The Impact of Cyclic Prefix on Capacity for LTE-A Using Open Loop Spatial Multiplexing

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Abstract: ***The Permanent need for increasing data rates has made the use of multiple input multiple output and orthogonal frequency division multiplexing is useful in fourth-generation networks, but some of these techniques give a reduction in the level of data transfer. The use of orthogonal frequency division multiplexing (OFDM) system for LTE depends on cyclic prefix (CP) to avoid inter-symbol and inter-carrier interference, however it is not introduce Increase system capacity, and it is wasting channel resources. In this paper, we will evaluate the impact of cyclic prefix on system capacity for two approaches, in first approach, we evaluate capacity with normal cyclic prefix and in second approach we tack the evaluation with extended cyclic prefix and make brief comparison between the two approaches. The study results show that Optimization of the signal -to-noise ratio and improve the system by increasing the number of antennas at the transmitter in Open Loop Spatial Multiplexing increases the system capacity, Finally we made a comparison between the normal cyclic prefix and extended cyclic prefix the result show that normal cyclic is better to increase the system capacity.***

Keywords: cyclic prefix, LTE, MIMO, OLSM

1. Introduction

The long term evolution Introduced new techniques to increase the data rate and reduce delay and Interference those techniques such as Orthogonal frequency division multiplexing, MIMO, transmit diversity, spatial multiplexing and cyclic prefix[1]. Despite the benefits of those technologies, but it had a negative effect on the performance of the system, because it adds more of a burden on the system and the objective of this study was to identify the cyclic prefix effect on capacity of the system.

The multiplicity of paths between sender and receiver and the obstacles such as buildings, trees and mountains generate a kind of delay that is called delay spread each signal have delay depends on the path between the transmitter and receiver so the faster signals in access is direct line-of-sight path signal.

A synchronizing process between the different delay spread component performed and adjusting their individual timings by the system before combining them but that typically in the time domain receiver, in LTE no need for this process because it operate on aggregate received signal directly.

To provide protection against multi- path delay the LTE system uses a cyclic prefix to make a guard period at the beginning of each OFDMA symbol [2].

To ensure efficiency the duration of the multi-path delay spread must be less than the duration of the cyclic prefix, the signal Suffer from low delay spread durations and high delay spread durations so LTE uses the normal cyclic prefix for the first scenario and the extended cyclic prefix for the last one.

This [3] table show cyclic prefix types

Table 1: Cyclic prefix types

	Normal Cyclic Prefix		Extended Cyclic Prefix	
	15 kHz subcarriers		15 kHz subcarriers	7.5 kHz subcarriers
	160 Ts	144 Ts	512 Ts	1024 Ts
Duration	5.2 micro s	4.7 micro s	16.7 micro s	33.3 micro s
Equivalent Distance	1.6 km	1.4 km	5 km	10 km
Overhead	160 / 2048 = 7.8 %	144 / 2048 = 7.0 %	512 / 2048 = 25 %	1024 / 4096 = 25 %

Next figure 1 represents the process of cyclic prefix:

The system Copies end of the main part of the OFDMA symbol to use it to create the cyclic prefix as shown in figure 1

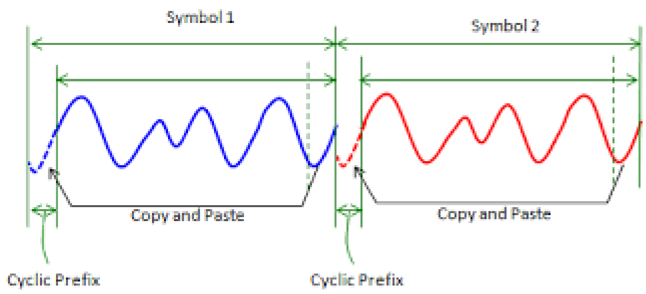

Figure 1: Cyclic prefix

2. System Model

A capacity study for the third LTE downlink transmission mode the open loop spatial multiplexing (OLSM 4X2) for case in (25, 30, 35, 40, and 100) MHz will be presented, the capacity calculations will be performed by two different approaches, the first approach takes into account the effect of the normal cyclic prefix, while the other approach takes into account the effect extended cyclic prefix and explain the differences.

2.1 The general capacity equation: [4]

$$C = w\,log_2(1+\frac{S}{N}) \qquad (1)$$

Where SNR is the signal to noise ratio and W is the effective bandwidth.

2.2 Capacity with correction factor: [5]

$$C = F * B\,log_2(1+SNR) \qquad (2)$$

Where SNR is the signal to noise ratio, B is the effective band width F is the correction factor.

2.3 Effective band width[5]

$$eB = \frac{N_{SC}*N_S*N_{rb}}{T_{sub}} \ldots\ldots\ldots\ldots\ldots (3)$$

Where N_{sc}=12 is the subcarriers in one RB, N_s is the number of OFDM symbols in one subframe (14 for normal Cyclic Prefix (CP) and 12 for extended cyclic prefix), N_{rb} is resource block 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 subframe equal to 1 ms. As it is illustrated in figure 2.6.

In one slot for normal cyclic prefix, the length of the first symbol is 5.2 microseconds while for the other six symbols the length is 4.7 microseconds, while for extended cyclic prefix the six symbols have the same length of 16.7 microseconds.

2.4 Correction factor: [5]

$$F = \frac{T_{frame} - T_{cp}}{T_{frame}} * \frac{N_{sc} * N_s/2 - R}{N_{SC} * N_s/2} \ldots\ldots\ldots\ldots\ldots (4)$$

The first part of the above equation represents the cyclic prefix loss in which 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, And the second part represents the reference symbols loss where R is the number of resource elements (RE) that carries the reference symbols in the antenna port (Reference Signal) (R) is provided to enable the user equipment (UE) to estimate the radio channel).

2.4 LTE Transmission mode 3: open-loop spatial multiplexing (OLSM 4X2)

Several data streams are transmitted over different parallel channels provided by the multiple transmit and receive antennas, figure 2 shows 4X2 MIMO.

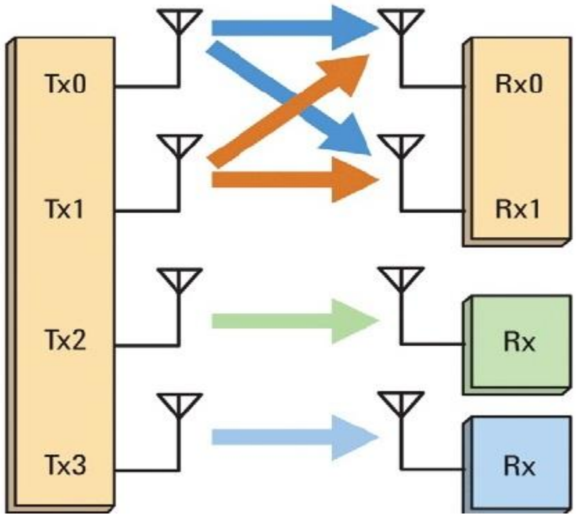

Figure 2: Multiple Input multiple Output (4X2)

The capacity for the first approach is: [5]

$$C = \min\ (N_T, N_R) * F\ \ * B\,log_2(1+SNR) \qquad (5)$$

Where min (N_T, NR) is the minimum number of the transmitting and receiving antennas.

3. Simulation Result

MATLAB tools have been used for evaluate the capacity. The figures (3to 7) below show the comparison of output curves between Signal to Noise Ratio (SNR) and capacity by the normal cyclic prefix and the extended cyclic prefix by using 4 number of transmit antenna (4), it is obviously normal cyclic prefix has better results than extended cyclic prefix and the capacity is proportional to the bandwidth.

3.1 Figures of capacity comparison:

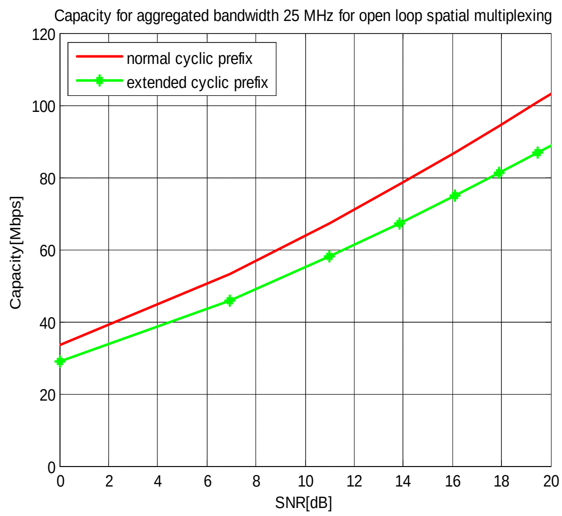

Figure 3: Capacity comparison for normal cyclic prefix and the extended cyclic prefix in 25 MHz.

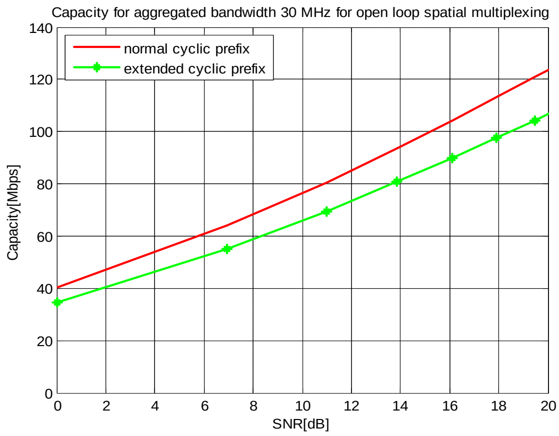

Figure 4: Capacity comparison for normal cyclic prefix and the extended cyclic prefix in 30 MHz.

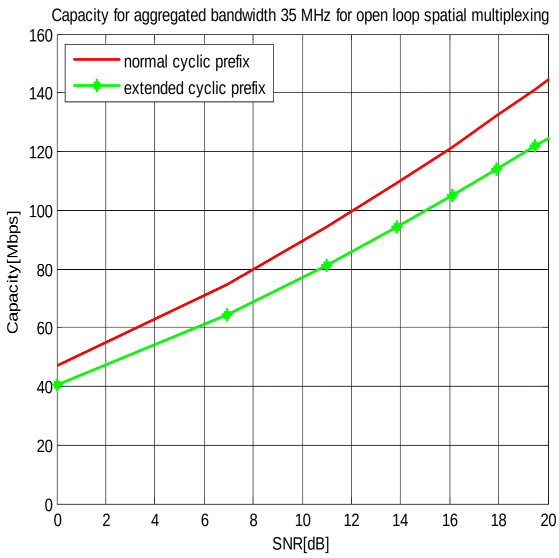

Figure 5: Capacity comparison for normal cyclic prefix and the extended cyclic prefix in 35 MHz.

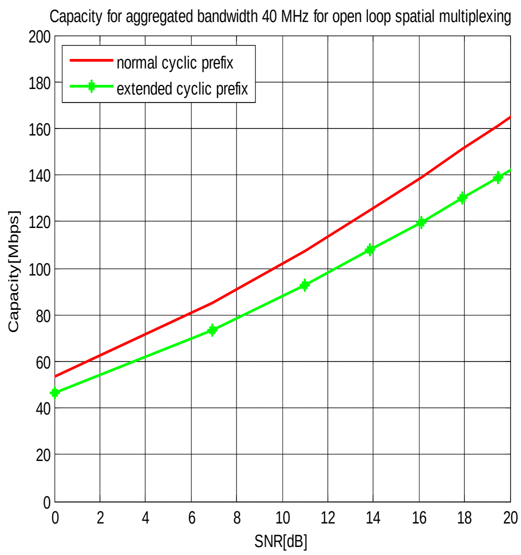

Figure 6: Capacity comparison for normal cyclic prefix and the extended cyclic prefix in 40 MHz.

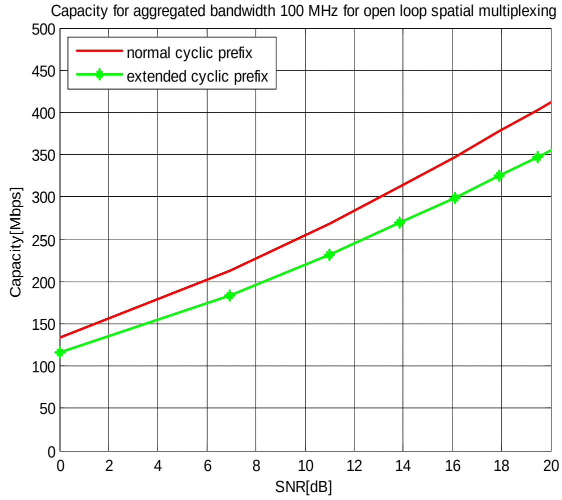

Figure 7: Capacity comparison for normal cyclic prefix and the extended cyclic prefix in 100 MHz.

3.2 Table 2 gives the numerical values of capacity comparison in Mbps for normal cyclic prefix and extended cyclic prefix in all bandwidth.

cyclic prefix	**capacity at SNR 19.46 dB**
25 MHz	
normal cyclic prefix	100.8
Extended cyclic prefix	86.94
The difference	13.86 Mbps
30 MHz	
normal cyclic prefix	120.9
Extended cyclic prefix	104.3
The difference	16.6 Mbps
35 MHz	
normal cyclic prefix	141.1
Extended cyclic prefix	121.7
The difference (in Mbps)	19.4 Mbps
40 MHz	
normal cyclic prefix	161.3
Extended cyclic prefix	139.1
The difference	22.2 Mbps
100 MHz	
normal cyclic prefix	403.1
Extended cyclic prefix	347.8
The difference	55.3 Mbps

4. Conclusion

The study results show that SNR improvement increase the capacity and the analysis show that numerical values of capacity in Mbps for normal cyclic prefix is highest than capacity in extended cyclic prefix for LTE downlink in all transmission bandwidths (25, 30, 35, 40 and 100) MHz.

This demonstrates that use the extended cyclic prefix decreases the system capacity because it has longer cyclic prefix duration than the normal cyclic prefix case.

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