Cell Breathing in CDMA Networks

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Abstract

The widespread deployment of wireless cellular technology affects the traditional concept of channel allocation and drives the necessity for novel load balancing techniques. Various load-balancing schemes have been proposed to assign channels to the cells such that the available channels are efficiently used and thus channel reuse, maximized. This is particularly important in networks where traffic distribution is non-uniform. Some of the well-known load-balancing schemes include the Directed Retry (DR), Channel Borrowing (CB), Channel Borrowing without Locking (CBWL), Load Balancing without selective borrowing (LBSB), Cell Breathing and a number of others. Each possesses both virtues and drawbacks. The objective of the paper is to provide an assessment of the capabilities of Cell Breathing in optimal CDMA network management. The paper studies the capabilities of cell breathing, its flaws and suggests possible solutions to the predicament.

1. 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 whereby the number of cell sites required is minimized while maintaining the quality of service provided. The focus of these studies was on the maximization of cell radius for a given maximum power transmitted while ensuring that the quality of service in a specified percentage of the cell area was met. Most studies were under the presumption of uniform traffic distribution in each cell.

In this paper, we analyze the impact of non-uniform traffic distribution in different cells on cellular network performance. Specifically, we are interested in understanding how cell breathing performs load balancing under non-uniform traffic distribution.

Cell breathing 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.

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 Figure 1, the reverse link handoff boundary between cell sites A and B is the locations such that

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

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.

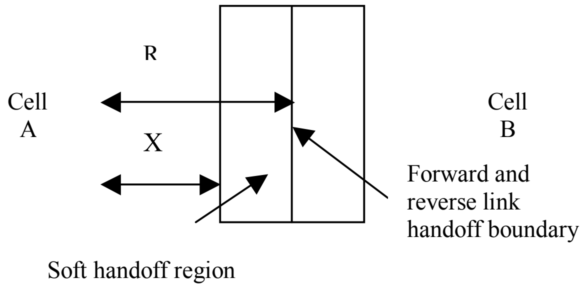

Figure 1. A balanced forward and reverse link handoff boundary case for two cells A and B

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

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

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 cell breathing.

A brief overview of the soft handoff process is given in Section 2. Positive impact of breathing on the forward link is discussed in Section 3 while Section 4 discusses its negative impact. In Section 5, possible solutions are suggested. The paper is concluded in Section 6.

2. Overview of the Soft Hand over Process

As discussed in Section 1, in IS95 CDMA systems 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 Ec/Io values as measured by the mobile primarily determines the handoff region. Figure 1 shows the handoff boundary of two adjacent cell sites marked as A and B. Since $I_o = I_{oA} + I_{oB,}$ 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.

Since the left side of the soft handoff region in Figure 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 (Figure 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 Figure 2. Therefore, if cell breathing 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. Of course, if the loading in all cell sites increase uniformly then the breathing algorithm will reduce the soft handoff region by roughly equal amount in all cells. In the next two sections, we investigate the impact of cell breathing on network performance.

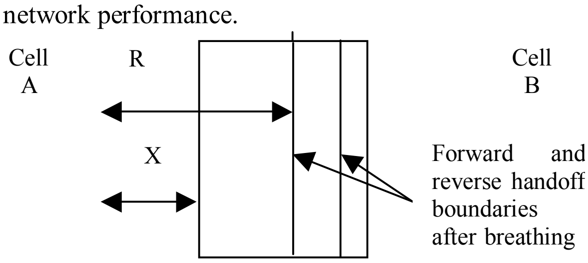

Figure 2. Handoff boundary has moved closer to cell A due to loading on cell A

3. Positive Impact of Breathing on Forward Link Performance

On the forward link, it is generally believed that once a given cell becomes heavily loaded, then the breathing algorithm will reduce the cell's coverage thereby shedding some of the traffic to the surrounding cells relieving the overloaded cell. Shedding of traffic from the heavily loaded cell occurs because, as discussed in Section 2, 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. This releases some of the radio links from the heavily loaded cell that serviced the users in soft handoff from the neighboring cells. The released radio links can be used to support new users in the heavily loaded cell. The question is how much capacity increase may be expected in the heavily loaded cell and what the impact will be to the overall cell quality.

In a situation where one specific cell is heavily loaded and all its surrounding cells are lightly loaded, if breathing algorithm is activated then the handoff boundary of the heavily loaded cell will move further inside that cell. In other words, the soft handoff boundary will move closer to the heavily loaded cell, Figure 2. Suppose that cell A in figure 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 breathing 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

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

which is smaller than it used to be prior to breathing. The α factor is due to breathing 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 Figure 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 Figure 2 approximately 1 dB for each dB of attenuation introduced by breathing 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 breathing is given by:

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

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. Note that the first component in the denominator of (4) is due to in-cell interference, from the multipath. Once the breathing attenuation is applied, the SNR seen by the mobile at the same location is given by

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

The difference between (4) and (5) is in the attenuation α and g'. In order to achieve the same SNR for the mobile after breathing as before breathing, 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 breathing attenuation will cause the FER o f 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 breathing. 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. 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. Figure 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 breathing 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. Therefore, as mentioned above, the forward gains will increase for all mobiles as breathing introduces attenuation.

In the two-path model described above, the increase in the forward gain for the traffic channels is initially less than the breathing 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 breathing attenuation, until the total traffic channel power going out of the cell becomes close to what it was prior to breathing attenuation. The output power after breathing 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 breathing 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 breathing 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.

Recall that based on the discussion in Section (2), 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 breathing. Then, the edge of the soft handoff region inside cell site A will not move much because it is determined by E_{ci}/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 breathing. 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. 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 breathing. Cell breathing increases the capacity of the heavily loaded cell using two mechanisms. First, cell breathing reduces power on the overhead channels equal to the amount of breathing 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 breathing. 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. 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 cell.

4. Negative Impact of Breathing on Forward Link Performance

This capacity increase may, however, be at a cost of reduction in call reliability of calls because the soft handoff region has been reduced. The reduced soft handoff may result in an increase in drop call rate. The reduced soft handoff region by breathing is particularly problematic in networks whose soft handoff region has already been reduced and optimized.

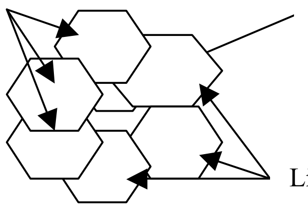

Figure 3a. No coverage holes develop when lightly loaded cells surround a heavily loaded cell

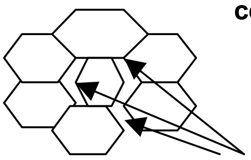

Figure 3b. Coverage holes develop when all cells are heavily loaded

Also, if situation arises where all cells are heavily loaded, all cells will be simultaneously attenuated by the breathing algorithm, causing coverage holes to develop (Figures 3a and 3b). The probability of call dropping increases, thus deteriorating the cellular network performance.

5. Solutions

Based on the above discussion breathing may provide a small amount of capacity gain in very limited traffic scenarios. However, there may be an impact to call quality if excessive breathing is allowed. The amount of breathing 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 breathing 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.

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.

6. Conclusion

The impact of cell breathing on the coverage of CDMA cells was studied. It was shown that the main impact of cell breathing is reduced soft handoff region. There is almost one dB reduction in soft handoff region for each dB of breathing attenuation. Therefore, if cell breathing is used to distribute traffic in certain deployment/traffic scenarios, the impact of reduced soft handoff region on call quality needs to be assessed. It was shown that under very specific deployment conditions where one cell is heavily loaded and is surrounded by lightly loaded cells, cell breathing might provide a small increase in capacity. This capacity gain may, however, be at some call quality cost. In order to minimize impact to call quality, the amount of breathing attenuation must be limited and controlled carefully.

References

1. C. Wheatly, "Trading coverage for capacity in cellular systems: A systems perspective, "Microwave Jl, 38 (7): 62-76, July 1995
2. Sajal K. Das, Prathima Agrawal, "A Distributed Load Balancing Algorithm for the Hot Cell

Problem in Cellular Mobile Networks", 1997 IEEE

3. A. Jalali, "On Cell Breathing in CDMA Networks", IEEE 1998
4. Zhang Youngbing, "A New Adaptive Channel Assignment Algorithm in Cellular Mobile Systems", 1999 IEEE