Kufa Journal of Engineering
Vol. 10, No. 3, July 2019, P.P. 100-113
Received 24 May 2018, accepted 10 January 2019

EFFECT OF CHANGING DFT PROCESS SIZE ON DATA RATE IN LTE UPLINK LAYER

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http://dx.doi.org/10.30572/2018/kje/100307

ABSTRACT

This paper deals with Matlab simulation of Long Term Evolution system (Lte) to show data rate of the uplink layer from user equipment toward the tower with respect to the size of Desecrate Fourier Transform process (DFT) which will be increased from 2 to the size of Inverse Desecrate Fourier Transform process (IDFT). Also it shows the way of using Cyclic Prefix technique (CP) in Lte system and its types which effect on the data rate for uplink layer.

Finally the results will show the value of Lte system data rate for different types of modulation and Cyclic Prefix which will be for many types of system bandwidth individually, and it will show the minimum and maximum values of (DFT) process size with the midpoint which is the best one.

KEYWORDS: Lte, Data Rate, DFT process size, Cyclic Prefix, Bandwidth.

1. INTRODUCTION

3GPP approved Lte as a 4G communication system to improve data rate with reducing the effect of Inter Symbol Interference (ISI) and multipath channel and latency and reduces Bit Error Rate (BER) of data transmission between user equipment (UE) & evolved Node B (e-NB). In Lte system there are two modulation methods used for uplink and downlink layer. In downlink from (e-NB) to (UE) the system uses Orthogonal Frequency Division Multiple Access (OFDMA) but for the uplink from (UE) to (e-NB) the system uses Single Carrier - Frequency Division Multiple Access (SC-FDMA).

Fig. 1 shows the main functions used to construct and implement Lte system, where black blocks use to implement (OFDMA) in downlink layer, but for the uplink layer the system uses the black and yellow blocks to implement (SC-FDMA). The paper first will show how to implement (OFDMA) then the same blocks will be used in implementing (SC-FDMA).

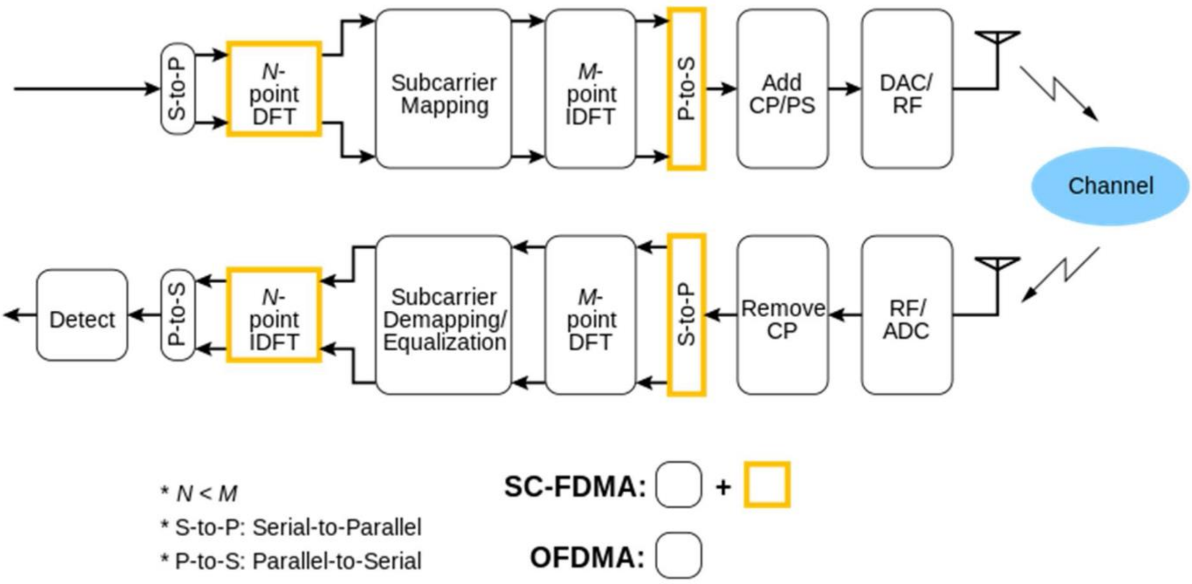

Fig. 1. OFDM A and SC-FDM A Block Diagram (Hyung et al., 2006).

1.1. Downlink Layer

Fig. 1 explains the downlink layer for the system and observes different blocks as shown below:-

1. The data will be changed from serial type to parallel type in (S-to-P block) equal to the size of the next blocks.

2. The data will change from binary bits into a series of symbols in (Subcarrier Mapping block) depending on the type of modulation. In Lte system there are three types of modulations, the first type is (QPSK) and the second type is (16QAM) finally the third type is (64QAM).

So (64QAM) gives the biggest data rate in the system meanwhile the lowest data rate provided by QPSK. In Subcarrier Mapping block there are a series of zeros will be adding (zero padding) to increase the size of mapping to be equal to the size of the next block.

3. In the block Inverse Discrete Furrier Transform (N-Pint IDFT) there is a series of frequencies will be generated its number depending on the bandwidth of the system and the most important thing is all these frequencies will be orthogonal with each other to reduce the effect of (ISI) and the overlapping of each other.

   In this block each one of the symbols will be carried by one frequency then all the signals will be added to each other to get OFDMA symbol.

4. There is a new process approved by 3GPP in Lte system called cyclic prefix insertion (CP) to reduce the effect of (ISI) and multipath over the channel. This process represented by the block (Add CP/PS). The idea of this process is copying the last part of OFDMA symbol and adding it to the start of itself in sender side with using a correlation process in receiver side to get back OFDMA symbols and removing the added parts as shown in Fig. 2.

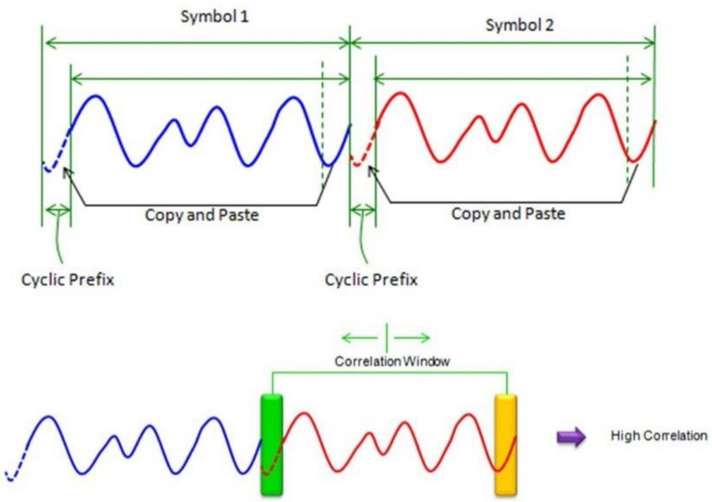

Fig. 2. Cyclic Prefix (Adding and Removing) (Share Tech Note, 2013).

There are two types of this process the first one is normal CP it copies a signal with a time equal to (4.7µs), here each slot will have 7 OFDMA symbols. The second type of CP is extended CP it copies a signal with a time equal to (16.6µs), with this type each slot will have 6 OFDMA symbols. Note that reducing the number of symbols per slot will reduce the throughput of the system but it worth when the channel has a huge (ISI) with a huge number of the multipath channel as shown in Fig. 3.

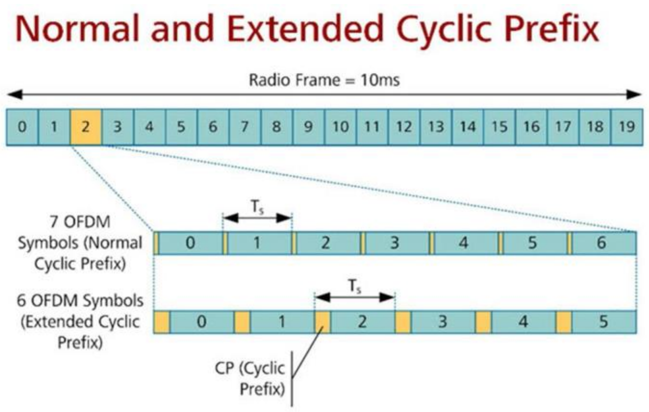

Fig. 3. Cyclic Prefix Types of Lte System (Danabayanaka, 2018).

5. The symbols will be converted from digital form into analog form in the block Digital to Analog Converter block (DAC/RF) to be transmitted through the channel.

6. In receiver side, the reverse processes will be applied on the received signals by using Analog to Digital Converter (RF/ADC) then removing Cyclic Prefix (Remove CP), a process (N- Point DFT) uses to change OFDMA symbols into a series of frequencies. To correct and get back the binary representation of data in a parallel series of bits by using the block (Subcarrier Demapping / Equalization). This series of bits will be pushed in the block (P-to-S) to change its shape from parallel form to serial form to get back the sent data.

The disadvantage of OFDMA is having high Peak to Average power Ratio (PAPR) which has high power consumption (kills the mobile battery quickly), for this reason 3GPP approved SC-FDMA in uplink layer for Lte system.

1.2. Uplink Layer

To explain data transmission in the uplink layer for Lte system we will use the same figure (Fig. 1) after adding new blocks (yellow blocks) to the system to get SC-FDMA symbols to be transmitted through the channel as shown below:-

1. The first and the most important different implementing OFDMA and SC-FDMA is adding a new process between (S-to-P and Subcarrier Mapping). This new process called M-Point Discrete Furrier Transform (M –Point DFT) with size equal to M. The main benefit of this new process is the system will have a cancellation of the effect of IDFT, so the data will be transmitted by using multicarrier for the same symbol with dividing symbol time into N Part to carry N number of SC-FDMA which will increase uplink data rate in the same time

it will reduce the value of (PAPR). There are many limitations of choosing the value of M for this process: -

M should be an even number. b. 0<<M<<N.

In the physical layer, the data will be sent as frames each one in 10ms longtime, these frames will be divided into subframes each one has (1ms) longtime, these subframes will be divided into two slots each one has (0.5ms) long time. Each slot will be divided into 7 symbols for the normal cyclic prefix (4.7µs) and it will be divided into 6 symbols for the extended cyclic prefix (16.6µs).

In the frequency domain the bandwidth will be divided into resource blocks, each one resource block has 12 subcarriers. Each one subcarrier has (15KHz) as shown in Table 1 below which contains the size of DFT process and the number of subcarriers (note that the difference between them is the number of zeros padding) as shown in Fig. 4. Table 2 shows the possible cases of M for different value of bandwidth.

Table 1. Channel bandwidths, Carrier & resource configuration for LTE system (Rohde and Schwarz, 2013).

Bandwidth	1.4 (MHz)	3 (MHz)	5 (MHz)	10	15	20
Resource Blocks Number (RB)	6	15	25	50	75	100
Number of sub-carriers	72	180	300	600	900	1200
Sub-carrier bandwidth			15 (KHz)			
Size of the DFT process	128	256	512	1024	1536	2048

Table 2. Possible cases of M can be used with the different vale of bandwidth.

Bandwidth MHz	Value of N	The possible value
1.4	128	2–72
3	256	2–180
5	512	2–300
10	1024	2–600
15	1536	2–900
20	2048	2–1200

The system uses the midpoint for the possible cases, that means it uses (M=36 for bandwidth 1.4MHz, M=90 for bandwidth 3MHz, M=150 for bandwidth 5MHz, M=300 for bandwidth 10MHz, M=450 for bandwidth 15MHz and M=600 for bandwidth 20MHz). The using of minimum value of M will provide the system low value of data rate but it will give the system high ability of detecting data stream, meanwhile using the higher value of M will provide the system higher data rate but it will give the system lower ability of detecting data stream with increasing of Bit Error Rate (BER). So the midpoint will be the best choice of using the value of M because it will give us a balance between the data rate of transmission and BER.

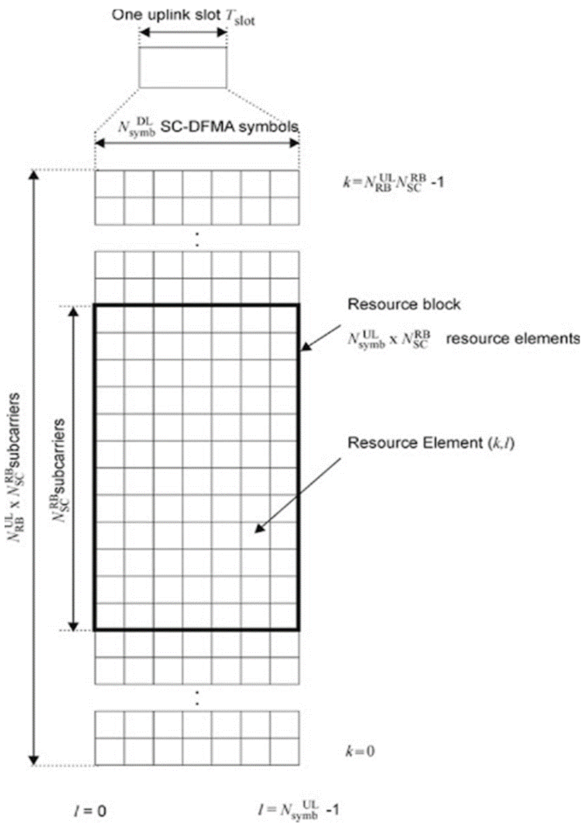

Fig. 4. LTE uplink physical resource grid (3GPP, 2009).

2. The second difference between implementing OFDMA& SC-FDMA is adding parallel to serial block (P-to-S) which will make Lte system sending the symbols over all the subcarrier in time domain one after one instead of adding them to gather and sending them as one OFDMA symbol.

The two added blocks should be added in the same place on the receiver side. The main advantage of using SC-FDMA is reducing PAPR to improve cell-edge performance and the second one transmit efficiency conserves handset battery life (reduce power consumption).

In Lte system each frame has time duration (10ms) so the duration of 1ms has 100 Lte frame, also each frame has 6 SC-FDMA symbols for extended CP but it has 7 SC-FDMA symbols for normal CP, so No. of symbol per second is 120 or 140. M is the value of DFT size. Note the type of modulation effect directly on No. of bits per one symbol before doing the IDFT process finally the equation which can be used to calculate Lte system will be as shown below:-

Data rate (b/s) = M × No. of symbols per frame × No. of frames per second × No. of bits per symbol

M is the size of DFT process.

2. EXPERI M ENTAL

In this paper a code of Matlab simulation used to simulate Lte system Release-8 running in different bandwidths (1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz & 20MHz) for fixed parameters to get the results of the uplink data rate. These results show data rate transmitted from UE to e-NB with a different value for M before pushing the symbols toward the IDFT process in the transmitter side, there are many parameters used in the simulation which fixed during all the study as shown below:-

1. The environment was a rural area.
2. The value of SNR was 15dB.
3. The speed of mobility was 3Km/h.
4. The simulation runs for a time period equal to 100 frame size which equals to (1second).
5. The duplexing was frequency division duplex (FDD).

The simulation runs for different modulation types which are QPSK (4-QAM), 16QAM & 64QAM.

3. RESULTS AND DI SCUSSI ON

The simulation run many times to get the final results that shown in graphs to explain the effect of changing the size in DFT process which implemented in sender side to get the cancelation of the effect of the IDFT process to have SC-FDMA instead of having OFDMA, this size is the value of M which increased from at least minimum (2) to the maximum value (size of IDFT). So the simulation showed data rate in (Mbit/s) for each possible case of M for many types of modulation and bandwidth also the paper shows the effect of using normal cyclic prefix or using the extended cyclic prefix in Lte system.

In Fig. 5 we deal with bandwidth (1.4MHz) which has a maximum value of IDFT size is 128 and 72 subcarrier so the value of (M) will change form (2 to 72) to get the changing in data rate in Mbit/s for many types of modulation (QPSK, 16QAM & 64QAM), each type studied in two cases the first case has normal Cyclic Prefix and the second case has extended Cyclic Prefix.

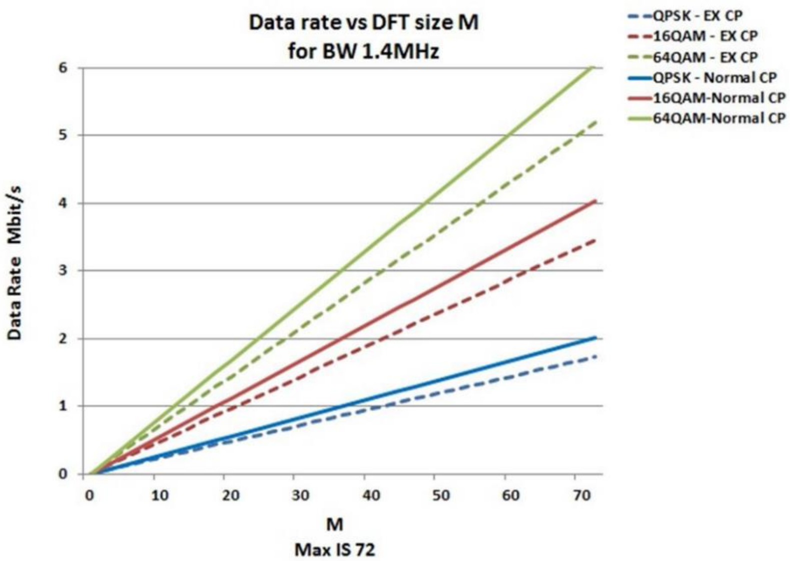

Fig. 5. Data rate vs M for BW 1.4M Hz.

So from the above graph it' s clear that increasing of M will increase data rate linearly meanwhile the value of data rate will increase when the value of modulation increases (because of increasing number of bits per each symbol), also the graph shows the system will have higher data rate if it uses normal Cyclic Prefix and it will have lower data rate if it uses extended Cyclic Prefix (each slot will have 7 symbols with normal Cyclic Prefix and 6 symbols with extended Cyclic Prefix), it' s clear here that the maximum value for M with this bandwidth will be 72. Table 3 below shows the midpoint of M when BW is 1.4MHz.

Table 3. Data rate for minimum, midpoint & maximum value of M for different cases and bandwidth 1.4M Hz.

Data Rate Mbit/s For BW 1.4MHz		M=2	M=36	M=72
extended CP	QPSK	0.048	0.864	1.728
	16QAM	0.096	1.728	3.456
	64QAM	0.144	2.592	5.184

Data Rate Mbit/s For BW 1.4MHz		M=2	M=36	M=72
Normal CP	QPSK	0.056	1.008	2.016
	16QAM	0.112	2.016	4.032
	64QAM	0.168	3.024	6.048

In Fig. 6 below the bandwidth will be (3MHz) which has a maximum value of IDFT size is 256 and 180 subcarrier so the value of (M) will change form (2 to 180) to observe the changing in data rate in Mbit/s for many types of modulation (QPSK, 16QAM & 64QAM), each type studied in two cases of Cyclic Prefix.

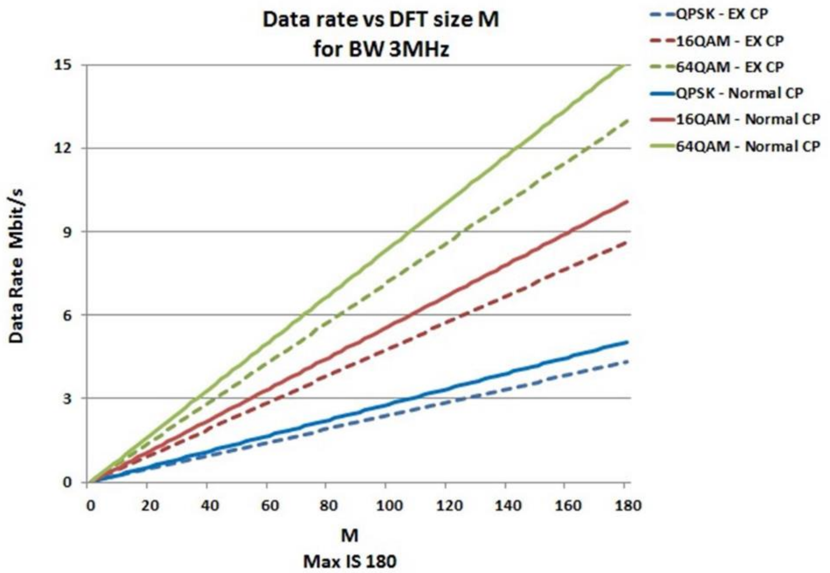

Fig. 6. Data rate vs M for BW 3M Hz.

So from the above graph it's clear that increasing of M will increase data rate linearly meanwhile the value of data rate will increase when the value of modulation increases, also the graph shows the system will have higher data rate if it uses normal Cyclic Prefix and it will have lower data rate if it uses extended Cyclic Prefix, but here the maximum value for M will be 180. Table 4 below shows the midpoint of M when BW is 3MHz.

Table 4. Data rate for minimum, midpoint & maximum value of M for different cases and bandwidth 3M Hz.

Data Rate Mbit/s For BW 3MHz		M=2	M=90	M=180
extended CP	QPSK	0.048	2.16	4.32
	16QAM	0.096	4.32	8.64
	64QAM	0.144	6.48	12.96

Data Rate Mbit/s For BW 3MHz		M=2	M=90	M=180
Normal CP	QPSK	0.056	2.52	5.04
	16QAM	0.112	5.04	10.08
	64QAM	0.168	7.56	15.12

Now the bandwidth will be (5MHz) for the experiment which has a maximum value of IDFT size is 512 and 300 subcarrier so the value of (M) will change form (2 to 300) to observe the changing of data rate in Mbit/s for many types on modulation (QPSK, 16QAM & 64QAM), each type studied in two cases of Cyclic Prefix as shown in Fig. 7.

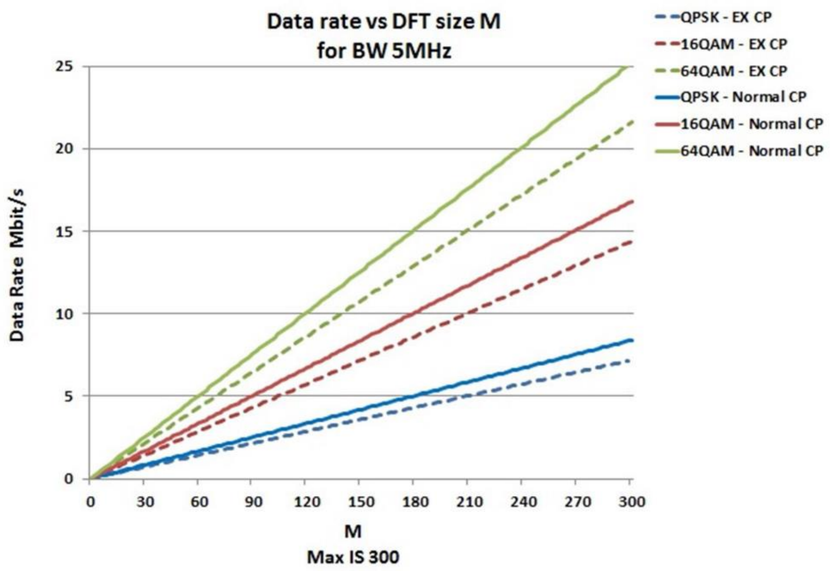

Fig. 7. Data Rate vs M for BW 5M Hz.

So from the graph it's clear that increasing of M will increase data rate linearly in the same time the value of data rate will increase when the value of modulation increases, also the grape shows the system will have higher data rate if it uses normal Cyclic Prefix and it will have lower data rate if it uses extended Cyclic Prefix, but here the maximum value for M will be 300. Table 5 below shows the midpoint of M when BW is 5MHz.

Table 5. Data rate for minimum, midpoint & maximum value of M for different cases and bandwidth 5M Hz.

Data Rate Mbit/s For BW 5MHz		M=2	M=150	M=300
extended CP	QPSK	0.048	3.6	7.2
	16QAM	0.096	7.2	14.4
	64QAM	0.144	10.8	21.6

Data Rate Mbit/s For BW 5MHz		M=2	M=90	M=180
Normal CP	QPSK	0.056	4.2	8.4
	16QAM	0.112	8.4	16.8
	64QAM	0.168	12.6	25.2

Fig. 8 will deal with bandwidth (10MHz) which has a maximum value of IDFT size is 1024 and 600 subcarrier so the value of (M) will change form (2 to 600) to observe the changing of data rate in Mbit/s for many types on modulation (QPSK, 16QAM & 64QAM), each type studied in two cases of Cyclic Prefix as shown below.

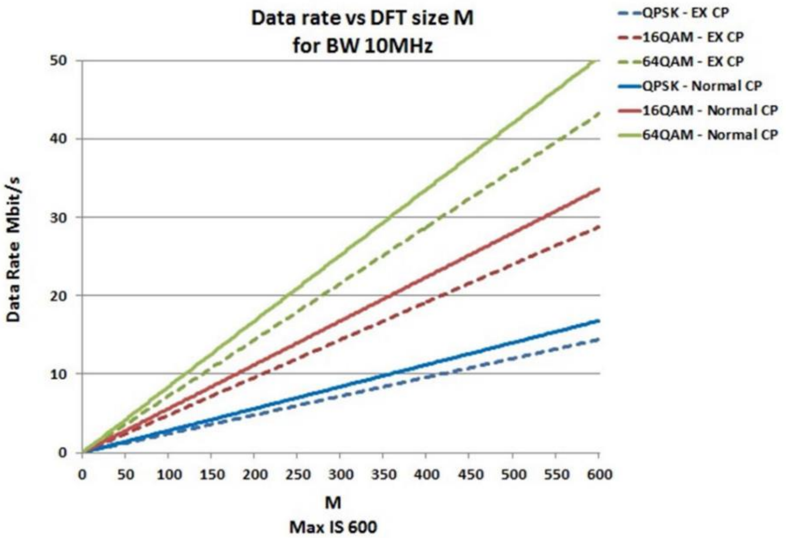

Fig. 8. Data rate vs M for BW 10M Hz.

So from the graph it's clear the increasing of M will increase data rate linearly meanwhile the value of data rate will increase when the value of modulation increases, also the grape shows the system will have higher data rate if it uses normal Cyclic Prefix and it will have lower data rate if it uses extended Cyclic Prefix, but here the maximum value for M will be 600. Table 6 below shows the midpoint of M when BW is 10MHz.

Table 6. Data rate for minimum, midpoint & maximum value of M for different cases and bandwidth 10M Hz.

Data Rate Mbit/s For BW 10MHz		M=2	M=300	M=600
extended CP	QPSK	0.048	7.2	14.4
	16QAM	0.096	14.4	28.8
	64QAM	0.144	21.6	43.2

Data Rate Mbit/s For BW 10MHz		M=2	M=300	M=600
Normal CP	QPSK	0.056	8.4	16.8
	16QAM	0.112	16.8	33.6
	64QAM	0.168	25.2	50.4

In Fig. 9 we deal with bandwidth (15MHz) which has a maximum value of IDFT size is 1536 and 900 subcarrier so the value of (M) will change form (2 to 900) to observe the changing of data rate in Mbit/s for many types on modulation (QPSK, 16QAM & 64QAM), each type studied in two cases of Cyclic Prefix.

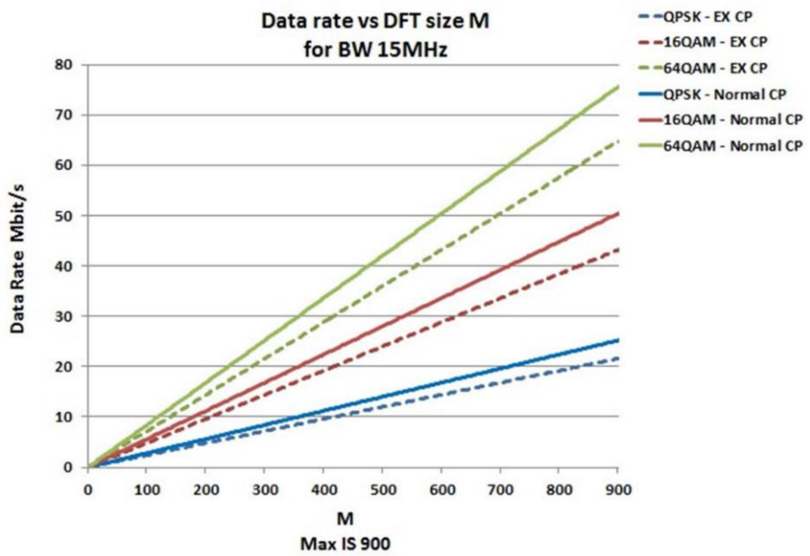

Fig. 9. Data rate vs M for BW 15M Hz.

So from the graph it's clear the increasing of M will increase data rate linearly and the value of data rate will increase when the value of modulation increases, also the grape shows the system will have higher data rate if it uses normal Cyclic Prefix and it will have lower data rate if it uses extended Cyclic Prefix, but here the maximum value for M will be 900. Table 7 below shows the midpoint of M when BW is 15MHz.

Table 7. Data rate for minimum, midpoint & maximum value of M for different cases and bandwidth 15M Hz.

Data Rate Mbit/s For BW 15MHz		M=2	M=450	M=900
extended CP	QPSK	0.048	10.8	21.6
	16QAM	0.096	21.6	43.2
	64QAM	0.144	32.4	64.8

Data Rate Mbit/s For BW 15MHz		M=2	M=450	M=900
Normal CP	QPSK	0.056	12.6	25.2
	16QAM	0.112	25.2	50.4
	64QAM	0.168	37.8	75.6

In Fig. 10 the simulation run with bandwidth (20MHz) which has a maximum value of IDFT size is 2048 and 1200 subcarrier so the value of (M) will change form (2 to 1200) to observe the changing of data rate in Mbit/s for many types on modulation (QPSK, 16QAM & 64QAM), each type studied in two cases of Cyclic Prefix.

So from the above graph it's clear the increasing of M will increase data rate linearly and we can observe the value of data rate will increase when the value of modulation increases, also the grape shows the system will have higher data rate if it uses normal Cyclic Prefix and it will have lower data rate if it uses extended Cyclic Prefix, but here the maximum value for M will be 1200. Table 8 below shows the midpoint of M when BW is 20MHz.

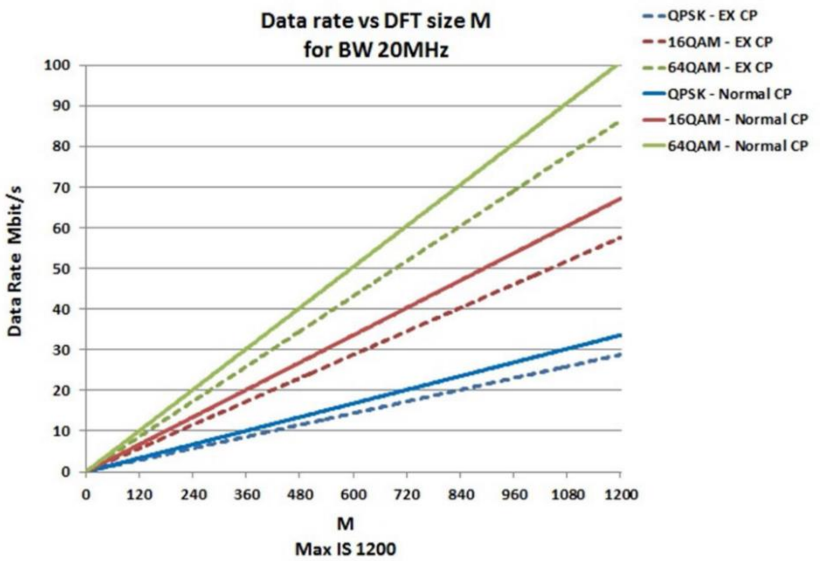

Fig. 10. Data rate vs M for BW 20MHz.

Table 8. Data rate for minimum, midpoint & maximum value of M for different cases and bandwidth 20M Hz.

Data Rate Mbit/s For BW 20MHz		M=2	M=600	M=1200
extended CP	QPSK	0.048	14.4	28.8
	16QAM	0.096	28.8	57.6
	64QAM	0.144	43.2	86.4

Data Rate Mbit/s For BW 20MHz		M=2	M=600	M=1200
Normal CP	QPSK	0.056	16.8	33.6
	16QAM	0.112	33.6	67.2
	64QAM	0.168	50.4	100.8

So as we can observe from the results above that the maximum value of Data Rate for Uplink Layer in Lte system by using SC-FDMA is (50.4Mb/s) when the system works with Bandwidth 20MHz, 64QAM modulation, normal Cyclic Prefix & the value of M is 600. Meanwhile the system has a maximum value of Data Rate for Downlink Layer in the system is (100.8Mb/s) by using OFDMA for the same parameter without using M (there is no FFT process before IFFT process in transmitter side).

4. CONCLUSI ON

The data rate in (Lte system uplink layer) will increase when the value of M (DFT process size) increases, also data date will increase when the type of modulation increases and data rate will increase with using normal Cyclic Prefix and it will decrease with using extended Cyclic Prefix. The best value of using M is using the midpoint of M for the possible cases to increase the data rate.

Using the midpoint of M will give us a balance between two parameters (data rate and the ability of data detection), finally the maximum value of data rate in the channel is (50.4Mb/s) for the uplink layer in Lte system.

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