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Capacity Improvement by Cell Splitting Technique in CDMA System over Telecommunication Network

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ABSTRACT:- *In this paper, we analyze the performance of CDMA system in telecommunication by using cell splitting technique to divide a biggest macro cell into micro, pico and femto cells. We have calculated the processing gain, number of subscribers requesting for service within each type of cell, user-transmitted in-band signal power to achieve desired SNR, probability that a call attempt fails and also compared the results by simulating their equations using MATLAB simulation software.*

Index Terms:- CDMA, processing gain, cell splitting, macro cell, microcell, pico cell, femto cell.

I. INTRODUCTION

In telecommunication, there are different types of multiple access techniques which are used to allow many mobile subscribers to share a finite amount of radio spectrum simultaneously. To achieve high capacity, the available spectrum is shared by allocating the channels (or bandwidth) to multiple subscribers simultaneously. The different multiple access techniques are as follows:

(A) Frequency Division Multiple Access (FDMA),
(B) Time Division Multiple Access (TDMA) , and
(C) Code Division Multiple Access (CDMA).

(A) Frequency Division Multiple Access (FDMA):

In frequency division multiple access (FDMA) technique, the available frequency band is divided into number of frequency channels allocated to all the subscribers to use at the same time simultaneously.

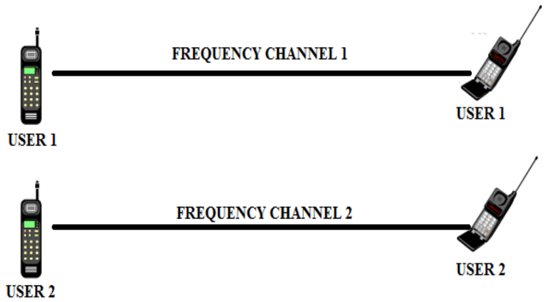

Figure (1): FDMA where different subscribers are assigned different frequency channels.

In FDMA, a unique frequency band or channel is assigned to each subscriber on demand when they require service. Any user can not share the same frequency band which is already assigned to other user. FDMA is an analog technology and has limited capacity. If an FDMA channel assigned to a particular subscriber which is not in use, then it cannot be used by other users to increase or share capacity, which is wastage of resource.

(B) Time Division Multiple Access (TDMA):

In time division multiple access (TDMA) technique, same available frequency band is allocated to all the users to use at different time slots.

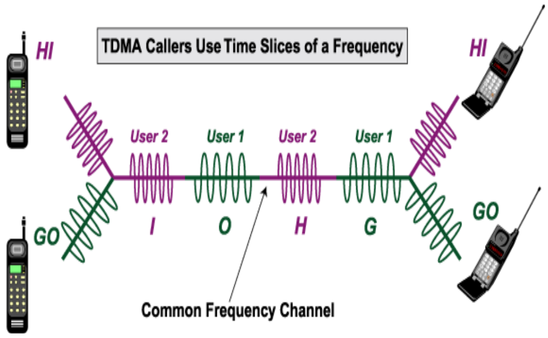

Figure (2): TDMA where different subscribers are assigned same frequency channel (band) at different time slots.

In TDMA, subscribers share a common channel or frequency, but use the channel only for a shorter time. Each subscriber is given a time slot and is allowed to transmit or receive during that time slot only. If all the available time slots in a given channel or frequency are used by the subscribers, then the next subscriber must be assigned to a time slot on another frequency.

(C) Code Division Multiple Access (CDMA)

CDMA is a code division multiple access technique which shares a common communication channel between multiple users simultaneously by assigning unique code to each user. In CDMA systems, a signal with very large bandwidth i.e. spreading signal is multiplied to the narrow band message signal. This spreading signal is a pseudo-noise (PN) sequence having chip rate greater than the bit rate (or data rate) of the message. The rate of generating pseudo random codeword is called chip rate (R_c). The bit rate or data rate (R_b) is baseband user information (i.e. user voice/data) rate. In CDMA, voice is digitized at different rates depending on the speech activity level. The ratio of chip rate to the data rate or information bit rate is processing gain. Processing gain measures the interference sensitivity for CDMA receivers. Processing gain is also sometimes known as spreading gain.

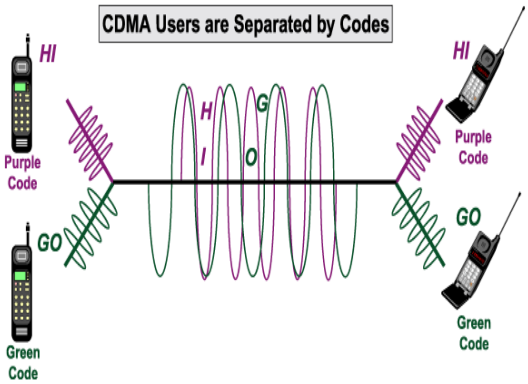

Figure (3): CDMA where different subscribers are assigned same frequency band simultaneously at the same time.

Larger the value of processing gain, larger is the coverage of each cell in CDMA system. Because as the processing gain increases, user-transmitted in-band signal power required or necessary to achieve a desired signal to noise ratio becomes less. In a CDMA system, all subscribers use the same frequency channel or carrier and transmit simultaneously. Each subscriber has a unique pseudo random codeword which is orthogonal to other codewords. At the destination, a time correlation operation is performed by the receiver to detect the desired codeword while other codewords are considered as noise due to decorrelation. The receiver needs to know the codeword used by the transmitter to detect the message signal. Each user independently operates without having knowledge of the other users. There are so many advantages of CDMA technology based mobile communication systems such as large capacity, good voice quality [1], [2]. The CDMA mobile communication network has a mobile switching centre (MSC), BSCs (Base Station Controllers), BTSs (Base Transceiver Stations), mobile stations (MSs), a visitor location register (VLR) and a home location register (HLR). CDMA is an advantageous technique for wireless communication. It has advantages over other multiple-access schemes, for example, higher spectral reuse efficiency, greater immunity to multipath fading, gradual overload capability, simple exploitation of sectorization and voice inactivity, and more robust handoff procedures [1], [3].

A CDMA system had been proposed for mobile communications as early as 1978 [4]. In 1980's Qualcomm confirmed practicability of implementing such type of CDMA system [5], [6], [7]. Some higher layer issues such as call admission control, analysis of soft handoff, and the effects of gradual overload and imperfect power control on capacity have also been considered [8], [9].

II. SYSTEM MODEL

Here, we consider a location area having a combination of larger cells which are further split into smaller cells to improve the capacity of the system. This is called cell splitting technique. In cell splitting, the highly congested larger cells (macro cells) are divided into smaller cells (micro, pico and femto cells etc.) each with their own base station and set of frequency channels. In cell splitting, a large number of low power transmitters take over an area previously served by a single, higher powered transmitter. Reduction of cell-radius makes the cell capable to handle extra traffic.

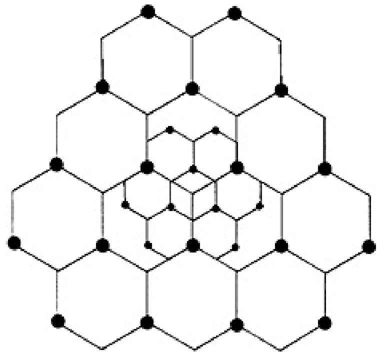

Figure (4): Cell Splitting

When the traffic load on a particular site is generated, then more numbers of base stations are required to provide service to the customers. Each cell consists of one base station i.e. BTS (Base Transceiver Station). So, here we have divided the larger macro cell into micro, pico and femto cells. These new cells have smaller radius than the larger cell and capacity increases as the number of channels per unit area increases [10]. Trunking inefficiencies experienced by sectored cells are not faced by Cell splitting technique. It enables the base station to oversee all handoff chores related to the microcells and reduces the computational load at the mobile switching centre (MSC) [11].

(A) Macro cell:

Macro cells are the larger cells having radius 1 mile and 15 miles. A macro cell uses a high power cellular base station (tower) to provide radio coverage. The transmit power range of macro cells is in the range of tens of watts. For macro cells, antennas are mounted on ground-based masts, rooftops and other existing structures, with a height providing a clear view over the surrounding buildings and terrain.

(B) Micro cell:

A micro cell covers a limited area such as a hotel, a mall, or a transportation hub. It is served by a low power cellular base station (tower). The range of a micro cell is less than two kilometres wide, while standard base stations may have ranges of up to 35 kilometres (22 mi). The transmit power range of micro cells is in the range of 5 Watts. A micro cell provides flexibility in site acquisition and improvement in economics compared to conventional cell splitting.

(C) Pico cell:

The range of a pico cell is 200 meters or less. The transmit power range of pico cells is in the range of 200 mW. With lower power pico cells, operators can benefit from a scale advantage on the parts used compared to larger power nodes, due to their similarities with handsets. A pico cell covers a small area, such as in-building (offices, shopping malls, train stations, stock exchanges, etc.), or more recently in-aircraft using small cellular basestation.

(D) Femto cell:

A femto cell is a small in size with low-power cellular base station which is used in a home or small business. The transmit power range of femto cells is in the range of less than 200 mW. A femto cell improves coverage and capacity. The range of a femto cell is on the order of 10 meters. In rural areas, femto cells can be used to give coverage.

III. PERFORMANCE ANALYSIS

We analyze the performance of telecommunication system in CDMA technology by using the equation of processing gain within each type of cell.

(A) Chip Rate:

In a CDMA system, each subscriber has a unique pseudo random codeword which is orthogonal to other codewords. The rate to generate pseudo random codeword is called chip rate (R_c).

(B) Bit Rate:

The bit rate or data rate (R_b) is baseband user information (i.e. user voice/data) rate. In CDMA, voice is digitized at different rates depending on the speech activity level.

(C) Processing Gain:

Processing gain is the ratio of chip rate to the data rate or information bit rate. Processing gain measures the interference sensitivity for CDMA receivers. Processing gain is also sometimes known as spreading gain. Larger the value of processing gain, larger is the coverage of each cell in CDMA system. Because as the processing gain increases, user-transmitted in-band signal power required or necessary to achieve a desired signal to noise ratio becomes less.

$$\boldsymbol{Processing\ Gain\ (P_g) = \frac{R_c}{R_b}} \qquad \textbf{(1)}$$

For CDMA chip rate (R_c) = 1.2288 Mega chips per second, bit rate (R_b) = 9.6 kbps.
Then processing gain,

$$\boldsymbol{(P_g) = \frac{1.2288 * 10^6 chips\ per\ second}{9.6 * 10^3 bits\ per\ second}}$$

$$\boldsymbol{P_g = 128}$$

$$\boldsymbol{P_g in\ dB = 10\ log_{10}(128) = 21.07\ dB}$$

or

$\boldsymbol{P_g in\ dB = 21\ dB\ \ (approximately)}$ for single subscriber.

Table : No. of Subscribers and Processing Gain

No. of Subscribers	Processing Gain
1	21 dB
2	18 dB
4	15 dB
8	12 dB
16	9 dB
32	6 dB

This table shows that, as the number of subscribers are increasing by multiple of 2 (i.e doubles), the processing gain reduces by 3 dB. Generally, if there are *S* number of subscribers supported by CDMA system, then

$$\boldsymbol{Processing\ Gain}$$

$$\boldsymbol{(P_g) = 21dB - (n * 3dB)} \qquad \textbf{(2)}$$

Where, $\boldsymbol{n = \frac{log_{10}(S)}{log_{10}(2)}}$ **(3)**

and number of subscribers supported by CDMA system

$$\boldsymbol{S = 10^{(n * log_{10}(2))}} \qquad \textbf{(4)}$$

For example, if number of subscribers, ***S=4***,

Then $\boldsymbol{n = \frac{log_{10}(4)}{log_{10}(2)} = 2}$

And

$$\boldsymbol{Processing\ Gain}$$

$\left(P_g\right) = 21dB - (2 * 3dB) = 15\ dB$ as shown in the table and so on.

Now to put the value of n into equation **(2),** we get

$$\left(P_g\right) = 21dB - \left(\left(\frac{log_{10}(S)}{log_{10}(2)}\right) * 3dB\right) \quad \textbf{(5)}$$

From equation **(1)**, it is clear that if the data rate or bit rate of subscriber's information increases, the processing gain decreases. As the number of users supported by a cell increases at a particular time, it means the information rate (or bit rate) of those subscribers increases at that site and processing gain of the current cell serving the users decreases.

We also know that, in a CDMA system, processing gain may be used to determine the received bit signal to noise ratio (SNR), that is,

$$\frac{E_b}{N_o} = Pg * \frac{P_u}{I_o} \quad \textbf{(6)}$$

Where, P_u is user-transmitted in-band signal power to achieve desired SNR $\left(\frac{E_b}{N_o}\right)$.

I_o is the interference level or value. SNR increases linearly with processing gain. As the value of processing gain increases, the coverage range of each cell in CDMA system increases. If the value of desired SNR is constant, interference level is constant, then to achieve desired signal to noise ratio (SNR), user-transmitted in-band signal power (P_u) decreases with an increase in the value of processing gain within that particular cell (or site).

(D) Erlang's Formula:

In 1909, some 30 years after the inauguration of first public telephone network, there was a mathematician A. K. Erlang who was working for the Copenhagen Telephone Company [12]. According to present report on NSF program FIND (Future Internet design), "Erlang formulas" for the Internet is an important open issue for future research [13]. A is the traffic intensity within the system, i.e.

$$A = \lambda * s \quad \textbf{(7)}$$

where, λ is call arrivals occurring rate (number of carried connections per unit of time) and s is mean holding time. Then the probability that a call attempt fails is given by Erlang's formula

$$E(n, A) = \frac{\frac{A^n}{n!}}{1 + A + \frac{A^2}{2!} + \cdots + \frac{A^n}{n!}} \quad \textbf{(8)}$$

n is number of MODEMs used in a MODEM pool of a cell or site.

If there are n = 4 modems in a modem pool and the offered traffic intensity is A = 2 erlang, then by Erlang's formula

$$E(4, 2) = \frac{\frac{2^4}{4!}}{1 + 2 + \frac{2^2}{2!} + \frac{2^3}{3!} + \frac{2^4}{4!}} = 9.5238\% = 9.5\%$$

i.e. the probability that a call attempt fails is 9.5% which indicates the quality of service. Smaller the value of probability that a call attempt fails, better is the quality of service within that cell.

If there are number of modems n=6, and the offered traffic intensity is A = 2 erlang, then

$$E(6, 2) = \frac{\frac{2^6}{6!}}{1 + 2 + \frac{2^2}{2!} + \frac{2^3}{3!} + \frac{2^4}{4!} + \frac{2^5}{5!} + \frac{2^6}{6!}} = 1.208459\% = 1.2\%$$

i.e. the probability that a call attempt fails is 1.2% which indicates improvement in the quality of service. Hence as the number of modems increases, probability of a call attempt failure decreases (if offered traffic is same for both the cases i.e. A=2 erlang). But in different larger and smaller cells offered traffic also varies.

IV. SIMULATION RESULTS

In this section, we have shown our results of processing gain in macro cell, in micro cell, in pico cell and in femto cell versus time (time may be considered in hours or any other unit of time). Here, we have considered time in hours. We get the simulated results using MATLAB software. In figure (5), we can see that processing gain is minimum in macro cell and is maximum in femto cell. As we split the larger congested macro cell into smaller micro, pico and femto cells, more number of subscribers are handled by more than one base station, due to which processing gain of the site to process the traffic generated by subscribers increases from a lower value in case of macro cell to higher value in case of micro and pico cells and highest value in case of femto cell.

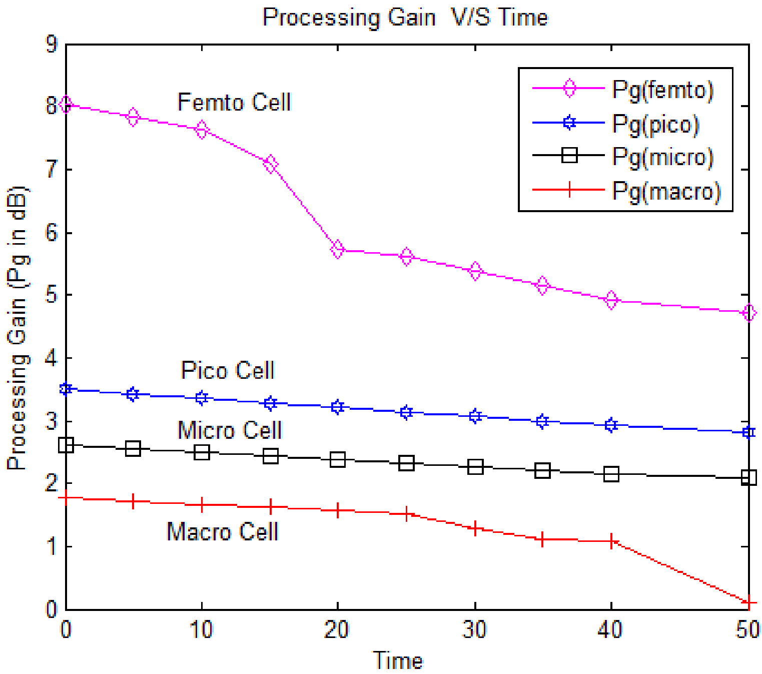

Figure (5): Processing Gain V/S Time

Suppose if we determine the performance of a site at a particular time t=5 hours, then our simulation result shows that :

processing gain in macro cell= 1.7212 dB, processing gain in micro cell= 2.5508 dB, processing gain in pico cell= 3.4261 dB, and processing gain in femto cell= 7.8230 dB

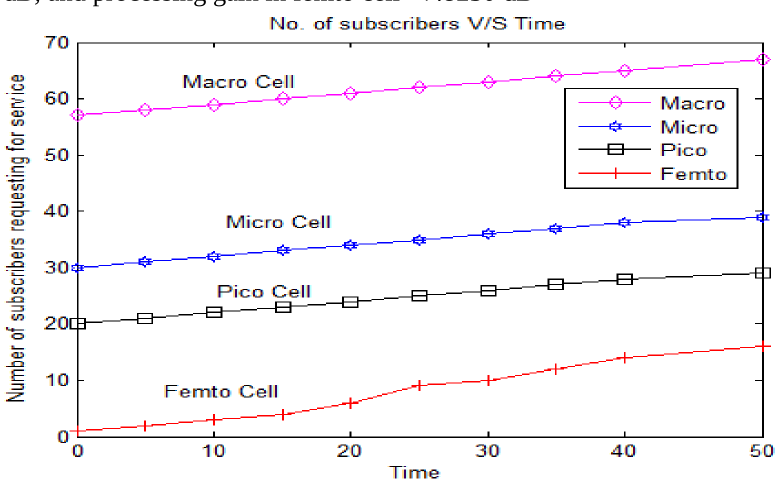

Figure (6): Number of subscribers V/S Time

Figure (6) shows that the number of subscribers requesting to get service in macro cell are increasing with time due to larger size while micro cell, pico cell and femto cell have less number of subscribers-requests per unit of time due to smaller size of these cells.

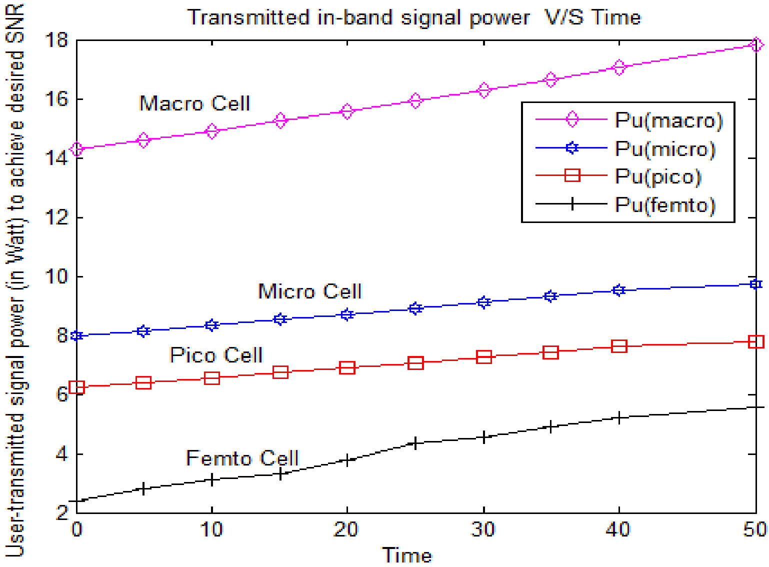

Figure (7): **Transmitted in-band signal power V/S Time**

Figure (7) shows that larger the value of processing gain in CDMA system, smaller is the value of user-transmitted in-band signal power to achieve desired SNR in macro, micro, pico and femto cells. Macro cell is the biggest cell, that is why it requires high value of user-transmitted in-band signal power to cover larger area of cell, while in smallest area of femto cell, user-transmitted in-band signal power to achieve desired SNR is least to cover smallest area because femto cell has highest processing gain. We have observed these simulated results of macro site, micro, pico and femto cells (or sites) per unit of time. Time may be considered in hours or any other unit of time.

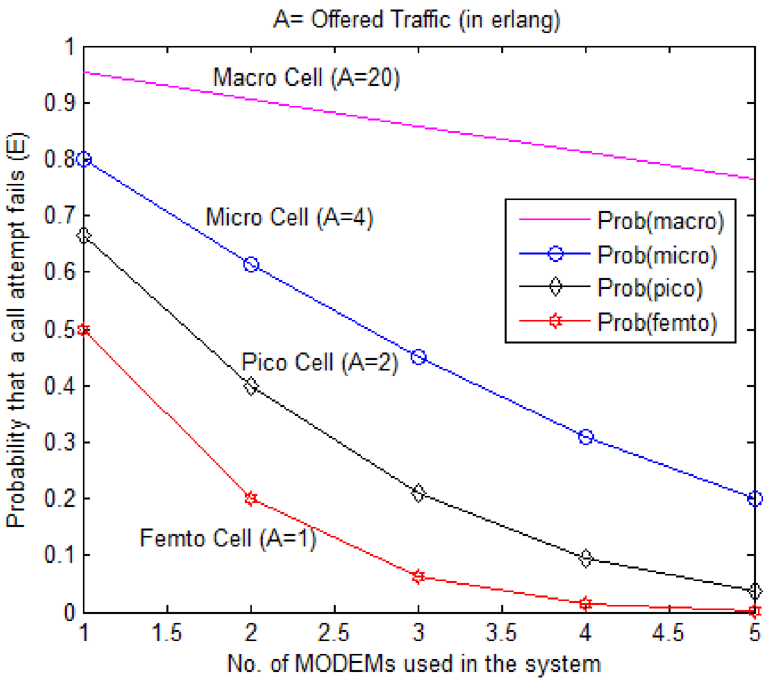

Figure (8): Probability that a call attempt fails V/S Number of MODEMs used in the system

Figure (8) shows that probability of failure of call attempts by subscribers within the cell reduces, if the system consists of more number of MODEMs (i.e. Combination of modulator and demodulator) and the offered traffic (A) is less in that particular system i.e. cell.

Here we have shown for example that, Offered traffic (A) = 20 erlang in macro cell, A= 4 erlang in micro cell, A= 2 erlang in pico cell, and A= 1 erlang in femto cell. Then the probability that a call attempt fails is more in macro cell and least in femto cell per unit of time (for e.g. hour), because more number of subscribers attempting call are present in macro (biggest) cell while least in femto cell.

V. CONCLUSION

From the simulation results, we can observe that in CDMA system, parameters such as processing gain of a particular site or cell having a base station to handle the traffic generated by subscriber can be improved or increased by dividing the site or cell into smaller cells with their individual base stations using cell splitting technique. Hence the advantage of Cell splitting technique is to improve the performance and capacity of the system by increasing processing gain, decreasing user-transmitted in-band signal power to achieve desired SNR and decreasing the probability of failure of call attempts.

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