMO capabilities as extension of the MIMO supports up to eight antennas with up to eight parallel data streams if eight transmitter and eight receiver antennas available (8x8 MIMO). This paper presents 2x2 MIMO LTE-Advanced in order to highlight the effect of MIMO capability on the system.

Aggregated LTE-Advanced is clarified in section II, while how peak data rate is increased with MIMO and different modulation techniques are in section III. The design of the new LTE-Advanced is discussed in section IV. Section V introduces the higher order modulation in combination with channel coding. Throughput of new LTE-A with QPSK Modulation, 16 QAM and 64 QAM are included with all the results and required calculations in sections VI, VII, and VIII. Finally, the main conclusions from this work with the important comparison are in section IX.

II. AGGREGATED LTE-ADVANCED

Carrier aggregation allows both an efficient use of spectrum already deployed and the required support for the resource allocation in new frequency bands. Figure 1 shows a schematic of the concept of carrier aggregation in LTE-A. Depending on the capabilities of the mobile terminal, the user may transmit and/or receive from multiple component carriers (CCs), in case of an LTE-A terminal with a maximum bandwidth of 100 MHz. Meanwhile, LTE Release 8 equipment may only transmit and/or receive in a single CC, with a maximum bandwidth of 20 MHz. Given the possible bandwidth configurations, the transmitter should support, depending on the capabilities of the mobile terminal, three possible scenarios: aggregation of several contiguous CCs within the same band, aggregation of several noncontiguous CCs within the same band and aggregation of several non-contiguous CCs located in different bands [2].

There are three main motivations in introducing carrier aggregation for LTE-Advanced in Release 10, due to its support of high data rates and efficient utilization of fragmented spectrum. A combination with other features defined in LTE Release 10, such as higher order MIMO, CA provides a powerful means to boost the peak user throughput in LTE Release 10 and to meet the IMT-Advanced requirements set by the ITU-R. CA allows aggregation of CCs dispersed across different bands as well as CCs having different bandwidths. CA also allows aggregation of cells having different coverage, thereby enabling flexible network deployments according to traffic demands. Moreover, each CC is backwards compatible with LTE Release 8 and Release 9, allowing smooth upgrade and migration of LTE networks towards LTE-Advanced. Further evolution of CA is expected in future releases of LTE to include more advanced features to support additional deployment scenarios [3].

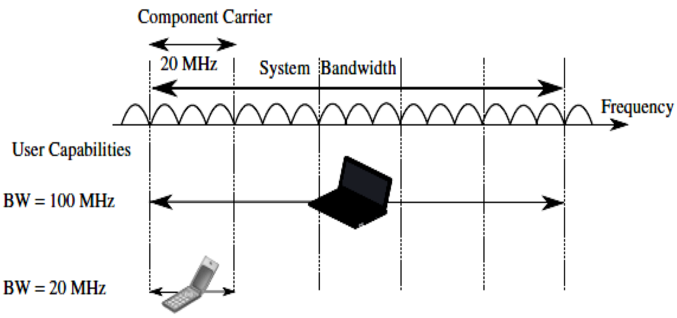

Fig. 1: Scenarios of carrier aggregation for LTE and LTE-Advanced [2]

In typical Time Division Duplex (TDD) deployments [4], the number of component carriers and the bandwidth of each component carrier in UL and DL will be the same. Component carriers originating from the same eNB need not to provide the same coverage. The spacing between center frequencies of contiguously aggregated component carriers shall be a multiple of 300 kHz. This is in order to be compatible with the 100 kHz frequency raster of LTE Rel-8 and at the same time preserve orthogonality of the subcarriers with 15 kHz spacing. Depending on the aggregation scenario, the nx300 kHz spacing can be facilitated by insertion of a low number of unused subcarriers between contiguous component carriers [5].

III. Peak Data Rate Increase with MIMO and Different Modulation Techniques

There are a number of ways in theory to push the peak data rate higher: larger bandwidth, higher-order modulation or multi-stream Multiple Input Multiple Output (MIMO) transmission and one of the fundamental technologies introduced together with the first LTE Release is the Multiple Input Multiple Output (MIMO) [6].

In LTE Release 10 spatial multiplexing was extended to support up to four layers in the UL and up to eight layers in the DL. This update improves cell spectral efficiency but also implies changes in the design of the reference signals and in the DL control signaling [2].

16QAM can double the bit rate compared with Quadrature Phase Shift Keying (QPSK) by transmitting 4 bits instead of 2 bits per symbol. 64QAM can increase the peak bit rate by 50% compared with 16QAM, since 64QAM transmits 6 bits with a single symbol.

On the other hand, the constellation points are closer to each other for higher-order modulation and the required signal-to-noise ratio for correct reception is higher. The difference in the required signal-to-noise ratio is approximately 6 dB between 16QAM and QPSK, and between 64QAM and 16QAM. Therefore, downlink 64QAM and uplink 16QAM can be utilized only when the channel conditions are favorable [7].

IV. System Model

MIMO is being used increasingly in many high data rate technologies including Wi-Fi and other wireless and cellular technologies to provide improved levels of efficiency. Essentially MIMO employs multiple antennas on the receiver and transmitter to utilize the multi-path effects that always exist to transmit additional data, rather than causing interference [8].

The schemes employed in LTE again vary slightly between the uplink and downlink. The reason for this is to keep the terminal cost low as there are far more terminals than base stations and as a result terminal works cost price is far more sensitive. For the downlink, a configuration of two transmit antennas at the base station and two receive antennas on the mobile terminal is used as baseline, although configurations with four antennas are also being considered.

MIMO is used to increase the overall bit rate through transmission of two (or more) different data streams on two (or more) different antennas - using the same resources in both frequency and time, separated only through use of different reference signals to be received by two or more antennas as shown in Figure 2.

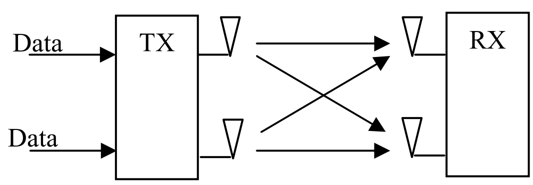

Fig. 2: Block diagram of 2x2 MIMO [8]

The system model of new LTE-Advanced depends on 2x2 MIMO using Orthogonal Frequency Division Multiple Access (OFDMA) which is a multiple access technique, exploiting the OFDM characteristics. OFDM allows only one user to use the system bandwidth for a given time. While OFDMA is multi-user OFDM, that enables the orthogonal subcarriers scheduling among multiple users at the same time, in order to efficiently utilize the radio resources.

Figure 3 and Figure 4 show block diagram of 2x2 MIMO Orthogonal Frequency Division Multiple Access (OFDMA) transmitter and receiver respectively. Firstly, the receiver contains the extra steps of channel estimation and equalization. Secondly, the transmitter inserts a cyclic prefix into the data stream, which is then removed in the receiver [9].

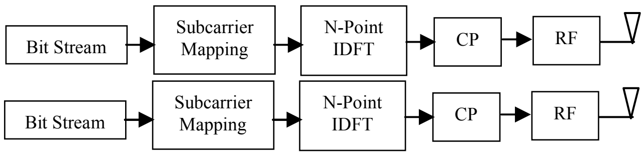

Fig. 3: OFDMA transmitter with 2x2 MIMO

First consider channel estimation each sub-carrier can reach the receiver with a completely arbitrary amplitude and phase. To deal with this, the OFDMA [10] transmitter injects reference symbols into the transmitted data stream. The receiver measures the incoming reference symbols, compares them with the ones transmitted, and uses the result to remove the amplitude changes and phase shifts from the incoming signal.

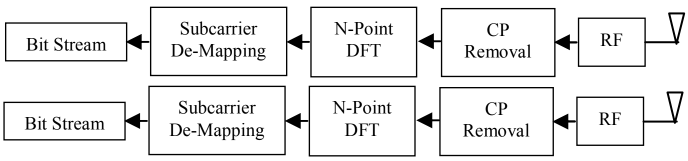

Fig. 4: OFDMA receiver with 2x2 MIMO [9]

In the presence of frequency-dependent fading, the amplitude changes and phase shifts are functions of frequency as well as time and affect the different sub-carriers in different ways. To ensure that the receiver can measure all the information it requires, the LTE reference symbols are scattered across the time and frequency domains. The reference symbols take up about 10% of the transmitted data stream, so do not cause a significant overhead.

V. Higher-Order Modulation in Combination with Channel Coding

Higher-order modulation schemes such as 16QAM and 64QAM require, in themselves, a higher receiver E_b /N_0 for a given error rate, compared to QPSK. However, in combination with channel coding the use of higher-order modulation will sometimes be more efficient that is, require a lower receiver E_b /N_0 for a given error rate compared to the use of lower-order modulation such as QPSK.
This may, occur when the target bandwidth utilization implies that, with lower-order modulation; no or very little channel coding can be applied. In such a case, the additional channel coding that can be applied by using a higher-order modulation scheme such as 16QAM may lead to an overall gain in power efficiency compared to the use of QPSK [11].

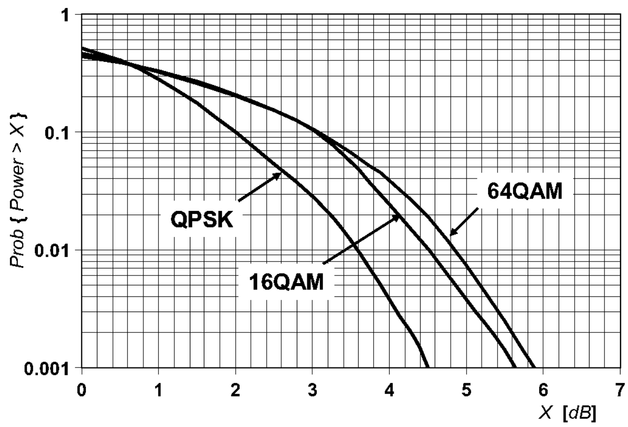

Fig. 5: Distribution of instantaneous power for different modulation schemes [11]

Figure 5 illustrates the distribution of the instantaneous power, more specifically the probability that the instantaneous power is above a certain value, for QPSK, 16QAM, and 64QAM respectively. The probability for large peaks in the instantaneous power is higher in the case of higher-order modulation.
Larger peaks in the instantaneous signal power imply that the transmitter power amplifier must be over-dimensioned to avoid power-amplifier nonlinearities, occurring at high instantaneous power levels, causing corruption to the signal to be transmitted. As a consequence, the power-amplifier efficiency will be reduced, leading to increased power consumption. In addition, there will be a negative impact on the power-amplifier cost. Alternatively, the average transmit power must be reduced, implying a reduced range for a given data rate [11].

VI. Throughput of New LTE-A with QPSK Modulation

According to the design of new LTE-Advanced; the maximum obtained channel bandwidth is 120 MHz. One of the most important blocks of LTE-Advances is the modulation technique because it affects the level of throughput and the accuracy of the system. The effect of modulation is represented by the used technique and code rate.

With LTE advanced, there are 6 more categories of UE added, UE supports 2x2 MIMO with 120 MHz = 600 RBs, 64QAM = 6 bits/RE

The number of resource elements (RE) in a subframe with 20 MHz channel bandwidth: 12 subcarriers x 7 OFDMA symbols x 100 resource blocks x 2 slots= 16800 REs per subframe. Each RE can carry a modulation symbol.

Assume 64QAM modulation and no coding, one modulation symbol will carry 6 bits. The total bits in a subframe (1ms) over 20 MHz channel is 16800 modulation symbols x 6 bits / modulation symbol = 100800 bits. So the data rate is 100800 bits / 1 ms = 100.8 Mbps.

The transmission bandwidth configuration =600 RBs. The used modulation technique is 64QAM which has 6 bits per resource element. This indicates that proposed LTE- Advanced is has convergent peak data rates to the standards of 3GPP.

This research provides a new bandwidth for LTE-Advanced that reaches up to 120 MHz, and at the same time the system keeps the efficiency on the same range while the throughput is increase. The aggregated throughput is sum of the data rates that are delivered to all terminals in a network; it is usually measured in bit per second.

In this situation the used modulation technique is Quadrature Phase Shift Keying (QPSK); it is applied on the system with 2x2 MIMO with various FEC 1/12, 1/6, 1/3 and 2/3. The QPSK uses four phases at 0, 90, -90 and 180 degrees. It gives high spectral efficiency and it is more efficient than BPSK because it uses two symbols at a time for modulation. Both BPSK and QPSK are power efficient in same way but QPSK is more bandwidth efficient than BPSK.

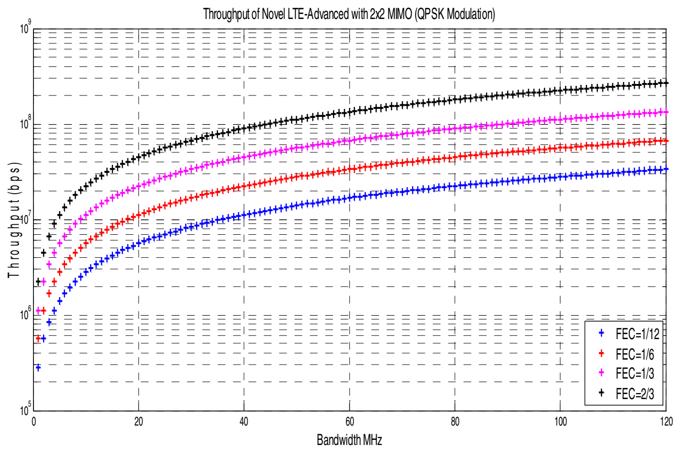

Fig. 6: Throughput of 2x2 MIMO LTE-A using QPSK modulation

Figure 6 shows the throughput plot relating to channel bandwidth from 0 to 120 MHz. The results indicates that when the code rate =1/12 the system will have minimum throughput. For example when the system simulated to broadcast on 120 MHz channel bandwidth; the corresponding throughput is 33.6 Mbps. When the code rate is increased to 1/6; it is clear that the throughput level of the system is improved and now the throughput of new LTE-A with channel bandwidth=120 MHz is 67.2 Mbps. As mentioned above the code rate 1/3 can be used with QPSK modulation; with this code rate the throughput has higher level and reach to 134 Mbps with 120 MHz channel bandwidth.

Finally, the maximum code rate can be used with QPSK is 2/3 which gives the best throughput as clear from Figure 6. The throughput of new LTE-A is 268 Mbps with 120 MHz channel bandwidth. As a result the code rate is directly proportional to throughput of system modulated using QPSK and the best code rate for the system with 2x2 MIMO is 2/3.

VII. THROUGHPUT OF NEW DESIGN OF LTE-A WITH 16QAM MODULATION

QAM is widely used with LTE-Advanced and with various modulation indexes. In this situation new LTE-Advanced is simulated using QAM with 16 as a modulation index to evaluate the performance of the system and show the effect of code rate on throughput of the system.

QAM has increased the efficiency of transmission for radio communication systems by using both phase and amplitude together. It is more susceptible to noise because its symbols are very close to each other therefore rate of interference increases. In this step 16QAM is used to simulate new LTE-Advanced and the throughput is plotted for three code rates 1/2, 2/3 and 3/4 to show performance of the system. Figure 7 shows the throughput plot relating to channel bandwidth from 0 to 120 MHz. The results indicates that when the code rate =1/2 the system will have minimum throughput. For example when the system simulated to broadcast on 120 MHz channel bandwidth; the corresponding throughput is 403 Mbps. When the code rate is increased to 2/3; it is clear that the throughput level of the system is improved and now the throughput of new LTE-A with channel bandwidth=120 MHz is 537 Mbps.

Finally, the maximum code rate can be used with 16QAM is 3/4 which gives the best throughput as clear from Figure 7. The throughput of new LTE-A is 604 Mbps with 120 MHz channel bandwidth. As a result the code rate is directly proportional to throughput of system modulated using 16QAM and the best code rate for the system with 2x2 MIMO is 3/4.

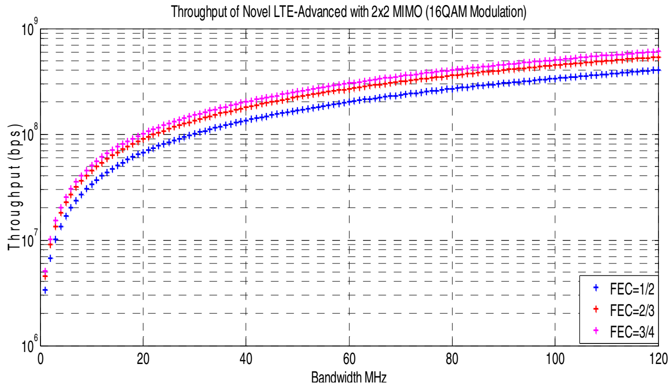

Fig. 7: Throughput of 2x2 MIMO LTE-A using 16QAM modulation

VIII. THROUGHPUT OF NEW LTE-A WITH 64QAM MODULATION

In order to show the effect of modulation index and code rate of QAM on throughput; A new LTE-Advanced is simulated using 64QAM modulation techniques.

In 64QAM it is allowed to depend 2/3 and 5/6 code rates in new LTE-Advanced system to show the best code rate which gives higher throughput and to obtain robust system. 64-QAM has high throughput as compared to BPSK and QPSK. It is important to use higher modulation schemes in order achieve high spectral efficiency and high transmission throughput. Whereas the lower order modulation schemes are less vulnerable to noise and interference in the channel.

Figure 8 shows the throughput plot relating to channel bandwidth from 0 to 120 MHz. The results indicates that when the code rate =2/3 the system will have minimum throughput. For example when the system simulated to broadcast on 120 MHz channel bandwidth; the corresponding throughput is 806 Mbps. The maximum code rate can be used with 64QAM is 5/6 which gives the best throughput as clear from Figure 8. The throughput of new LTE-A is 1.008 Gbps with 120 MHz channel bandwidth. As a result the code rate is directly proportional to throughput of system modulated using 64QAM and the best code rate for the system with 2x2 MIMO is 5/6.

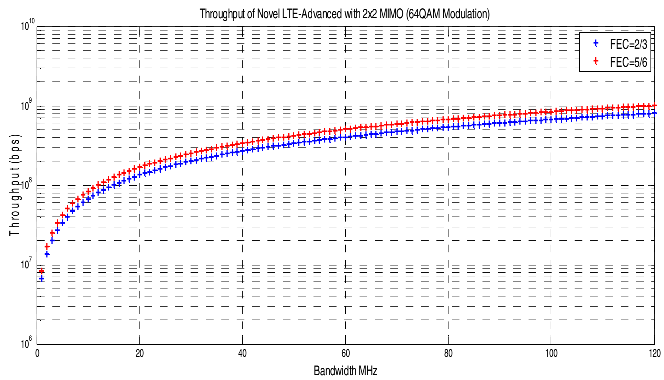

Fig. 8: Throughput of 2x2 MIMO LTE-A using 64QAM modulation

IX. CONCLUSIONS

MIMO of the LTE major technology innovations used to improve the performance of the system. This technology provides LTE with the ability to further improve its data throughput and spectral efficiency above that obtained by the use of OFDM. Although MIMO adds complexity to the system in terms of processing and the number of antennas required, it enables far high data rates to be achieved along with much improved spectral efficiency. As a result, MIMO has been included as an integral part of LTE. It is concluded that the new design of LTE-Advanced supports bandwidths of 40 MHz, 60 MHz, 80 MHz, 100 MHz and 120 MHz with better performance and higher throughput. For the system with contiguous and noncontiguous carrier aggregation, it is clear that increasing the bandwidth from 100 MHz to 120 MHz led to the advantage of using six component carriers instead of five which gives higher level of throughput. From simulating LTE-Advanced using various modulation techniques such as: QPSK, 64QAM and after evaluation of throughput; it is clear that 64QAM gives the best performance for LTE-Advanced and makes the system has high throughput if the used code rate is 5/6.

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