A Novel LTE-Advanced Carrier Aggregation with Higher Throughput

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Abstract

Carrier Aggregation (CA) is one of the important features of Long Term Evolution-Advanced (LTE-Advanced), which is being standardized in Third Generation Partnership Project (3GPP) as part of LTE Release 10. This study also presents throughput results based on different parameters; Beyond 20 MHz, the only reasonable way to achieve LTE-Advanced highest target peak-throughput rate is to increase the transmission bandwidth, relative to Release 8. This paper presents a novel LTE-Advanced depending on carrier aggregation to get better performance of the system; the simulation is applied with 8X8 Multiple Input Multiple Output (MIMO) LTE-Advanced using different modulation techniques such as: QPSK, 64QAM (Quadrature amplitude modulation) in order to determine the higher throughput to depend it in design; the maximum throughput result is based on assuming 64QAM data modulation, maximum bandwidth 120 MHz and 5/6 code rates.

Keywords: *Throughput, LTE-Advanced, Carrier Aggregation, MIMO*

1. Introduction

Long Term Evolution (LTE) has been developed in a process where design targets for performance parameters play an important role. One target is for the peak data rate over the radio interface. The original design targets for the first release of LTE are documented in 3GPP TR 25.913 [1]. The target capability when operating in a 20 MHz spectrum allocation is a peak data rate of 100 Mbps in the downlink and 50 Mbps in the uplink. The numbers assume two receive antennas in the terminal for the downlink capability and one transmit antenna for the uplink capability. These target numbers are exceeded by a good margin by the peak data rate capability of the specified LTE standard. LTE release 8 supports peak data rates of 300 Mbps in the downlink and 75 Mbps in the uplink by using spatial multiplexing of four layers (4x4 MIMO) in the downlink and 64QAM (quadrature amplitude modulation) in both downlink and uplink. There is no absolute peak data rate target expressed for LTE release 10; it is instead expressed relative to the channel bandwidth as a peak spectral efficiency, with targets of 15 bit/s/Hz for downlink and 6.75 bit/s/MHz for uplink [2]. LTE release 10 exceeds those numbers by a good margin. The assumptions for deriving the peak spectral efficiency numbers is a deployment with 20 MHz channel bandwidth, 8x8 MIMO in the downlink, and 4x4 MIMO in the uplink. Spectrum allocation is a peak data rate LTE-A of 1 Gbps in the downlink and 500 Mbps in the uplink [3].

2. Carrier Aggregation in LTE-Advanced

LTE-Advanced extends LTE Rel.-8 with support for Carrier Aggregation (CA), where two or more component carriers (CCs) are aggregated in order to support wider transmission bandwidths up to 100 MHz and for spectrum aggregation [4]. It shall be possible to configure all component carriers which are LTE Rel-8 compatible, at least when the aggregated numbers of component carriers in the uplink (UL) and the downlink (DL) are the same. Not all component carriers may necessarily be LTE Rel-8 compatible. A terminal may simultaneously receive or transmit one or multiple component carriers depending on its capabilities:

- An LTE-Advanced terminal with reception and/or transmission capabilities for carrier aggregation can simultaneously receive and/or transmit on multiple component carriers.
- An LTE Rel-8 terminal can receive and transmit on a single component carrier only, provided that the structure of the component carrier follows the Rel-8 specifications.

Carrier aggregation is supported for both contiguous and non-contiguous component carriers with each component carrier limited to a maximum of 110 Resource Blocks in the frequency domain using the LTE Rel-8 numerology. It is possible to configure user equipment (UE) to aggregate a different number of component carriers originating from the same eNB and of possibly different bandwidths in the UL and the DL. In typical Time-Division Duplex (TDD) deployments [5], 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 n *x* 300 kHz spacing can be facilitated by insertion of a low number of unused subcarriers between contiguous component carriers [6].

3. Multiple Input Multiple Output (MIMO)

One of the fundamental technologies introduced together with the first LTE Release is the Multiple Input Multiple Output (MIMO) [7]. The model of radio interface of the MIMO system contains M_{TX} transmitter antennas and N_{RX} receiver antennas which describes the connection between the LTE-A base station (eNodeB) and the mobile station (UE). The time-varying channel impulse response between the j^{th} ($j=1,2,...M_{TX}$) transmit antenna and the i^{th} ($i=1,2,...N_{RX}$) receive antenna is denoted as $h_{i,j}(\tau,t)$. This is the response at time t to an impulse applied at time t- τ. The composite MIMO channel response is given by the NRX x MTX matrix H(τ,t) shown in equation (1) where τ is the time spread and t is the channel time variance.

$$H(\tau,t)=\begin{bmatrix} h_{11}(\tau,t) & h_{12}(\tau,t) & \cdots & h_{1M}(\tau,t) \\ h_{21}(\tau,t) & h_{22}(\tau,t) & \cdots & h_{2M}(\tau,t) \\ \vdots & \vdots & \cdots & \vdots \\ h_{N1}(\tau,t) & h_{N2}(\tau,t) & \cdots & h_{NM}(\tau,t) \end{bmatrix}_{N_{RX}\cdot M_{TX}} \quad (1)$$

While Figure 1 shows the scheme of the antenna arrays is illustrated, as well. The vector $[h_{1,j(\tau,t)}, h_{2,j(\tau,t)}, \ldots, h_{NRX,j}(\tau,t)]^T$ obtained from $H(\tau,t)$ is referred to as the spatio temporal signature induced by the j^{th} antenna across the receive antenna array [8].

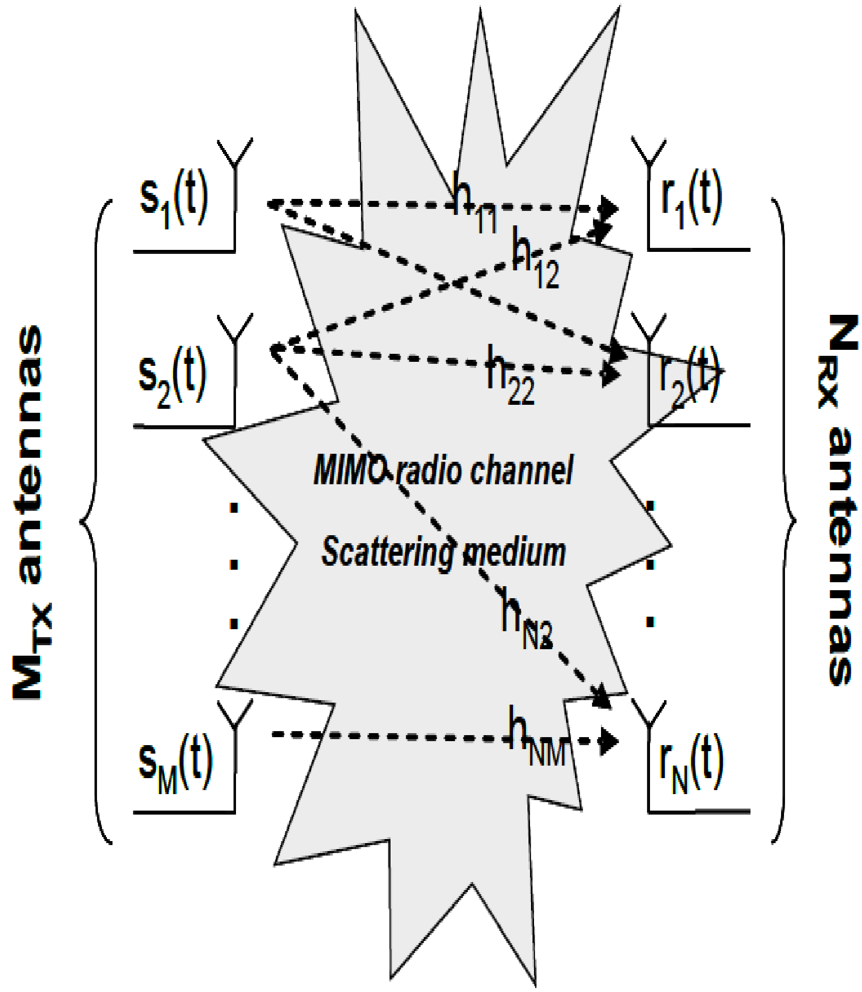

Figure 1. Two Antenna Arrays in a Scattering Environment

Given that the signal $s_j(t)$ is transmitted from the j^{th} transmit antenna, the signal received at the i^{th} receiver antenna is modeled by equation (2) that represents the stochastic discrete time MIMO channel model where $n_i(t)$ is additive noise at the receiver and $h_{i,j}(\tau,t)$ indicates the channel impulse response coupling the j^{th} transmitter to the i^{th} receiver element. $\alpha_{i,j}(q,n)$ is the complex coefficient from j^{th} transmitter to the i^{th} receiver antenna at the delay τq and the discrete time n. These channel coefficients, $\alpha_{i,j}(q,n)$, are zero-mean complex identical independent distribution (i.i.d.) random complex Gaussian quantities with variance $\sigma^2\alpha(q)$. The channel coefficients also have their amplitudes shaped in the frequency domain by the Doppler spectrum obtained by classical Jakes low-pass filter. The Doppler spectra depend on the speed of the user and the carrier frequency.

Finally, given the proposed stochastic model, the MIMO channel is easily simulated on a computer by generating Q x M_{TX} x N_{RX} uncorrelated complex Gaussian processes and the combination of all of these processes generates the MIMO channel with independent Rayleigh fading.

$$r_i(t)=\sum_{j=1}^{MTX} h_{ij}(\tau,t)*s_j(t)+n_i(t),\, i=1,2,\cdots,NRX \quad \text{where} \quad h_{ij}(\tau,t)=\sum_{q=1}^{Q}\alpha_{ij}(q,t)\delta(t-\tau_q) \tag{2}$$

4. Channel Estimation

Figure 2 is a detailed block diagram of Orthogonal Frequency-Division Multiple Access (OFDMA). It is very like the block diagram shown earlier, but with two extra processes. 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].

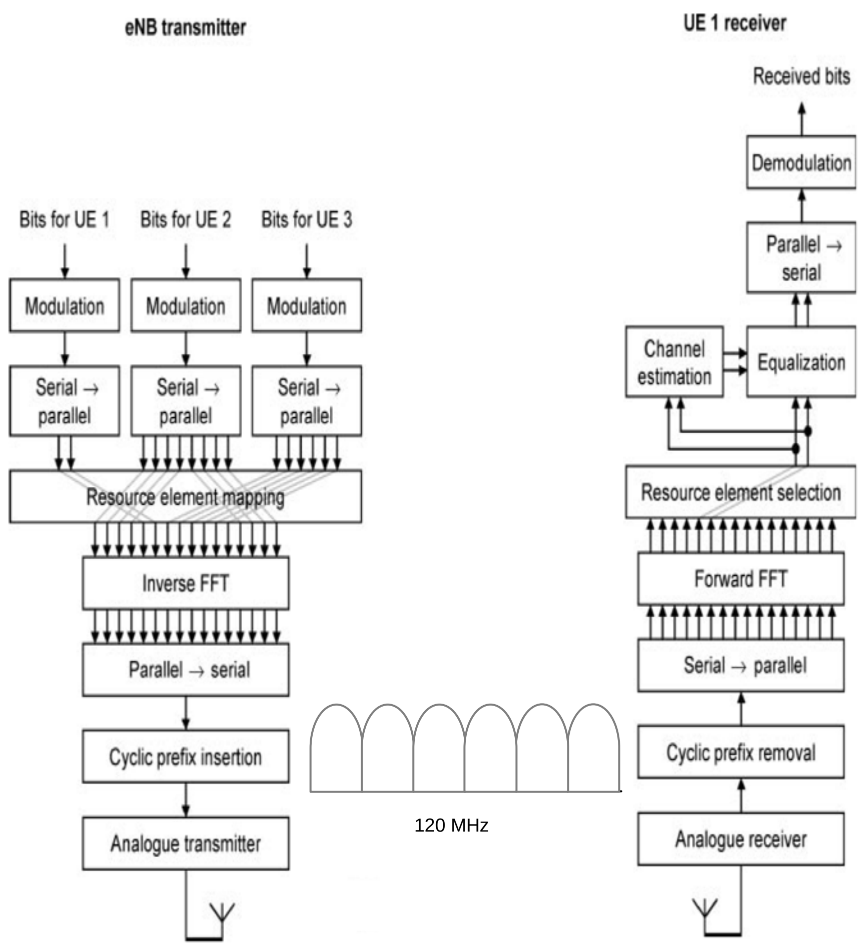

Figure 2. OFDMA Transmitter and Receiver

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. 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 subcarriers 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.

5. Mathematical Formulations of Novel LTE-Advanced Throughput

According to the design of Novel 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 8 x 8 MIMO.

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.

To calculate peak data rate and compare results with 3GPP standards [11] and depending on Table 1; When channel bandwidth =120 MHz, the transmission bandwidth configuration =600 RBs.

The used modulation technique is 64QAM which has 6 bits per resource element. Now, for 8 x 8 MIMO systems, eNB can transmit 2 codeword on 4 antennas each. From Table 1: One-layer to four-layer TBS translation table, the transport block size *i.e.*, the data sent in one codeword will be **299856** bits/100 RB per codeword but 299856 is considered for code rate =0.75 and for code rate= 5/6 the data sent in one codeword is 333173, So, eNB can transmit 333173 * 2 * 6 = 3998080 bits/ms = ~4Gbps, on the other hand, the practical results that is done for Novel LTE-Advanced shows that peak data rate for 120 MHz channel bandwidth is 4.032 Gbps, this indicates that proposed LTE- Advanced is has convergent peak data rates to the standards of 3GPP.

Table 1. One Layer to Four Layer TBS Translation [11]

Note: Transport blocks mapped to four-layer spatial multiplexing (TBS)

TBS_L1	TBS_L4	TBS_L1	TBS_L4	TBS_L1	TBS_L4	TBS_L1	TBS_L4
776	3112	2280	9144	7224	29296	24496	97896
808	3240	2344	9528	7480	29296	25456	101840
840	3368	2408	9528	7736	30576	26416	105528
872	3496	2472	9912	7992	31704	27376	110136
904	3624	2536	10296	8248	32856	28336	115040
936	3752	2600	10296	8504	34008	29296	115040
968	3880	2664	10680	8760	35160	30576	124464
1000	4008	2728	11064	9144	36696	31704	128496
1032	4136	2792	11064	9528	37888	32856	133208
1064	4264	2856	11448	9912	39232	34008	137792
1096	4392	2984	11832	10296	40576	35160	142248
1128	4584	3112	12576	10680	42368	36696	146856
1160	4584	3240	12960	11064	43816	37888	151376
1192	4776	3368	13536	11448	45352	39232	157432
1224	4968	3496	14112	11832	46888	40576	161760
1256	4968	3624	14688	12216	48936	42368	169544
1288	5160	3752	15264	12576	51024	43816	175600
1320	5352	3880	15264	12960	51024	45352	181656
1352	5352	4008	15840	13536	55056	46888	187712
1384	5544	4136	16416	14112	57336	48936	195816
1416	5736	4264	16992	14688	59256	51024	203704
1480	5992	4392	17568	15264	61664	52752	211936
1544	6200	4584	18336	15840	63776	55056	220296
1608	6456	4776	19080	16416	66592	57336	230104
1672	6712	4968	19848	16992	68808	59256	236160
1736	6968	5160	20616	17568	71112	61664	245648
1800	7224	5352	21384	18336	73712	63776	254328
1864	7480	5544	22152	19080	76208	66592	266440
1928	7736	5736	22920	19848	78704	68808	275376
1992	7992	5992	23688	20616	81176	71112	284608
2024	7992	6200	24496	21384	84760	73712	293736
2088	8248	6456	25456	22152	87936	75376	**299856**
2152	8504	6712	26416	22920	90816		
2216	8760	6968	28336	23688	93800		

6. Throughput of Novel LTE-A with 16QAM Modulation

This research provides a novel 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 (bps).

A). Throughput of 4x4 MIMO

In this scenario the used modulation technique is QPSK; it is applied on the system with 4x4 MIMO with various FEC (1/12, 1/6, 1/3 and 2/3). Figure 3 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 67.2 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 Novel LTE-A with channel bandwidth=120 MHz is 134 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 268 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 3. The throughput of Novel LTE-A is 537 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 4x4 MIMO is 2/3.

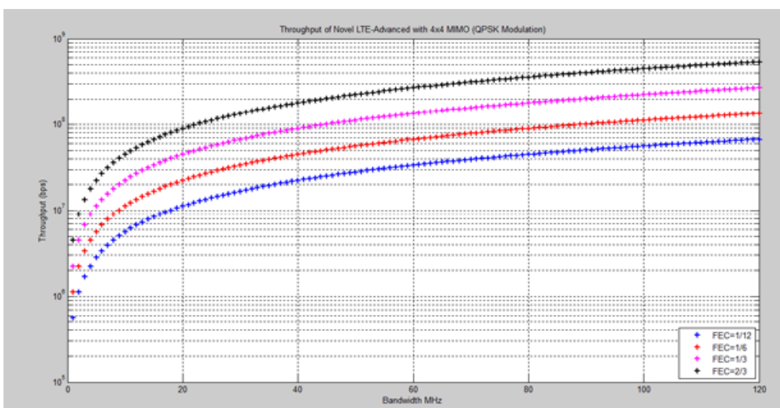

Figure 3. Throughput of 4x4 MIMO LTE-A using QPSK Modulation

B). Throughput of 8x8 MIMO

In this case the used modulation technique is QPSK; it is applied on the system with 8x8 MIMO with various FEC (1/12, 1/6, 1/3 and 2/3). Figure 4 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 134 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 Novel LTE-A with channel bandwidth=120 MHz is 268 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 537 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 4. The throughput of Novel LTE-A is 1.07 Gbps 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 8x8 MIMO is 2/3.

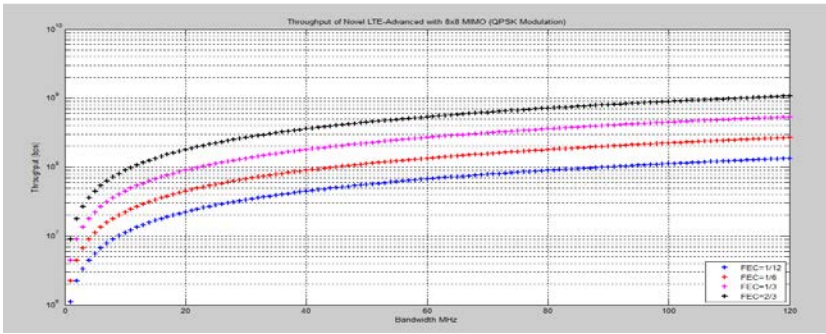

Figure 4. Throughput of 8x8 MIMO LTE-A using QPSK Modulation

7. Throughput of Novel LTE-A with 16QAM Modulation

QAM is widely used with LTE-Advanced and with various modulation indexes. In this situation Novel 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.

A). Throughput of 4x4 MIMO

In this step 16QAM is used to simulate Novel 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 5 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 806 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 Novel LTE-A with channel bandwidth=120 MHz is 1.07 Gbps.

Finally, the maximum code rate can be used with 16QAM is 3/4 which gives the best throughput as clear from Figure 5. The throughput of Novel LTE-A is 1.21 Gbps 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 4x4 MIMO is 3/4.

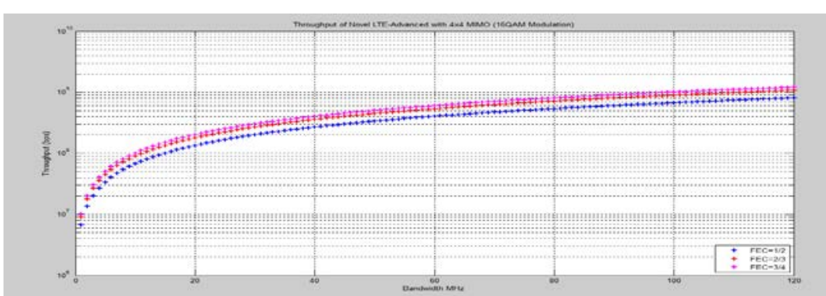

Figure 5. Throughput of 4x4 MIMO LTE-A using 16QAM Modulation

B). Throughput of 8x8 MIMO

Figure 6 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 1.6 Gbps. As mentioned above the code rate 2/3 can be used with 16QAM modulations; with this code rate the throughput has higher level and reach to 2.15 Gbps with 120 MHz channel bandwidth. The maximum code rate can be used with 16QAM is 3/4 which gives the best throughput as clear from Figure 6. The throughput of Novel LTE-A is 2.41 Gbps 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 8x8 MIMO is 2/3.

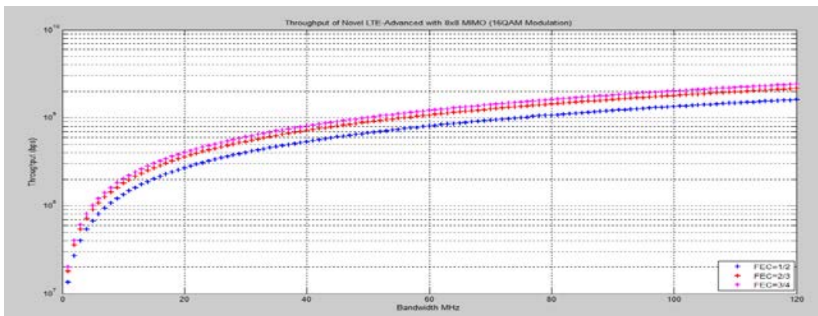

Figure 6. Throughput of 8x8 MIMO LTE-A using 16QAM Modulation

8. Throughput of Novel LTE-A with 64QAM Modulation

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

A). Throughput of 4x4 MIMO

Figure 7 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 1.6 Gbps. The maximum code rate can be used with 64QAM is 5/6 which gives the best throughput as clear from Figure 7. The throughput of Novel LTE-A is 2.01 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 4x4 MIMO is 5/6.

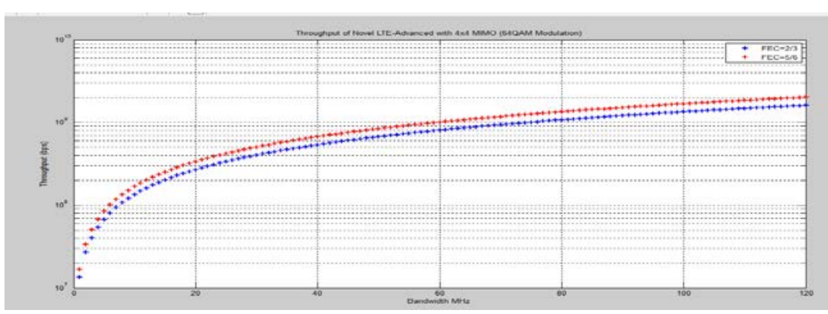

Figure 7. Throughput of 4x4 MIMO LTE-A using 64QAM Modulation

B). Throughput of 8x8 MIMO

Figure 8 shows the throughput plot relating to channel bandwidth from 0 to 120 MHz. The results indicates that when the code rate is to 2/3; it is clear that the throughput level of the system is improved and now the throughput of Novel LTE-A with channel bandwidth=120 MHz is 3.2 Gbps. 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 Novel LTE-A is 4.032 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 8x8 MIMO is 5/6.

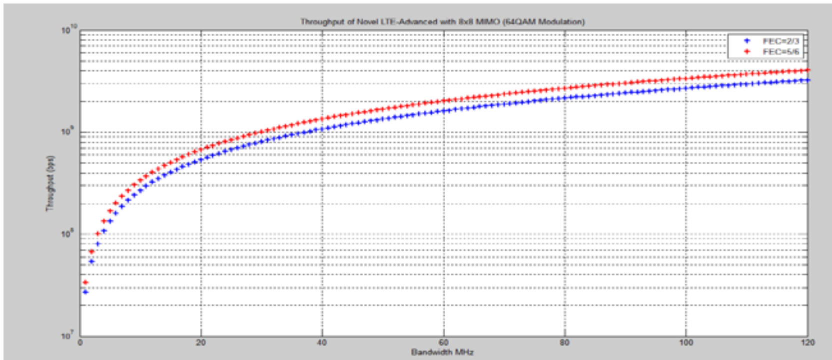

Figure 8. Throughput of 8x8 MIMO LTE-A using 64QAM Modulation

9. Conclusions

The simulation results presented demonstrate the high possibility of LTE-Advanced in terms of both, overall spectral efficiency which benefit all of operators and high cell edge performance that benefit the end-user. In addition, this research proved that enhancement of LTE-A which includes bandwidth equal to 100 MHz and peak data rate 1 Gbps; the proposed implemented LTE-A presented better performance, larger bandwidth and better peak data rate at the same level of efficiency of LTE-Advanced system. The new design supports bandwidths of 40 MHz, 60 MHz, 80 MHz, 100 MHz and 120 MHz with progressive peak data rates exceeds 4 Gbps. The main advantages of designed systems (contiguous and non-contiguous) are getting better coverage and improve spectral efficiency (cell edge and average) which is achieved through robust interference management and greater flexibility with wideband deployments by employing wider bandwidth by carrier aggregation across bands. From simulating LTE-Advanced using various modulation techniques such as: QPSK, 64QAM and after evaluation of peak data rate; it is clear that 64QAM gives the best performance for LTE-Advanced and makes the system has high peak data rate if the used code rate is 5/6.

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