Dynamic Cell Sizing in CDMA Networks

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Abstract: The increasing demand for cellular communications access require a substantial increase in traffic capacity and full coverage of service area. In urban areas, the ratio of traffic demand in the busiest hour to the quietest hour can be very substantial.   To accommodate for the increase in traffic during peak hours, a variety of options are possible - more carriers may be added to existing cell-sites, the cell may by be split into several smaller cells or alternatively, additional base stations may be built. However, these methods require the operator to derive a new frequency plan and as for the case of cell splitting, and additional base station construction, a new coverage plan will be required. The cost of installing new hardware and devising new frequency and coverage plans is considerable. It is therefore vital for an operator to ensure that their resources are utilized to their full potential. In light of the above, a more flexible network is required. In this paper, the potential benefits of dynamically controlling the size of any given cell within a layer of hierarchical cells are investigated.   Its weaknesses are also studied and possible solutions are suggested to overcome the existing flaws.

Key Words: Dynamic Cell Sizing, Capacity, Coverage, Non-uniform Traffic, Bi-directional Impact, Coverage Holes

Introduction

Cellular communication networks divide the geographical area into smaller hexagonal regions, called cells. Over the last few years, a great deal of work has been done to study optimal CDMA cell design where the number of cell sites required is minimized while maintaining the quality of service. The focus of these studies was on the maximization of cell radius for a given transmit power while ensuring that the grade of service in a specified percentage of the cell area was met. The ultimate goal of the research was to utilize existing resources to their full potential. The deficiency here is that most of these analyses were made under the presumption of uniform traffic distribution in cells within the network.

In this paper, we analyze the impact of non-uniform traffic distribution in different cells during peak hours. We will look into how the dynamic cell sizing mechanism performs load balancing under non-uniform traffic distribution during peak hours.   The capacity improvement obtained will be observed.   A valuable insight of the weaknesses of dynamic cell sizing mechanism is also made, in addition to a concluding section on possible ways to overcome the flaws.

Dynamic cell sizing is a mechanism that attempts to keep the forward and reverse link handoff boundaries balanced by changing the forward link coverage according to the changes in the reverse link interference level (Jalali, 1998; Qiu and Mark, 1998). Reverse link handoff boundary is defined as the contour of mobile locations between neighboring cells where the received signal to noise ratio at the two base stations is the same. Referring to Fig. 1, the reverse link handoff boundary between cell sites A and B is the locations such that

$$\frac{E_{bA}}{N_{tA}} = \frac{E_{bB}}{N_{tB}}$$
(1)

where E_{bi}/N_{ti} is the signal to noise ratio received at base station i for the mobile under consideration, E_{bi} is the received bit energy and N_{ti} is the spectral density of total interference at base station i.
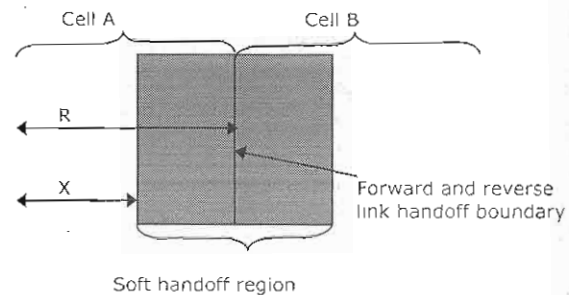

Fig.1: A Balanced Forward and Reverse Link Handoff Boundary Case for Two Cells A and B

Forward link handoff boundary is defined as the contour of the mobile locations where

$$\frac{E_{cA}}{I_o} = \frac{E_{cB}}{I_o}$$
(2)

where E_{ci} is the received pilot chip energy of i-th pilot and I_o is the spectral density of the total power seen by the mobile.

It can be seen from (1) and (2) that, if the interference levels are the same at both base stations and the same amount of power is transmitted on the pilot channel from each base station, then the forward and reverse handoff boundaries will coincide; the boundary will be half way between the two cell sites for a uniform propagation model.

As the reverse link traffic load is increased, the thermal noise at the base station increases. It is clear from (1) that the reverse link handoff boundary will move closer to the base station whose rise over thermal noise is greater.

Then, to balance the reverse and forward link handoff boundaries, the pilot signal of the cell with greater base station interference must be reduced. The mechanism used to reduce pilot power on a cell based on the increase in the reverse link interference level is referred to as dynamic cell sizing (Jalali, 1998; Qiu and Mark, 1998)

Materials and Methods
The objective of this research is to identify a quick, low-cost solution for the problem of traffic overflow in certain areas during peak hours. The potential benefits of dynamic cell sizing, as a means of shedding traffic of heavily loaded cells to less heavily loaded cells in the vicinity, is examined. This was done through investigation of previous work in related areas and evaluating existing solutions. Thereby, a thorough study of the efficiency of dynamic cell sizing as a prospective solution to the traffic distribution problem during peak hours was completed.

Previous studies focused on the application of dynamic cell breathing in maximization of cell radius so as to fully utilize available resources. These were done under the presumption of uniform traffic distribution in cells within the network. Here, though the goal of employing available resources to its full potential prevails, concentration will be given to the dynamic cell sizing mechanism during peak-hour traffic, where some cells are more heavily loaded than others. This is to ensure that load balancing is achieved (Das et al., 1997 and Zhang Youngbing, 1999).

Also, where previous studies focused on gains in the capacity and coverage, this paper will look into the weaknesses of the mechanism have as well. Possible solutions to the mechanism's weaknesses are then proposed.

Results and Discussion
Overview of the Soft Hand Over Process: In CDMA systems, overlapping regions called soft handoff regions are necessary for mobiles near the cell boundary to perform handoff and to counteract fluctuations of receiving power (Qiu and Mark, 1998) (Fig. 1). The mobile measures the pilot E_c/I_o from neighboring cell sites. If a pilot is found whose E_c/I_o is above a threshold called T_ADD, the mobile reports that pilot to the base station. The pilot is to be included in the set of pilots in soft handoff referred to as the active set. On the other hand, if the E_{ci}/I_o of a pilot in the active set is below a threshold called T_DROP for more than a certain time, the mobile will report that pilot to the base station. The pilot may then be removed from the active set. Therefore, the pilot E_c/I_o values as measured by the mobile primarily determines the handoff region. Fig.1 shows the handoff boundary of two adjacent cell sites marked as A and B. Since $I_o = I_{oA} + I_{oB,} + N_o$ where I_{oi} is the power spectral density of the total signal received from cell site i at the mobile and N_o is the thermal noise power spectral density, then we get $I_o \approx I_{oA}$ near the edge of the soft handoff region closer to cell site A. In other words, the edge of the soft handoff region near

one cell site is primarily determined by the total signal power from that cell site(Jalali, 1998).

Since the left side of the soft handoff region in Fig. 1 is determined by E_{cB}/I_o, i.e. the signal to interference ratio seen on pilot B, then the left side of the handoff region does not move when the pilot power of cell A is reduced. The right edge of the soft handoff region (Fig.1) however is determined by E_{cA}/I_o; therefore, as the pilot power of cell A is reduced, the right edge of the soft handoff region moves closer to cell site A as shown in Fig. 2. Therefore, if dynamic cell sizing is active, then as cell loading is increased in cell A and surrounding cell sites remain lightly loaded, the soft handoff region inside the neighboring lightly loaded cell sites will reduce. In the next section, we investigate the impact of dynamic cell sizing on network performance.
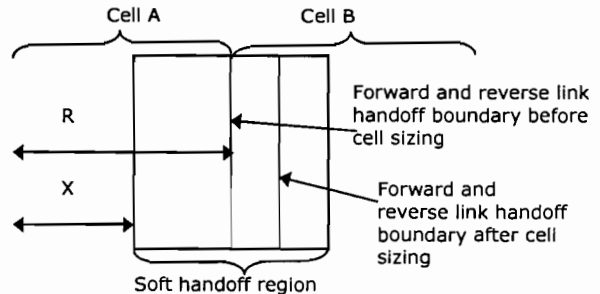

Fig.2: Handoff Boundary has Moved Closer to Cell A Due to Loading on Cell A

Impact of Dynamic Cell Sizing on Forward Link Performance: On the forward link, once a given cell becomes heavily loaded, the cell sizing algorithm will reduce the cell's coverage by shedding some of the traffic to the surrounding cells, thereby relieving the overloaded cell. Shedding of traffic from the heavily loaded cell occurs because, as discussed in Section "Overview of the Soft Hand Over Process", the soft handoff region on the side of the cell with less loading shrinks. As a result, some of the mobiles in the lightly loaded cell which were in soft handoff with the heavily loaded cell will now go out of soft handoff with the heavily loaded cell. The released radio links can be used to support new users in the heavily loaded cell. The issue is the amount of capacity increase expected in the heavily loaded cell and the impact on overall cell quality.

Consider the case where cell A in Fig. 2 is heavily loaded and cell B lightly loaded. Then, in order to move the handoff boundary by an equal amount that the interference has risen in a cell, the dynamic cell sizing algorithm will introduce an attenuation equal to α on the forward link of cell A in response to a rise over thermal noise in cell A's reverse link. The pilot by E_{cA}/I_o seen from pilot of cell A will be changed to

$$\frac{\alpha E_{cA}}{I_{oA} + I_{oB} + I_{oC}} \quad (3)$$

which is smaller than it used to be prior to cell sizing (Jalali, 1998). The α factor is due to cell sizing on cell A. Now the edge of the soft handoff region closer to cell B will move away from cell B. Assuming that 35% of the cell area is in soft handoff and approximating the cell area by a circle, we have X=0.8R in Fig. 1. We note that for large path loss exponents of 4, inside cell B the denominator of (3) will be dominated by I_{oB}. Therefore, the handoff boundary moves to the left in Fig. 2 approximately 1 dB for each dB of attenuation introduced by cell sizing on cell A.

As the handoff boundary is moved closer to cell A, the one benefit that may be obtained is that users that are inside cell B and are in soft handoff with cell A may fall out of soft handoff with cell A, relieving some capacity from cell A to be used for users that are inside cell A. However, the attenuation α is applied to the total power going out of cell A, the overhead as well as the traffic channels; therefore, we need to assess the impact of this attenuation on the traffic channels in cell A. The SNR seen by a mobile prior to attenuation introduced by cell sizing is given by:

$$SNR = \sum_{j=1}^{L} \frac{gI_{or}\beta_j}{(1-\beta)I_{or} + I_{oC} + N_o} \qquad (4)$$

where g is the fraction of total forward link power given to a mobile referred to as the forward gain, L is the total number of multipath components captured by the mobile from cell A, I_{or} is the total power received by the mobile from cell A, β_j is the fraction of the total power received by the mobile from cell A that is received on the j-th multipath component (which sum to 1 over all multipath j), I_{oC} is the out of cell interference (Jalali, 1998). Note that the first component in the denominator of (4) is due to in-cell interference, from the multipath. Once the cell sizing attenuation is applied, the SNR seen by the mobile at the same location is given by

$$SNR = \sum_{j=1}^{L} \frac{\alpha g' I_{or}\beta_j}{\alpha(1-\beta)I_{or} + I_{oC} + N_o} \qquad (5)$$

The difference between equations (4) and (5) is in the attenuation α and g'. In order to achieve the same SNR for the mobile after cell sizing as before cell sizing, we need to increase g', the fraction of power allocated to the mobile. In other words, we need to determine g' such that (4) and (5) are equal in order to maintain the same FER. Therefore, the forward gain of the traffic channel will increase to achieve the same SNR as before. Note that in the actual system the reduction in the SNR due to cell sizing attenuation will cause the FER of the users to increase. The power control will then automatically increase the forward gain of all users whose FER has increased in order to lower their FER values to the desired values.

If there is a single path seen by the mobile, it is then clear from equations (4) and (5) that g' must increase by an amount equal to α in order to maintain the SNR. Suppose α=1dB. Then the soft handoff region will move by about 5% for the path loss exponent of 4 which means now about 25% of the area of cells surrounding cell A will be in soft handoff with cell A instead of 35% of the area prior to cell sizing. In other words, 10% of mobiles in communication with cell A may be shed to other cells by putting them out of soft handoff with cell A (Jalali, 1998). Note that here we are assuming that all surrounding cells are lightly loaded resulting in a net 10% shedding of traffic to the surrounding cells. Throughout, we have assumed circular cells and that cell A is surrounded by 6 other cells. Fig.1 and 2 only show 2 cells for simplicity.

In a single path case, it is clear from equations (4) and (5) that there needs to be a dB for dB increase of forward gain for each dB of cell sizing attenuation in order to maintain the traffic channel SNR.

Next, consider the case where there are two multipath components with the weaker paths' power equal to half the power of the stronger path, i.e. β_1=0.67 and β_2=0.33. Also, assume I_{oc}/I_{or}=0.25; separate simulations have shown that in about 54% of the cell area I_{oc}/I_{or}>0.25. In this case, by substituting into equations (4) and (5) and setting them equal we find that g'=1.1g. In other words, there is a 10% increase in forward gain in about 54% of the cell area. Note that this 54% of the mobiles correspond to the outer area of the cell. If we let I_{oc}/I_{or} =0.5, which corresponds to about 40% of the cell area, then substitution into (4) and (5) gives g'=1.14g (Jalali, 1998). Therefore, as mentioned above, the forward gains will increase for all mobiles as cell sizing introduces attenuation.

In the two-path model described above, the increase in the forward gain for the traffic channels is initially less than the cell sizing attenuation, but as the forward gains are increased initially, the total power going out of the cell increases. Then, we can apply equation (5) iteratively to find out how much the forward gains will be increased in response to the increase of in cell interference. Therefore, eventually the traffic channel forward gains will increase by the same amount as the cell sizing attenuation, until the total traffic channel power going out of the cell becomes close to what it was prior to cell sizing attenuation. The output power after cell sizing will be less due to lower power on overhead channels. Note that we are assuming that the overhead channels (pilot, paging and synchronization) are not power controlled and their power is therefore reduced due to the cell sizing attenuation. The reduction of total transmit power due to reduced power on the overhead channels will eventually be used by new users and therefore the total transmit power will remain unchanged before and after cell sizing under heavy loading conditions. Of course, the mobile whose forward gains were near their upper limit, their allocated power will decrease due to hitting the upper limit of the forward gain.

From Section "Overview of the Soft Hand Over Process", was given that the edge of the handoff region on the cell site *i* is determined by the ratio E_{ci}/I_o. Based on the above discussion, the power being transmitted from the heavily loaded cell site will remain almost constant after cell sizing. Then, the edge of the soft

handoff region inside cell site A will not move much because it is determined by E_{cB}/I_o which has not changed. The edge of the soft handoff region inside cell B which is determined by E_{cA}/I_o, however is reduced because the pilot power transmitted from cell A is reduced due to cell sizing. The reduction of soft handoff area in cell B results in the reduction in the number of soft handoff links that cell A must support for users inside cell B. Therefore, the main sources of capacity increase in the scenario where a heavily loaded cell is surrounded by a tier of lightly loaded cells is the shedding of traffic to other cells and lower power on the overhead channels on the heavily loaded cell (Qiu and Mark, 1998). There will also be some additional capacity due to the mobiles, which were at their upper limit of forward traffic gain; these mobiles' power cannot be increased which leave some room for new traffic. But this additional capacity is at the cost of higher FER for some mobiles.

Based on the above discussion, the forward link capacity of a heavily loaded cell, which is surrounded, by lightly loaded cells may be increased through cell sizing. Cell sizing increases the capacity of the heavily loaded cell using two mechanisms. First, cell sizing reduces power on the overhead channels equal to the amount of cell sizing attenuation. For instance, if 25% of the power had been allocated to the overhead channels and 1dB attenuation was applied to cell, then the amount of power on overhead channels would reduce to 20% of total available power before cell sizing. This results in approximately 6% increase in forward link capacity due to reduced overhead. The second mechanism that increases forward link capacity is by shedding mobiles to other lightly loaded cells (Jalali, 1998). As discussed above, one dB attenuation will result in reduction of soft handoff region of the surrounding cells from 35% to 25%. Therefore, under uniformly distributed traffic conditions there may be up to 10% increase in capacity. Therefore, one dB of breathing may provide at most 15% capacity increase in a heavily loaded cell that is surrounded by lightly loaded cells. .

This capacity increase may, however, be at the cost of reduction in reliability of calls. This is because the soft handoff region has been reduced. The reduced soft handoff may result in an increase in dropped call rate. The reduced soft handoff region by cell sizing is particularly problematic in networks whose soft handoff region has already been reduced and optimized (Spilling and Nix, 2000).
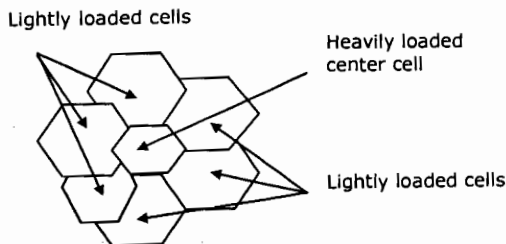

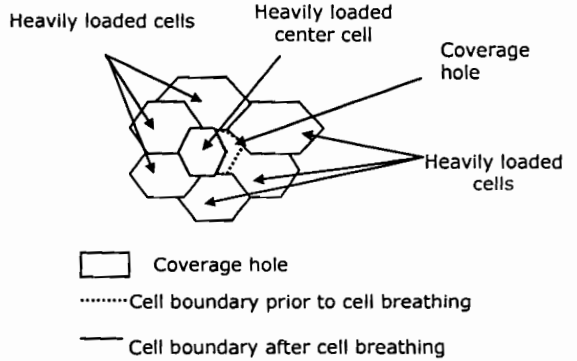Fig.3a: No Coverage Holes Develop When Lightly Loaded Cells Surround a Heavily Loaded Cell

Fig.3b: Coverage Holes Develop when all Cells are Heavily Loaded

Also, previously, the line of reasoning was in a single direction. We controlled the size of a particular cell by varying the adjacent cell's pilot power. Realistically however, the cell whose size is being control may also vary its pilot power to dynamically change the size of the other cell. Thus, for each pair of cells, the impact is bi-directional.

The dual directional interaction of cell-pairs leads to some intriguing occurrences. Assume the instance when a center cell and all its first tier neighbors are heavily loaded. At the outset, the center cell's dynamic sizing mechanism moves the boundary between the center cell and an adjacent cell inwards towards the direction of the center cell so as to allow the mentioned neighbor to accommodate for the additional traffic in the center cell. However, due to a lack of channels in the other cell too, its mechanism may instead move the boundary further away from the center cell. Thus, the courses of action taken by the mechanism of the two adjacent cells contradict one another. If both were to shrink simultaneously to take care of the increasing traffic load in its own cell, then coverage holes would develop (shown in Fig. 3a and 3b). Consequently, calls are dropped and grade of service may not be maintained. The dual directional influence is similar for all cell-pairs. Thus, coverage holes may develop between any two heavily loaded cells.

A center cell will receive dual directional impacts from all cells within its first tier. Similarly, all first tier cells will also receive dual directional impacts from its surrounding first tier cells. The same influence is observed in cells of subsequent tiers. Thus, a multifarious interaction of a vast number of cells is observed. Future work will investigate these diverse interactions.

Solutions: Based on the above discussion, dynamic cell sizing may provide a small amount of capacity gain in limited traffic scenarios. However, there may be an impact to call quality if excessive cell sizing is allowed. The amount of cell sizing attenuation must be limited to a small amount so as not to adversely impact the soft handoff region and overall call quality.

The extent of cell sizing can be limited through the use of Call Admission Control (CAC). The CAC mechanism is used to decide when a new call can be accepted.

Schemes that are based on the measured noise rise can be used to set the minimum cell size. Any new calls will be blocked once the interference reaches a certain level.

The occurrence of coverage holes may be controlled by having the dynamic cell sizing algorithm to adjust the cell size according to time-varying traffic distribution. This may be achieved by employing a traffic prediction scheme that efficiently exploits past traffic patterns to predict current traffic.

From this, we can see that it is important to consider both network coverage and call blocking when planning a CDMA network. Detailed network planning requires a specialized CDMA planning tool. These tools use traffic information and propagation predictions to determine the coverage of the CDMA network.

Most 3G network planning tools utilize the 'power control loop' method. Analytical techniques can also be used, but these are slow when the traffic load is high. It is important for the tool to consider call blocking as well as network coverage. The tools can also be used to predict the soft-hand over regions.

Conclusion

The potential benefits of dynamic cell sizing as a quick, low-cost solution to the problem of traffic overflow in certain areas during peak hours was examined. Cell sizing was shown to increase the forward link capacity by two mechanisms, by reducing power on overhead channels and by shedding traffic of heavily loaded cells to lightly loaded cells. However, the impact of reduced soft handoff region on call quality needs to be assessed. The bi-directional influence of the cells on each cell-pair must also be considered.

It was shown that under very specific deployment conditions where one cell is heavily loaded and is surrounded by lightly loaded cells, cell sizing might provide a small increase in capacity. On the other hand, conflict may arise when a heavily loaded cell is placed adjacent to another heavily loaded cell.

In order to minimize impact of cell sizing on call quality, the amount of cell sizing attenuation must be limited and controlled carefully. For this, a variety of call admission, cell planning and traffic prediction tools may be used.

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