Interference Estimation in Cellular Systems

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ABSTRACT
CDMA is the most efficient multiple access scheme since it has neither frequency limitation like FDMA nor time limitation as in TDMA. Since all the users in CDMA uses the same frequency it is highly prone to interference. Interference decreases the capacity of the system. Estimation of the amount of interference is essential in network design so the interference factor is calculated with the help of distance ratio in various cases such as the user remaining stationary, and the user moving randomly in this paper.

General Terms
Interference, capacity

Keywords
Distance ratio, static case, and dynamic case

1. INTRODUCTION
Cellular network is a network over geographical areas called as cells served by a base station. This cellular network provides high radio coverage. The cellular network provides wireless connection to the mobile terminal even during the movement of the user. The main advantage of the cellular system is that it provides maximum capacity with the limited spectrum. The basic cellular system consists of mobiles, base station and a switching center. With the help of a base station a mobile user can communicate to another user. Most of the cellular systems are full duplex communication systems. There are two channels related to the mobile and base station. Uplink or reverse channels are used to communicate between mobile to base station and downlink or forward channel used to communicate from base station to mobile. This ensures that the transmission and reception channel will be on different channels so as that the user can transmit and receive signals simultaneously. The base station consists of transmitter and receivers which will handle two different signals at the same time. Mobile consists of an antenna, control circuitry and transceivers. The connection between the base station and the switching center is mainly through microwave links or fiber optic cables. The users which are very near to the base station transmits signal of high strength and the users which are very far transmits signal of less strength. This is called as near far effect. The power levels obtained at the base station is different. The idea is to decrease the power level when other networks are in the range of a particular base station. This technique is called as power control. The antennas used at the base station are directional which points in different directions which increase the traffic capacity of the base station. Cellular system consists of unlimited number of clusters. Cells are grouped together to

form cluster. No cells in the cluster use the same frequency band. The cluster size may varies from 3 to 12 and can be denoted as k. Frequency used in one cluster can be used in another cluster provided that the cells using the same frequency should be at least separated by three cell units. The cells that use the same frequency are known as co channel cells. Since same frequency can be used in a different cluster the effective utilization with the limited spectrum is achieved. This concept is called as frequency reuse. We choose the smallest possible value of k to maximize the capacity over a given coverage area. The factor 1/k is called the frequency reuse factor of a cellular system.

In any cellular system or cellular technology, it is necessary to have a scheme that enables several multiple users to gain access to it and use it simultaneously .There are four main multiple access schemes. The multiple access schemes are known as FDMA, TDMA and CDMA .In FDMA, the total bandwidth is divided into non-overlapping frequency bands. Each user is allocated a different frequency band for the duration of the connection, whether the channel is used or not. During the period of the call, no other user can share the same frequency band. The bandwidths allocated for FDMA channels are relatively narrow say about 25–30 kHz so FDMA is usually implemented in narrowband systems.. FDMA is one of the oldest access techniques which were used in AMPS. Here in this technique inefficient utilization of bandwidth is experienced. And in this technique there is frequency limitation since the users can use only the particular frequency band. Time division multiple access (TDMA) systems divides the spectrum into time slots and in each slot only one user is allowed to either transmit or receive. Unlike in FDMA systems, which accommodate analog frequency modulation (FM), TDMA uses digital modulation. Data transmission of a TDMA system is not continuous but occurs in bursts. Because of burst transmission, synchronization is required in TDMA systems. Generally, the complexity of TDMA mobile systems is higher compared with FDMA systems. And the main disadvantage of TDMA system is network synchronization. This technique has also time limitation since the users can use the entire frequency spectrum only during the particular time. CDMA was the next technique which employed spreading sequence for each user which was orthogonal to each other. This technique ensured that

frequency reuse factor of one is used which maximizes the capacity. Capacity is mainly affected by processing gain, voice activity factor etc. The most important factor which affects capacity is interference. The interaction of two or more signals that may cause noise is called as interference. Inteference occurs from the neighboring cells. Interference can be of different types: in-cell and out-of-cell interference. Interference estimation leads to understanding the relationship between coverage and capacity of the system and how it is affected by interference and the importance of transmit power for network planning. In –cell interference is caused from the users in the same cell since every user uses the same frequency band. In-cell interference can be controlled by automatic power control of the base station. Since the interference caused by the outside cells cannot be controlled by the basestation which is inside the cell. The out-of -cell interference consists of mainly (i) cochannel interference-when two or more base stations in a cellular system transmits at the same frequency. This occurs when same channels are assigned to two different cells in different clusters which are not far enough apart. This can be eliminated by increasing the distance between the cochannel cells which use the same frequency (ii) Adjacent channel interference- It is mainly caused when the adjacent frequencies are assigned to the adjacent cells. Proper assignment of the frequencies to adjacent channels will avoid this type of interference. Signal to interference ratio is the main parameter which decides the efficiency of the system. It is the ratio of received power to the interference power. If signal to interference ratio increases then the bit error rate also decreases.

2. MODEL OF THE SYSTEM

In CDMA, all cells use the same frequency band and this is known as a re-use factor of one. In a CDMA system, the user occupies the entire allocated spectrum. Since all the hexagonal cells have the same frequency, each cell causes interference to its neighboring cells which affects capacity of the system. Let us assume a case where there are N users and the required received signal strength is S and N-1 interfering users each of signal strength S the strength SNR

$SNR=S/(S(N-1))=1/(N-1)$ (1)

Energy to noise density ratio is obtained by considering information rate and bandwidth.

$Eb/N_0.=(S/r)/(N-1)(S/B)=(B/r)/(N-1)$ (2)

Considering the background noise D

$E_b/N_0=(B/r)/((N-1)+(D/S))$ (3)

For the CDMA system, the capacity of the system is equivalent to the number of users the system can support.

$C=\lambda[1 + (1/\alpha)\{(B/r)/((E_b/N_0)(1+f))-(D/S)\}]$ (4)

λ- sectorisation factor, α- voice activity, E_b/N_0- bit energy to noise density ratio, B/r- processing gain, f- Interference factor D- Thermal noise power, S- Power of each signal

In order to increase the capacity the transmit power should be kept as low as possible and it should not be decreased to such an extent that E_b/N_o should not fall below the required level. From the equation it is very clear that f has very large influence on capacity so estimation of f is unavoidable. So measure of interference is done with the help of interference factor. In order to design the interference factor first we have to assume a desired cell and an interfering cell (user in the interference cell causes interference to the user in the desired cell).

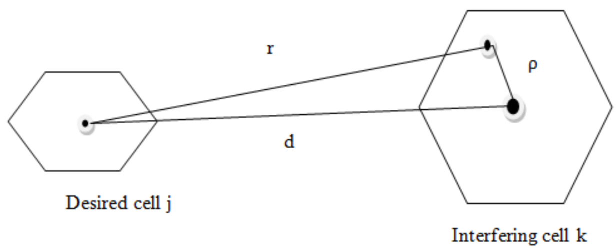

Fig 1: Illustration of interference

Consider the interference experienced by the user at the base of the desired cell j from the stationary interfering user situated at distance r from its base in the interfering cell k. A power level of $p_n^{(k)}$ is required for the n^{th} interfering user, and similarly , and the s^{th} desired user in cell j requires a received power of $p_s^{(j)}$. The interference power which is received at the base j is thus proportional to the transmit power $p_{t,n}^{(k)}$ divided by the path loss r^n. The interference factor f(k,j) is the ratio of interference power to the desired power. When the desired received power for the user under consideration is $p_r^{(j)}$, the interference factor f is:

$F_{n,,q}(k,j)=((p\wedge(k)/(r\wedge n))/(p\wedge(j)) =\delta_{n,q}(k,j)(\rho/r)\wedge n$ (5)

where $\delta_{m,q}(k,j)$= 1 and considering a spatial distribution with K number of users so the interference factor is purely dependent on the distances between the interfering user and the desired user and the path loss exponent**.** i varies from 1 to K.

$F =\sum_i ((p_i/r_i)\wedge n)/K$ (6)

3. PROBLEM STATEMENT

In cellular systems the main limitation is interference. To reduce the interference the magnitude of interference should be known. For estimating the magnitude of interference several calculations are done but proper parameters are not considered and impractical assumptions are done to minimize the complexity of calculation of the interference. The main problem in these assumptions are inaccurate results are obtained. This can be easily explained when an assumption such as line of sight channel with no fading is assumed. Practically such a scenario does not exist. So the estimation made is incorrect. Even the signal attenuation which takes place beyond RLOS is not considered. Homogenous environment is assumes such that signal attenuation is not considered. The other major problem which the interference calculation experiences is that the estimation of interference factor at the borders of the cell is difficult since the interfering user switches to two base stations of the cells and signal strength varies at a great speed.

4. ANALYSIS OF INTERFERENCE IN VARIOUS CASES

In this paper the interference which is caused by adjacent cells surrounding a single desired cell is calculated. The interference is mainly calculated with the help of distance ratio and the path loss component. We can estimate interference factor mainly for various cases. In this paper two cases that is interfering user remaining stationary (static) and the interfering user moving randomly with respect to time(dynamic) are considered. For dynamic two cases are considered (i) a desired cell experiencing interference from a single interfering cell in which users are moving at different velocities and (ii) a desired cell surrounded by a single tier of cell(about six cells) in which users are moving randomly and with different velocities.

4.1 Static case

The interference factor is analyzed with the help of distances and propagation path loss constant. The main concept used is as distance between the transmitter and receiver increases the signal strength received at the receiver is decreased. The signal strength is inversely proportional to the square of distance of transmission. Even the path loss as a major effect on interference factor since large attenuation of the signal occurs due to the absorption of the signal. So these are the main factors which contribute for interference. In this case, the users are distributed in a spatial manner that is the position of users is randomly generated with the help of matlab function and the distance between the interfering user and the base station is important than the direction in which the user moves. Each user has a different position. So in order to calculate the interference, we should separately consider each users position and its relative distance to the base stations. Two distances are calculated (i) distance between the user's position and the centre of desired cell(r) (ii) distance between the user's position and the centre of the interfering cell (ρ) as in fig 1. After calculating the distances then divide them to obtain spatial distance ratio. Propagation path loss can also be considered by raising the spatial distance ratio to the power of exponent path loss constant (n). This procedure is repeated for each user, to obtain the interference factor contributed by all the users and the number of users (K).The cumulative effect is taken into consideration. The formula for interference factor is

$F = \sum_i ((p_i/r_i)^\wedge n)/K$ (6)

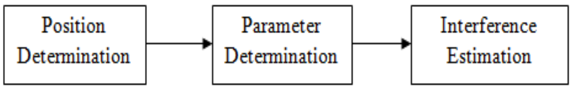

Fig 2: Static Case

4.2 Dynamic case

This case the users are mobile and move randomly throughout the cell, creating more closely the scenario in practice. We calculate the interference factor with respect to time. As f varies with time, it can cause a considerable corresponding change in interference, and hence capacity of the system changes with time. Dynamic case is again split into 2 subcases (i) a desired cell with a single interfering cell with mobile users moving at different velocities and (ii) six outside cells surrounding the desired cell, with the same user mobility. The radius of the desired and the interfering cell can vary**.** The formula for interference factor is

$F(t) = \sum_i [\rho_i(t)/ r_i(t)]^n/K$ (7)

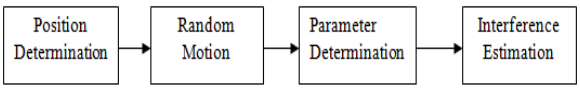

Fig 3: Dynamic Case

For dynamic case the user's mobility should be considered. Not only the mobility but the velocity of each user is different. So the random walk as well as the velocity should be created for each user. The initial position of the users is uniformly distributed within the cell, and the random walk is generated with the help of independent Gaussian processes for each Cartesian dimension.

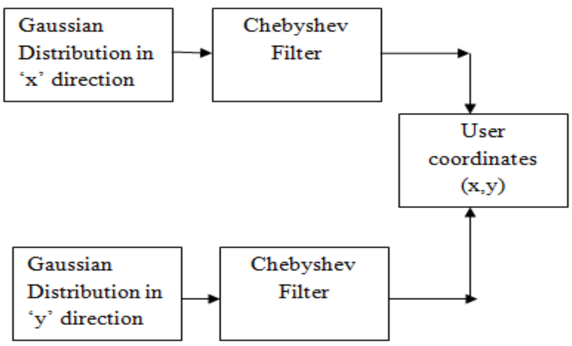

Fig 4: Generation of random motion

To account for user's velocity each user's random position is filtered with a Chebyshev filter with bandwidth B. This bandwidth B is proportional to the Doppler shift , $B \sim f_{D,}$ where f_D is the maximum Doppler frequency incurred due to motion given by $f_{D,}=vf_c/c$ where v=mobile velocity in m/s, f_c=carrier frequency, and c=speed of light. We assume that the velocity of a person using a cell phone while driving on a road is V_{road}=30m/s and the velocity of a man walking on a street is V_{walk}=1m/s. Hence bandwidth of filter $F_D/Rb=3/10^3=3*10^{-3}$.We have varied the bandwidth of filter from 0.1 to 0.001 to account for velocities varying from 30m/s to 1m/s in case of man walking on street and driving on a road).The user velocity is directly proportional to the bandwidth B of the chebyshev filter, which is an added advantage since interference mainly depends on the velocity of the user and changes rapidly as the velocity of the user changes.

4.1.1 Single Interfering Cell Case

As mentioned earlier the random walk is generated by the Gaussian process, and it is filtered using a Chebyshev filter such that it becomes more practical. User's positions are varied with time samples and the velocity is proportional to bandwidth of the Chebyshev filter. Boundary conditions are applied to restrict the user movement to within the required radius. We assume that the number of users entering and leaving the cell is same. This artificial condition provides a constant number of mobile users per cell. Another way is to force the user inside the cell such that user is not allowed to move out of the cell. It's found that these two approaches yield the same results. Thus the interference factor for each mobile user is calculated after calculating the distance between position of the user and the center of desired as well as interfering cell and the final interference factor is obtained by adding each user's interference factor.

4.1.2 Six interfering cells surrounding a single desired cell

Usability and reliability of a network and its services determines the QoS of a cellular network. It forms the basis of dimension and planning. The major issue for a user is the continuity of the connection. Forced termination of the call may be due to many reasons in the network. Forced termination occurs due to two reasons (i) resource insufficiency (ii) link unreliability. When a mobile user moves to a different cell during the process of a communication, a handoff must take place. Resource insufficiency means that call gets dropped due to unavailability of free channels. When the received signal to interference ratio falls below a threshold value then the connection is said to be unreliable. At this point handoff should be done to avoid call dropping. There are two types of handoff: hard handoff and soft handoff. In cellular network, a hard handoff is the most common handoff mechanism in a network. This takes place when a call gets connected to a new base station if the signal strength received from that base station is more than the signal strength received from its original base station.

A hard handoff is also called as 'Break-before-Make' handoff. Soft handoff takes place when the mobile station receives approximately same strength of signals from more than one base station. Sometimes the signals from different base stations are combined and so reliable transmission can be made. But when the mobile station receives stronger signal from any of their base stations then it will automatically disconnect all other connections to different base stations. Thus, soft handoff process ensures that the MS is always connected to the BS and the strongest signal is obtained. So in order to implement handoff, we have to consider more than one cell. As it is known that the cellular system consists of group of cells which makes up a single cluster. The cluster idea is taken in order to implement the concept of handoff in a more effective manner. By grouping cells into clusters, handoff from one cluster to another can be easily understood and thus implemented in a simpler manner. Cluster size may vary from six to twelve but the all the cells in a single cluster should use different frequencies to communicate since interference increase if co channel cells are present in the same cluster. Here 6 cells are considered to be in a single tier of cellular system. As it is observed in Fig:5 the six interfering cells and the desired cell forms a single cluster. Even if they use different frequencies interference can occur from the outside cells, that is, from these surrounding cells.

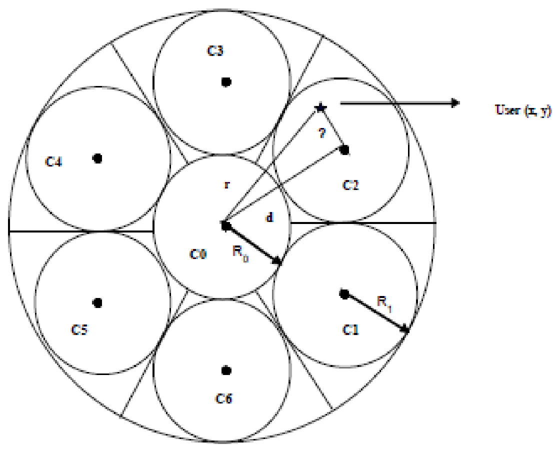

Fig 5: Single cell surrounded by six interfering cells

Co represents the desired cell surrounded by interfering cells C_1-C_6. The radius of each interfering cell is r_1 while the radius of the desired cell is r_0. The mobile users are uniformly distributed among these six cells and they cross each cell handoff occurs. The distance between each user and the centre of the desired cell is denoted by r and the distance between each user and the base station is given by ρ. A circle circumscribing all the six interfering cells will have a radius of three if we consider $r_0=r_1$. The users motion are restricted between a circle of radius three and a circle of radius one. Thus they can move from one cell to another but should be inside the circumscribing circle. As the users move from one cell to another, handoff occurs that is the call gets transferred from one base station to the other. The interference factor is computed as a function of distance ratio and path loss. As soon as the distance between the user and the old base station exceeds than the distance between the new base station the handoff occurs to the new base station. It will remain connected until the distance between the user and another base station is small. So the distance is calculated and then the minimum is taken to find out the cell in which the user resides. The interference factor is computed as same as single case but in this case interference is summed over all the users of all the six cells. ρ_{ij} indicates the value of ρ of user i in cell j. i indicates the number of cells considered(six in this case). j-the number of users.

$$F(t) = \sum_i \sum_j [\rho_{ij}(t)/ r_{ij}(t)]^n/6K \qquad (8)$$

5. SIMULATION RESULTS

The proposed work has been modeled in MATLAB programming language. Different cases are analyzed such as static case where the users in the interfering cell remains stationary and dynamic case where users are moving with respect to time, both single cell as well as six cell case. Results are analyzed in terms of tabular columns and graphs.

5.1 Static Case

A single interfering cell is populated with users which are stationary. In this case the results are analyzed in such a way that the variation of the interference factor of the system with the variation of the position of as close to equal length as possible. As it can be observed from the table 1, changes in the position of the user will not bring changes in the interference factor. This is because the magnitude of the distance between user and cell remains the same. But when the magnitude of the position is changed (halved or doubled), corresponding changes can be observed in the interference factor

Table 1. Interference factor for various positions of user in static case

Position of the user	IF
(x,y)	0.070
(-x,-y)	0.070
(-x,-y)	0.070
(x,-y)	0.070
(x/2,y/2)	1.8524
(2x,2y)	0.030

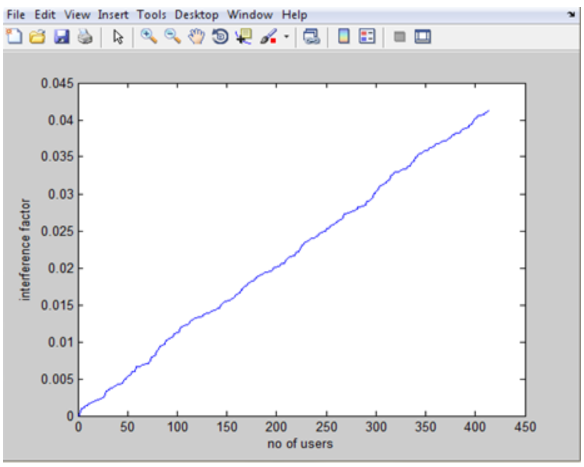

Fig 6: Plot of f versus number of users

As the number of user in the interfering cell increases the interference experienced by the users in desired cell increases. This is due to the fact that the interference factor is a summation of interferences from each user.

5.2 Dynamic Case

As explained before the interference factor calculated varies with time. Two cases are analyzed here.

5.2.1 Single interfering cell case

Since the interference factor changes with time a particular value for interference factor is not present. So interference factor for 5 samples are displayed.

Table 2. Interference factor for various positions of user in dynamic case for single cell

Position of the user	Interference factor for 5 samples				
(x,y)	0.1484	0.1155	0.0438	0.0551	0.0933
(x,-y)	0.1474	0.1156	0.0435	0.0552	0.0935
(-x,y)	0.1477	0.1150	0.0433	0.0557	0.0938
(-x,-y)	0.1471	0.1153	0.0430	0.0554	0.0939
(x/2,y/2)	1.211	1.4767	1.0062	0.9239	0.9695
(2x,2y)	0.0028	0.0175	1.1707	0.3030	0.3202

The interference factor does not follow a particular pattern as the time varies. So neither an increase nor decrease pattern is expected. But the interference factor estimated will be much more approximate than in the static case but less accurate than the six cell case considered later. As observed in static case the interference factor increases as the distance gets halved and decreases as the distance gets increased.

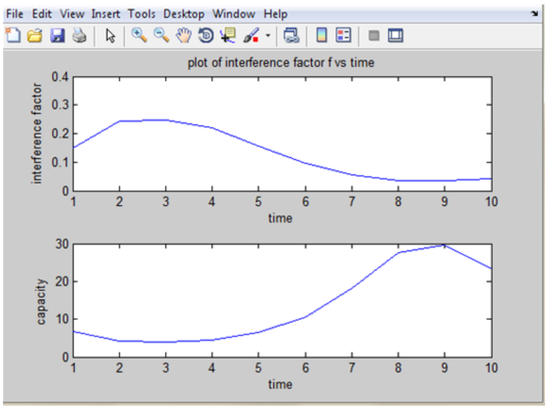

Fig 7: Plot of interference factor and capacity versus time

The figure gives an approximate value of capacity or the number of users that the cellular system can support without the quality of service of any user falling below a required minimum. The capacity for this case is estimated only by taking interference into account.

5.2.2 Six interfering cells case

Six interfering cells are considered around the desired cell where users are moving with respect to time and can move from one cell to another and can exhibit handoff mechanism.

Table 2. Interference factor for various positions of user in dynamic case for six cells

Position of the user	Interference factor for 5 samples				
(x,y)	0.552	0.463	0.066	0.005	0.007
(x,-y)	0.513	0.415	0.007	0.004	0.003
(-x,y)	0.512	0.486	0.005	0.001	0.002
(-x,-y)	0.514	0.416	0.006	0.007	0.009
(x/2,y/2)	2.998	2.985	2.927	1.927	1.932
(2x,2y)	0.006	0.019	1.207	0.400	0.800

On considering six cells around the desired cell, handoff can be done from one cell to another so more practical scenario is considered and thus an accurate measurement of interference factor is made since we consider six cells. The interference factor of a single cell is very less compared to the interference created by the adjoining cells. This indicates that as the distance increases interference decreases among these cells handoff is possible and the value of interference is calculated which is more than considering a single interfering cell is.

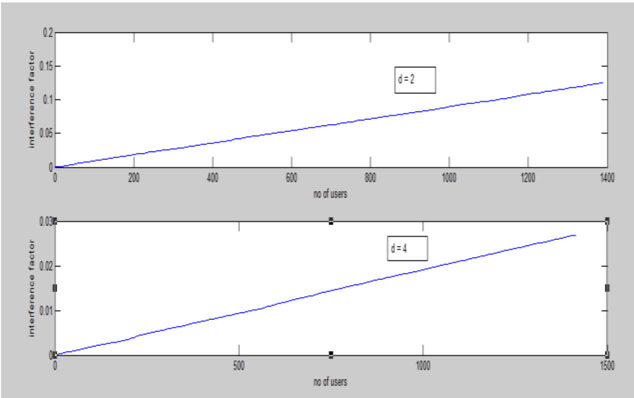

Fig 8: Plot of interference factor versus no: of users for d=2 and d= 4

6. CONCLUSION

In the first case that is static case, a single interfering cell with K users is considered and it is concluded that the interference factor increases as the number of users increases. In the dynamic case the users are moving and the interference and capacity curves are plotted. Variation of interference factor with number of users as well as distance between the interfering cell and the required base station are also plotted. A single tier of cells are considered and the value of interference factor is obtained. More number of tiers can be considered for accurate results.

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