AWGN Channel Capacity for Multi-Cell Interference Model in WCDMA-FDD Systems

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Summary

Cellular phones have experienced an exponential growth worldwide over the last decade with more than one billion cell phone users projected in the near future. Indeed, cellular phones have become a critical business tool and part of everyday life in most developed countries. Moreover, wireless services give us the capability of being "always on". On the other hand, service providers must support new technology and infrastructure in order to fulfill their customers' requirements. These requirements include the better quality of service (QoS), and the insurance of full service reachability without temporal or spatial restrictions, i.e., insurance of any time any where communications. Moreover, these requirements put cellular service providers in great challenge due to the limited spectrum resources and the increased number of mobile users. Hence, the wireless operators have to increase the capacity of their systems in order to meet the level of demand but with data rates not are more than maximum channel data rate. In This Paper, the effect of increasing channel bandwidth and transmitted signal power on the maximum data rate that can be transmitted on the channel with small amount of errors (Maximum channel capacity) was considered. The analysis was carried out for speech and data users with different data rates for two types of channels: AWGN channel neglecting inter-cell and intra-cell interference , and AWGN channel with both inter-cell and intra-cell interference for Multi-cell WCDMA-FDD interference parameters (7-cells). It was noticed as a conclusion drawn from this Paper that to increase the number of users it is required to increase the channel bandwidth or increase the received signal power by increasing the transmitted signal power.

Keywords:
Claude Shannon, CDMA, WCDMA, Mobile communications, Channel Capacity.

I. Introduction

The growing demand for wireless communication makes it important to determine the capacity limits of these wireless channels. These capacity limits dictate the maximum data rates that can be achieved without any constraints on delay or complexity of the encoder and decoder.

Channel capacity was pioneered by Claude Shannon [1], where he developed a mathematical theory of communication based on the notion of mutual information between the input and output of a channel. Shannon defined capacity as the mutual information maximized over all possible input distributions. The significance of this mathematical construct was Shannon's coding theorem and converse, which proved that a code did exist that could achieve a data rate close to capacity with negligible probability of error, and that any data rate higher than capacity could not be achieved without an error probability bounded away from zero.

II. Analysis and System Model

Consider a discrete-time additive white Gaussian noise (AWGN) channel with channel input/output relationship y(i) = x(i) + n(i), where x(i) is the channel input at time i, y(i) is the corresponding channel output, and n(i) is a white Gaussian noise random process as shown in figure (1) .

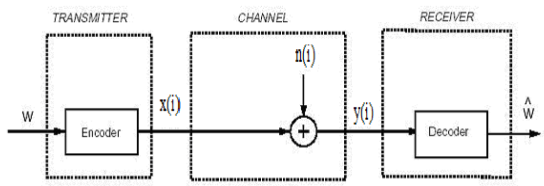

Figure 1

Assume a channel bandwidth W and transmit Power S_t. To calculate the channel SNR, the power in x(i) divided by the power in n(i), is constant and given by $\gamma = S_r/(\eta_0.W)$, where η_0 is the power spectral density of the noise. The capacity of this channel is given by Shannon's well-known formula [1].

$$C = R_{\max} = W.Log_2(1+SNR) = W.Log_2(1+\gamma) \quad (1)$$

Where the capacity units are bits/second (bps). Shannon's coding theorem proves that a code exists that achieves data rates arbitrarily close to capacity with arbitrarily small probability of bit error. The converse theorem shows that any code with rate R > C has a probability of error bounded away from zero.

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1- WCDMA-FDD Channel Capacity with AWGN

Assuming presence of thermal noise and Neglecting Intra-cell and Inter-cell interference so the SNR will be as follows:

$$\gamma = SNR = \frac{S_r}{N_p} = \frac{S_r}{\eta_o.W} \quad (2)$$

So the Channel capacity may be expressed as:

$$C = R_{\max} = W.Log_2(1+\frac{S_r}{\eta_o.W}) = W.Log_2(1+\frac{S_r}{N_p}) \quad (3)$$

When the bandwidth is increased without limit; channel Capacity will be calculated as follows:

$$Let\ \mathrm{x} = \frac{\mathrm{S_r}}{\eta_o.W},\ \mathrm{so}: \frac{1}{\mathrm{x}} = \frac{\eta_o.W}{\mathrm{S_r}},\ \mathrm{so}: \mathrm{W}\ \alpha\ \frac{1}{\mathrm{x}}$$

$$C = R_{\max} = \lim_{W \approx \infty} \frac{S_r}{\eta_o}.\frac{W.\eta_o}{S_r}.Log_2(1+\frac{S_r}{\eta_o.W})$$

$$C = R_{\max} = \lim_{W \approx \infty} \frac{S_r}{\eta_o}.Log_2(1+\frac{S_r}{\eta_o.W})^{\frac{W.\eta_o}{S_r}}$$

$$C = R_{\max} = \lim_{x \approx 0} \frac{S_r}{\eta_o}.Log_2(1+x)^{\frac{1}{x}} = \frac{S_r}{\eta_o} Log_2(e)$$

$$C_{W \approx \infty} = (1.44)\frac{S_r}{\eta_o} \quad (4)$$

Equation (4) states that When no restrictions on bandwidth the Capacity will be directly proportional to the received signal power

2- WCDMA Channel Capacity with AWGN and interference

Assuming the presence of thermal noise, Intra-cell and Inter-cell interference for multi-cell WCDMA communication system for seven cell interference model as shown in figure 2 [2].

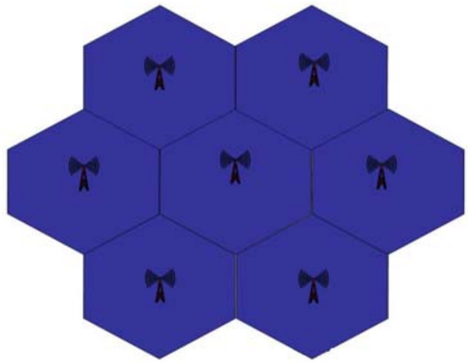

Figure 2

The SNR can be expressed as:

$$\gamma = SNR = \frac{S_r}{N_p + I_{own} + I_{other}} = \frac{S_r}{\eta_o.W + I_{own} + I_{other}} \quad (5)$$

Where: I_{own} is the interference come from the same cell users and I_{other} is the interference come from other cell users. So the Channel capacity may be expressed as:

$$C = R_{\max} = W.Log_2(1+\frac{S_r}{\eta_o.W + I_{own} + I_{other}})$$

$$= W.Log_2(1+\frac{S_r}{N_p + I_{own} + I_{other}})$$

Or

$$C = R_{\max} = W.Log_2\left(1+\frac{S_r}{N_p + (N-1).S_r + N.(K-1).S_I}\right)$$

Where K is the number of cells in interference model and N is the number of users per cell .For simplified path loss model, the received power may be expressed as:

$$P_r = P_t.(\frac{\lambda}{4\pi d_o})^2.(\frac{d_o}{d})^\gamma.G_b.G_m$$

$$P_r\,\alpha\,(\frac{1}{d})^\gamma$$

$$\frac{P_{r1}}{P_{r2}} = (\frac{d_2}{d_1})^\gamma$$

$$for:\ P_{r1} = S_r\ \text{and}\ P_{r2} = S_i$$

Assume that the distance between each MS and BS in the neighbor cells is neglected as compared with the distance between the two base stations which is equal to $\sqrt{3}R$, therefore:

$$d_1 = R \text{ and } d_2 = \sqrt{3}R$$

$$\text{And}: S_I = (\frac{R}{\sqrt{3}R})^{\gamma}.S_r = (\frac{1}{\sqrt{3}})^{\gamma}.S_r :$$
$$\textit{for} \text{ minimum received power}$$

Using the above definitions the channel capacity may be expressed as:

$$C = R_{\max} = W.Log_2\left(1 + \frac{S_r}{N_p + (N-1).S_r + N.(K-1)\left(\frac{1}{\sqrt{3}}\right)^3.S_r}\right) \quad (6)$$

Or

$$C = R_{\max} = W.Log_2\left(1 + \frac{1}{\frac{N_p}{S_r} + (N-1) + N.(K-1)\left(\frac{1}{\sqrt{3}}\right)^3}\right) \quad (7)$$

Where K is the number of cells per system (which is assumed to be 7 cells for the first tier interference model) and N is the average number of users per cell. Using the above definitions, equation (7) can be written as:

$$C = R_{\max} = W.Log_2\left(1 + \frac{1}{\frac{\eta_o.W}{S_r} + (N-1) + N.(7-1)\left(\frac{1}{\sqrt{3}}\right)^3}\right) \quad (8)$$

The system parameters used in simulation for both voice and data users are shown in tables 1 and 2.

Table (1): WCDMA system parameters for Voice users, [3].

Bandwidth	Received Signal power	$\eta = \frac{N_z}{W_s}$	SNR	Bit rate	P.G.
5 MHz	$1.612*10^{-11}$ w	10^{-16}	0.03224= -14.9 dB	12.5kbps	400
				44kbps	114
10 MHz	$1.612*10^{-11}$ w	10^{-16}	0.01612= -17.9 dB	12.5kbps	800
				44kbps	228
20 MHz	$1.612*10^{-11}$ w	10^{-16}	0.00806= -20.9 dB	12.5kbps	1600
				44kbps	456

Table (2): WCDMA system parameters for data users, [3].

Bandwidth	Received Signal power	$\eta = \frac{N_z}{W_s}$	SNR	Bit rate for data	P.G.
5 MHz	$7.9433*10^{-11}$ w = -101 dB	10^{-16}	0.158866= -7.99 dB	144kbps	34.7
				384kbps	13
10 MHz	$7.9433*10^{-11}$ w = -101 dB	10^{-16}	0.079433= -11 dB	144kbps	69.4
				384kbps	26
20 MHz	$7.9433*10^{-11}$ w = -101 dB	10^{-16}	0.0397165= -14 dB	144kbps	138.8
				384kbps	52

III. Simulation Results

1- WCDMA-FDD Channel Capacity with AWGN

Assuming voice transmission for speech users; the relation between the channel capacity and Bandwidth is shown in figure (3).

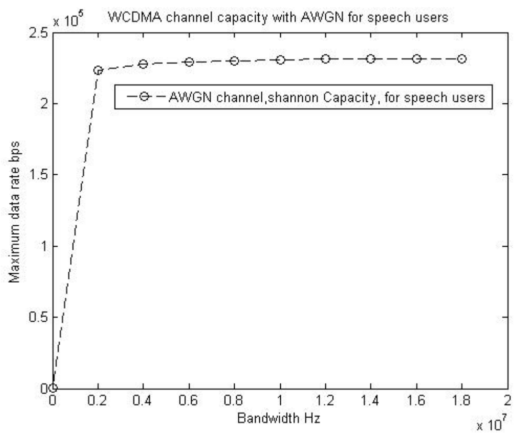

Figure 3

For data Users, the relation between the channel capacity and Bandwidth is shown in figure (4).

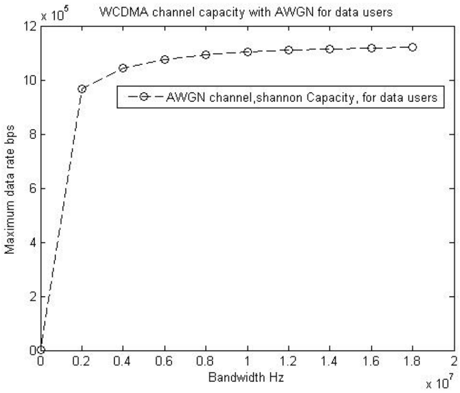

Figure 4

Figures(5, 6, and 7) show the maximum channel data rate of WCDMA Communication system for different number of speech and data users with AWGN as a function of bandwidth, Neglecting inter-cell, and intra-cell interference. It is shown that the Channel capacity is directly proportional to the B.W. and increasing channel bandwidth will increase the channel capacity at the same SNR.

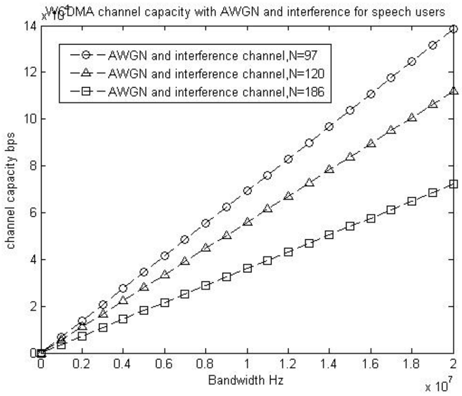

Figure 5

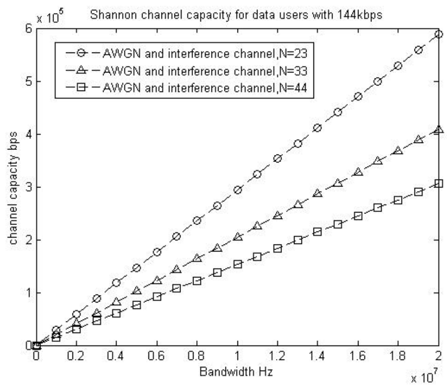

Figure 6

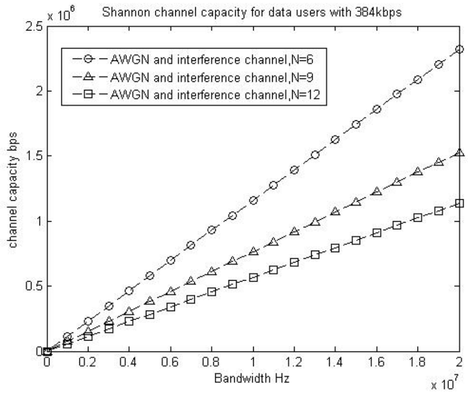

Figure 7

And the following table shows the Channel Capacity for speech and data users using three channel bandwidths 5, 10, 20 MHz.

Table (3): WCDMA channel Capacity with AWGN

Channel Bandwidth	5 MHz	10 MHz	20 MHz
Channel Capacity for speech users	228 kbps	230 kbps	231 kbps
Channel Capacity for data users	1.0636Mbps	1.102Mbps	1.1238Mbps

From table (3) it can be seen that the channel capacity is independent on channel bandwidth for large values of bandwidth as shown in equation (4) for constant signal to interference ratio.

2- WCDMA Channel Capacity with AWGN and interference

For speech users; the relation between the channel capacity and the average number of users per cell with different values of channel bandwidth is shown in figure (8). For data users; the relation between the channel capacity and the average number of users per cell with different values of bandwidth is shown in figure (9).

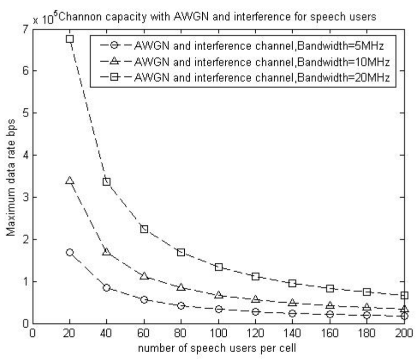

Figure 8

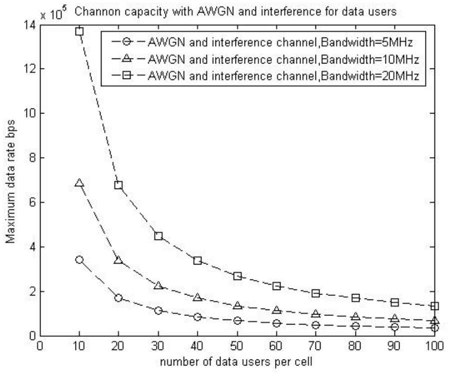

Figure 9

From Figures (8,9) and table (3) it is shown that for the same bandwidth of WCDMA multi-cell communication system with AWGN , inter-cell , and intra-cell interference the channel capacity increases as the number of users decrease .

Figure (10) shows that the channel capacity of WCDMA multi-cell communication system with AWGN , inter-cell , and intra-cell interference is directly proportional to the SNR at fixed number of users ; Therefore, for more QoS the SNR must be increased.

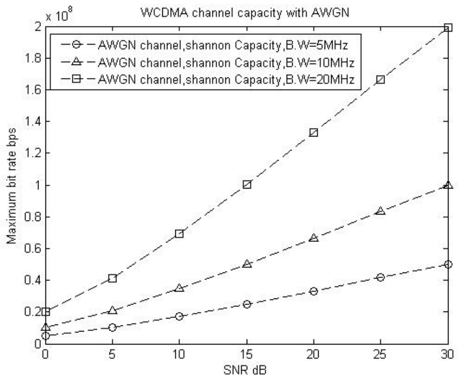

Figure 10

Table (4) shows the effect of increasing number of speech or data users and increasing data rate on channel capacity (maximum channel data rate) using AWGN channel with inter-cell and intra-cell interference for WCDMA seven cells interference model.

IV. Conclusion

This Paper is concerned with the effect of increasing channel bandwidth and transmitted signal power on the maximum data rate which can be transmitted on the channel with less frequent error (Maximum channel capacity). The analysis is made for speech and data users with different data rates on two types of channels , the first was the AWGN channel neglecting inter-cell and intra-cell interference , and the second was AWGN channel with both inter-cell and intra-cell interference using Multi-cell WCDMA interference.

Table (4): WCDMA channel Capacity with AWGN and interference

Type of Users	N	B.W.=5 MHz	B.W.=10 MHz	B.W.=20 MHz
Speech user 12.5 kbps	97	C=3.459 $*10^{4}$bps	C=6.919 $*10^{4}$bps	C=1.3838 $*10^{5}$bps
Speech user 12.5 kbps	120	C=2.7952 $*10^{4}$bps	C=5.5905 $*10^{4}$bps	C=1.1181 $*10^{5}$bps
Speech user 12.5 kbps	186	C=1.8021 $*10^{4}$bps	C=3.6043 $*10^{4}$bps	C=1.0085 $*10^{5}$bps
Data users 144 kbps	23	C=1.4704 $*10^{5}$ bps	C=2.9409 $*10^{5}$ bps	C=5.8818 $*10^{5}$ bps
Data users 144 kbps	33	C=1.0217 $*10^{5}$ bps	C=2.0434 $*10^{5}$ bps	C= 4.0867 $*10^{5}$ bps
Data users 144 kbps	44	C=7.6490 $*10^{4}$ bps	C=1.5298 $*10^{5}$ bps	C=3.0596 $*10^{5}$ bps
Data users 384 kbps	6	C=5.8073 $*10^{5}$ bps	C=1.1615 $*10^{6}$ bps	C=2.3229 $*10^{6}$ bps
Data users 384 kbps	9	C=3.8191 $*10^{5}$ bps	C=7.6382 $*10^{5}$ bps	C=1.5276 $*10^{6}$ bps
Data users 384 kbps	12	C=2.8452 $*10^{5}$ bps	C=5.6904 $*10^{5}$ bps	C=1.1381 $*10^{6}$ bps

It may be concluded that the channel capacity for AWGN may be increased by increasing Channel Bandwidth or increasing the receive signal to noise ratio. On the other band for both inter-cell and intra-cell interference channel model, the channel capacity may be increased by increasing Channel Bandwidth or increasing the receive signal to noise ratio.

The last conclusion that can be drawn from this chapter is that the WCDMA capacity is inversely proportional to the Channel Capacity.

V. References

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