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# Dynamic Optimization of Soft Handoff Thresholds for a Base Transceiver Station in CDMA Networks

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## ABSTRACT

This work presents a dynamic optimization protocol which is aimed at improving the performance of a cell in a CDMA network during call handoff process by reducing the number of dropped calls. The protocol responds to a changing number of call requests in a cell by adjusting soft handoff thresholds in such a way as to minimize call drops. The optimization model and a Genetic Algorithm (GA) based solution to the dynamic optimization problem are presented. Original simulation programmes were written in Java and results from simulations performed using the proposed method and the existing handoff protocol based on static preprogramming of the threshold values show that the proposed method outperforms the existing method.

**Keywords:** CDMA, Handoff, Dynamic Optimization, Genetic Algorithm, CDMA, Networks

## 1.0 Introduction

In a cellular wireless communication network, the coverage is divided into cells, each having a base station (BS) to transmit and receive signals with mobile stations (MS's) within the cell. The signals are then relayed via a mobile switching center to the backhaul switching network, which handles call processing, security, billing, etc. When a mobile station traverses a cell boundary, it is required that the user be connected to another base station for better link quality. This process of switching from one base station to another is called handoff, (Viterbi 1995, Stuber, 1996). In CDMA networks, codes are used to determine active calls and since the available codes are limited, the calls that are activated per time are also limited; hence, the need for optimization of parameters that determine call activation in order to reduce the number of drop calls during handoff. Existing CDMA handoff techniques (Rege et al, 1995, Vakil et al, 2000, Chan et al, 2002) reveal that mobile communication infrastructure involved in the handoff process are treated as 'dummy' parts of a system in the sense that they only react to the state of their environment. In these schemes, the mobile infrastructure is pre-programmed to determine when handoffs occur and how many calls can be activated per time. The static handoff protocol makes use of a preset handoff signal strength threshold which is prejudicial to the state of a given cell per time. In order to have a more flexible protocol, it is necessary to consider a scenario in which the mobile communication infrastructure possesses some form of cognitive properties which allow it to not only react to cell states but also take call activation decision in response to a given cell state. Such a decision is to be taken with respect to the caller density in a cell and the number of available codes per BS transceiver. The call

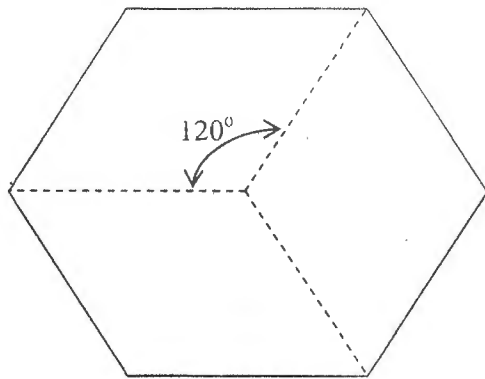
activation decision to be taken is the dynamic setting of a soft handoff threshold in the cell.

In this work, a Genetic Algorithm (GA) based dynamic optimization technique that minimizes the number of dropped calls during intra-cell handoff, i.e. soft handoff is presented. The objective of this research work is to develop a soft handoff protocol based on a proposed cognitive property of a base station. The protocol is aimed at improving the quality of service in a CDMA network by maximizing the number of possible active calls in densely populated cell sites; reducing the call drop rates; maximizing channel utilization and reducing the rate of call blocking (Mathar and Schmeink, 2001).

The model formulation of the proposed protocol is presented in the section 2.1. After that, the GA-based technique adopted for optimizing soft handoff threshold parameters in a cell is discussed. Simulation experiments carried out to validate the proposed protocol and the results obtained are also presented.

## 2.1 Proposed Soft Handoff Model

Figure 1 shows the sectorized configuration of base transceiver station in a CDMA cell. Each of the three transceivers in the cell covers a 120° sector. When a mobile station moves from one sector in the cell to another, an intra-cell soft handoff occurs depending on the signal strength measured by the mobile station and the positional distribution of other mobile stations in that cell.



## 2.2 CDMA Handoff Parameters

Mobile stations in a cell are grouped into one of three sets depending on their activity status and code availability on the base transceiver stations in the cell. All mobile stations that are currently making use of the traffic channels belong to the active set; those that have strong enough signal strength and are ready to be active at any time belong to the candidate set, while the mobile stations which do not belong to any of the afore mentioned but may be moved into the candidate set (when codes are available) belong to the neighbour set. The classification of the mobile stations depends on the following CDMA handoff parameters:

### 2.2.1 Add Threshold ( $T_{add}$ ): Pilot available threshold.

This refers to the minimum signal strength required for a mobile station to be moved from the neighbour set to the candidate set. When a mobile station has a maximum signal strength which is greater than  $T_{add}$ , then it sends measurement message of pilot (mobile station on a given CDMA frequency) strength to move the pilot from the neighbour set to the candidate set.

### 2.2.2 Drop Threshold ( $T_{drop}$ ): Pilot Drop threshold

This refers to the lowest allowable signal strength threshold below which a mobile station is moved from the active set or candidate set into the neighbour set.

### 2.2.3 Active vs. Candidate Sets Comparison Threshold ( $T_{comp}$ ):

This signal strength threshold is used to determine whether a mobile station should be moved from the candidate set to the active set.

## 2.3 Formal Description of Cell Status

A cell consists of three transceivers and allows for the presence of mobile stations. A typical cell is described here using a signal strength matrix which

describes the perception of the mobile stations of the cell in terms of signal strength from the three transceivers; and a call activity matrix which describes the classification of mobile stations in the cell into active, candidate and neighbour sets. The call activity matrix is the perception of the base station controller of mobile stations resident in the cell.

### 2.3.1 Signal Strength Matrix

The mobile station is responsible for measuring the signal strength. The signal strength in a cell is represented with a  $(n \times 3)$  matrix. The rows stand for mobile stations, while the columns stand for the base station transceivers (TRX).

$$E = \begin{pmatrix} e_{1,1} & e_{1,2} & e_{1,3} \\ \vdots & \vdots & \vdots \\ e_{n,1} & e_{n,2} & e_{n,3} \end{pmatrix} \quad (1)$$

where  $e_{i,j}$  signal strength of TRX  $j$  as measured at mobile station  $i$

### 2.3.2 Call Activity Matrix

Call activity matrix is the matrix that shows if a call is in the active set or the candidate set or the neighbour set.

$$E' = \begin{pmatrix} e'_{1,1} & e'_{1,2} & e'_{1,3} \\ \vdots & \vdots & \vdots \\ e'_{n,1} & e'_{n,2} & e'_{n,3} \end{pmatrix} \quad (2)$$

$$e'_{n,j} = \begin{cases} 1 & \text{if } (e_{n,i} - e_i^{tc}) > 0 \text{ and } e_{n,j} > e_{n,k} + \frac{1}{2}e^{tcomp} \\ 0 & \text{iff } (e_{n,j} - e_i^{tc}) > 0 \\ -1 & \text{if } e_{n,i} < e_i^{tc} \end{cases} \quad (3)$$

where  $e'_{n,j}$  = call activity for each sector

$e_{n,j}$  = call signal strength

$e_i^{tc}$  = candidate threshold of TRX  $j$

$e_{n,k}$  = active signal

$e^{tcomp}$  = comparison threshold

Equation (3) determines the values in the call activity matrix. It simply means that if the signal strength of TRX,  $j$  measured by mobile station  $n$  ( $e_{n,j}$ ) is greater than the candidate threshold ( $e_i^{tc}$ ) in sector  $j$  and  $e_{n,j}$  is greater than the active signal ( $e_{n,k}$ ) plus half of comparison threshold, then  $e'_{n,j} = 1$ , i.e. the mobile station is moved to the active set. If the signal strength ( $e_{n,i}$ ) is just greater than candidate threshold ( $e_i^{tc}$ ) then  $e'_{n,i} = 0$ , i.e. the mobile station is

classified as a member of the candidate set. If the signal strength ( $e_{n,j}$ ) is less than candidate threshold ( $e_j^{tc}$ ) then  $e'_{n,j} = -1$  and the mobile station is grouped with the neighbour set.

### 3.1 Soft Handoff Optimization Problem

The intra-cell soft handoff optimization problem is defined as follows:

#### 3.1.1 Objective Function

$$\max c^a = \sum_{j=1}^3 c_j^a \quad (4)$$

Where  $c^a$  = active call set for cell

$c_j^a$  = active call set for TRX  $j$

$j$  = sectors 1, 2, or 3

#### 3.1.2 Decision Variables

The decision variables for this model are  $(e_1^{tc}, e_2^{tc}, e_3^{tc})$  which are also known as  $T_{add1}$ ,  $T_{add2}$ ,  $T_{add3}$ . These chromosomes are not constant, and they determine the state of a mobile station whether it will fall in the neighbour set or candidate set or active set.

#### 3.1.3 Constraints

$$e_{aj}^{tc} \geq e^i \quad (5)$$

$$c_j^a \leq q \quad (6)$$

where

$e_j^{tc}$  = candidate threshold

$e^i$  = minimum signal strength for quality call

$c_j^a$  = active call set for TRX  $j$

$q$  = codes for TRX  $j$

Equations (5) and (6) mean that the sum of active calls in a TRX must not be greater than the total number of communication codes available for each TRX. The reason for this is that it is not possible for the system to deploy the resources it does not have, i.e. codes cannot be allocated if they are no longer available.

### 4.1 Model Simulation

The solution to the optimization problem was obtained using Genetic Algorithm. The chromosomes for the population are constructed using the decision variables which are the  $T_{add}$ s for all the TRXs. The fitness function is the objective function while the constraints are defined as the eligibility criteria for the chromosomes.

### 4.2 Simulation Algorithm

*Step 1: Generate random population of  $m$  chromosomes.*

*Step 2: Calculate the fitness of chromosomes.*

*Step 3: Rank the chromosomes in descending order of fitness, i.e. from the highest fitness to the lowest.*

*Step 4: Use 50% selection rate to determine the number of chromosomes to keep and discard the others.*

*Step 5: Mate the parents to produce the same number of offspring.*

*Step 6: Calculate the fitness of the new population*

*Step 7: Rank the chromosomes in descending order of fitness.*

*Step 8: Mutate the new population exclude the elite.*

*Step 9: Calculate the fitness of the new population*

*Step 10: Rank the chromosomes in descending order of fitness.*

*Step 11: Do step 4 to 10 until iteration is equal to generation.*

*Step 12: Print fittest chromosome.*

#### 4.2.1 Initialization of the Population

To begin the GA, an initial population of  $N_{pop}$  chromosomes is defined. A matrix represents the population with each row in the matrix being a  $1 \times n$  array (chromosome) of continuous values. Each chromosome is a potential solution or a candidate solution to the problem. This means that every chromosome in the population satisfies all the constraints but may not be the best combination of continuous values that gives the best cost. If the search or solution space is small, a small number of chromosomes can be used for the initial population but if the solution space is large enough, in order to explore it faster, it is good to generate a large number of chromosomes for the initial population. In this work, the number of chromosomes used was 10,000. This number was obtained from conducting a number of experiments to obtain the optimal population in terms of computational speed and quality of solution.

#### 4.2.2 Fitness Function

The objective of the model is to determine the best value of  $T_{add}$  that will maximize the active calls.

#### 4.2.3 Selection

Selection is done by ranking the fitness of chromosomes from the population in descending order so that those with higher fitness values are at the top. A percentage of the chromosomes at the bottom are discarded and are replaced by the offspring of the fit ones through mating.

#### 4.2.4 Mutation

Number of genes in the chromosome mutated is obtained by multiplying the mutation rate by

mutation rate chosen for this model is 30% of the genes in a chromosome. Npop = no of chromosome in the initial population = 8  
No of decision variables = 3

$\therefore \text{Mutation} = 0.3 * (8 - 1) * 3 = 6.3$   
Six random numbers are chosen to select the rows and columns of variables to be mutated. The values that match the selected rows and columns are replaced with new random variables.

### 4.3 Simulation Scenarios

Some experiments were performed to validate the proposed protocol in which the BSC is made to respond dynamically to the state of a cell per time. The experiments performed include varying the number of available codes on each TRX (with a maximum of 64 codes), and varying the number of mobile stations in a cell. The proposed protocol was also compared with the existing protocol which is based on statically programmed base station controllers.

### 5.1 Results and Discussion

After obtaining experimental results from the activities conducted in section 4.3, the results are presented for analysis and discussions here in sections 5.2 through 5.4.

### 5.2 Results of Varying Available Codes on TRX

The maximum number of codes available on each TRX is 64, but 61 are used to make calls while the remaining 3 are used for sync, pilot, and paging (Chan, 2005). From Table 1, it can be seen that with the same number of phone call requests from mobile stations, the active calls increase and the dropped calls reduce as the codes increase.

Table 1: Result on Varying Available Codes on TRXs

| Codes | Phone Call Request | Active Calls | Dropped Calls |
|-------|--------------------|--------------|---------------|
| 43    | 847                | 764          | 83            |
| 49    | 847                | 788          | 59            |
| 55    | 847                | 809          | 38            |
| 61    | 847                | 828          | 19            |

### 5.3 Results of Varying Number of Call Requests in a Cell

From Table 2, it can be seen that the number of active calls increase with increase in the number of call requests just as the number of dropped calls also increase with increase in the number of phone call requests but the performance of the protocol can be measured in terms of the active calls to dropped calls ratio which decrease with increase in phone call requests. This clearly displays the effect of congestion in a cell. However, the effect of dynamic optimization of the TRX thresholds is

revealed in the changing values of the active calls and dropped calls as against a situation in which these values will remain constant irrespective of changes in the number of mobile stations making phone call requests especially for request numbers that make a cell congested.

Table 2: Result on varying randomize phone call request.

| Phone call request | Active calls (A) | Dropped calls (D) | Performance (A:D) |
|--------------------|------------------|-------------------|-------------------|
| 847                | 828              | 19                | 43.58             |
| 952                | 929              | 23                | 40.39             |
| 1045               | 1007             | 38                | 26.50             |
| 1135               | 1087             | 48                | 22.65             |
| 1415               | 1318             | 97                | 13.59             |

### 5.4 Comparison of Results from Dynamically Optimized BTS and Statically Programmed BTS

The experiment carried out was to vary the number of phone call requests from mobile station in the cell during simulation using both the proposed method and the existing method. Simulations were done for different numbers of available TRX codes. It should be noted that the varying number of call requests during a simulation is intended to illustrate changing conditions within a cell. For the experiments conducted, same or equal number of call requests was used. Table 3 shows the results from the simulations. Preset threshold values were used for the TRXs in the cell for the statically programmed BTS.

Table 3: Performance with Phone call request vector {180,63,72,59,90,68,87,94,57,77}

| Codes | Phone Call Requests | Proposed Method (Dynamic Programming) |               | Existing Method (Static Programming) |                      |                      |                      |                      |                      |
|-------|---------------------|---------------------------------------|---------------|--------------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|       |                     | Active Calls                          | Dropped Calls | Active Calls                         |                      |                      | Dropped Calls        |                      |                      |
|       |                     |                                       |               | T <sub>add</sub> = 3                 | T <sub>add</sub> = 5 | T <sub>add</sub> = 8 | T <sub>add</sub> = 3 | T <sub>add</sub> = 5 | T <sub>add</sub> = 8 |
| 43    | 847                 | 764                                   | 83            | 736                                  | 688                  | 579                  | 111                  | 159                  | 268                  |
| 49    | 847                 | 788                                   | 59            | 762                                  | 721                  | 639                  | 85                   | 126                  | 208                  |
| 55    | 847                 | 809                                   | 38            | 791                                  | 759                  | 698                  | 56                   | 88                   | 149                  |
| 61    | 847                 | 828                                   | 19            | 817                                  | 792                  | 754                  | 30                   | 55                   | 93                   |

From Table 3, it can be seen that the proposed method performs better than the existing method regardless of the values chosen as  $T_{add}$  for the TRXs in the cell. It is also clear that the higher the threshold value, the poorer the performance of the statically programmed BTS, since more candidate calls will be prevented from being move into the active set.

### 6.1 Conclusions

A method to dynamically optimize the performance of a base station in a CDMA network by using the soft handoff threshold of each of the three sectorized TRXs in a cell has been presented. From the results obtained from simulation, it is clear that the proposed method outperforms the existing method. This is due to the fact that the proposed method allows the base station controller to dynamically change the values of the handoff thresholds in response to the changing conditions in the cell in terms of phone call requests from mobile stations, while in the existing method, the threshold values are preprogrammed thereby removing any form of intelligence from the handoff activities within a cell. A dynamically optimized handoff process improves on the quality of service by reducing the number of dropped calls.

As a subject for further research, the performance of a dynamically optimized inter-cell handoff in a CDMA network could be investigated. In this case, optimization will no longer be limited to a cell but to a group of cells in which the base stations behave like cognitive agents and work together to improve the performance of the network by sharing handoff threshold information and also learning from call activity in the environment.

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