Reference document for SEAMCAT-3 Wiki Help database

SEAMCAT CDMA Algorithms

Part A. CDMA Downlink Modeling

Part A.1: Concept Description

CDMA Downlink Power Control Methodology for SEAMCAT (VOICE ONLY)

Based on October 2003 contribution of Lucent Technologies (CEPT Doc. STG(03)12Rev.1)

1. Introduction

CDMA downlink power control is a complex process involving various layers of signaling, measurement and modulation/demodulation procedures. It is not feasible to model signaling, link and chip level details of CDMA power control in network level simulations performed by SEAMCAT due to the complexity and CPU time constraints. Hence, it is necessary to adopt the two-step approach employed widely in the industry for the simulation of CDMA based systems. The first step utilizes link level simulations that model fast fading channels, power control procedures and actual chip level algorithms to generate outputs that map channel power requirements to link quality (e.g. frame erasure rate, FER). Such simulations involve the knowledge of intricate details of the CDMA signaling procedures and modulation/demodulation methods. Major CDMA vendors develop link level simulations and contribute their results to the standard bodies. Since the link level results are independent of most system level variations (cell sizes, amplifier ratings, antenna types, etc.), they are applicable to a wide variety of network configurations. The second step in the simulation of CDMA involves system level simulations that actually model the CDMA network on a macro scale. Since the required channel power vs. link performance data is available from the link level results, transmit power levels for CDMA channels can be calculated and utilized in the system level modeling of a CDMA network.

The approach described above enables the reuse of link level data to model various network configurations. Furthermore, through the use of the link level data, an accurate power control model is implicitly included in the system level simulations that run at moderate complexity. The same approach can be used to model power control in SEAMCAT as presented in this paper.

2. Simulation Methodology

2.1. Overview

The main goal of the downlink power control in SEAMCAT is to calculate the total BS output power and the success rate (% of calls with no link quality degradation) for a given snapshot of the system. BS output power is a key parameter in the scenarios where CDMA is the interferer. Success rate, on the other hand, is crucial in CDMA victim scenarios. One possible way to analyze the impact of other system interference on CDMA is to compare the success rates in the presence and absence of external interference.

A snapshot of the mutually existing systems is modeled at each event generation in SEAMCAT. Hence, at each event generation the power control algorithm should also be run for the CDMA cell, whether it is the victim or the interferer. This is achieved as shown in appendix A. The setup block is inherited from the higher layers of SEAMCAT and consists of initializing the system parameters. The next step involves the generation of traffic for power control, calculation of appropriate path losses within the CDMA cell layout and determination of soft handover states. Power control is then performed by utilizing the link level data via an iterative process. Finally, necessary outputs are generated and fed into the interference calculation modules in SEAMCAT.

For simplicity, this paper describes the CDMA downlink power control methodology for omni-cells. However, extension to multi-sector cells is straightforward. In a multi-sector configuration, each sector should be treated in the same way a cell is treated in the omni configuration.

2.2. Setup

CDMA specific parameters needed to perform the power control procedure are: (in addition to the existing parameters for the interfering system such as AID, cell radius, antenna patterns, noise floor, etc.)

Link level data	-Power fraction curves
Mobility distribution	-Distribution of speed among users
Voice activity factor	-Average activity of a voice channel (between 0 and 1)
Call drop threshold	-Threshold to determine call drops
Success threshold	-Threshold to determine perfect link quality
Pilot fraction	-% of max BS power allocated to pilot
Overhead fraction	-% of max BS power allocated to overhead channels (paging, etc.)
Max. Traff. Chan Pow.	-Maximum allowable broadcast power (per traff. chan. per BS)

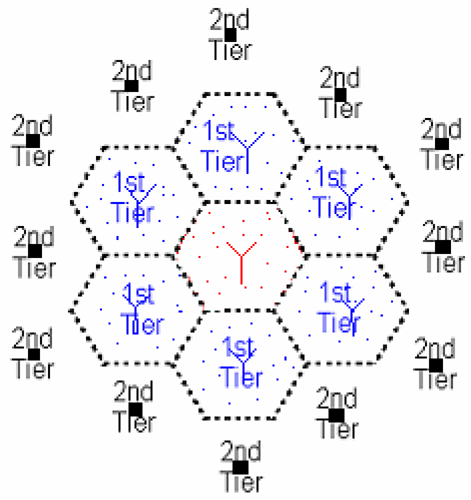
This list can be extended as needed in order to give users more flexibility in simulating CDMA based technologies.

2.3 Traffic Generation

Cell Layout

While the BS output power and the outage ratio is likely to be calculated for a single CDMA cell, accurate modeling of power control requires the consideration of inner-system interference generated by the surrounding tiers of CDMA cells. The significance of other cell interference in CDMA requires that at least two tiers surrounding the cell of interest be considered. However, BS power and outage statistics will only be collected from the center cell, which has the most accurate interference background (two surrounding tiers).

Cells surrounding the center cell will not be visible to the higher levels of SEAMCAT and will only be used to generate the inner-system other-cell interference background for the center cell, see figure 1.



-Center cell - Included in SEAMCAT interference analysis: simulated mobiles and BS

- 1st Tier cells - Not visible outside power control: simulated mobiles and BS's

-2nd Tier cells- Not visible outside power control: simulated mobiles and BS's

Figure 1. Cell layout for power control

Wrap-around

The SEAMCAT implementation of cell layout in the downlink follows the wrap-around principle, described in detail in Uplink description in Part B of this annex.

Mobility and Activity

Since higher levels in SEAMCAT consider only a single CDMA cell, the wrap-around layout may need to be generated separately in the power control module. It is expected that the user placement be done consistently with SEAMCAT's existing algorithms. However, once the users are placed, their mobility assignment should also be done. Actual mobility of the users cannot be simulated easily in a static simulation, but the effects of mobility on the channel power can be modeled in a limited sense. While the users will be treated at fixed locations within each snapshot, each will be assigned a speed to determine their channel conditions (fast fading), which will be used in the determination of their channel power requirements. This allows the flexibility to simulate various system configurations (fixed, highway, pedestrian, etc.). Furthermore, since CDMA channels do not hog resources during periods of silence in speech, each user should also be assigned its activity state at a given snapshot. The activity state can be defined as a binomial random variable taking on the values 0 (inactive) and 1 (active). A value of 1 would correspond to the full utilization of the voice channel and 0 would correspond to silence (no transmission). The probability of assigning the active and inactive states can be determined via the average downlink voice activity factor for the particular CDMA technology. (i.e. assign 1 with probability voice_ activity, 0 with probability 1-voice_activity). Consequently, only the users with activity state of 1 are considered in the power control calculations and users with activity state of 0 are ignored since they do not consume any power resources.

2.4 Path Loss

In order to carry out the power control calculations, path loss between each user and BS needs to be calculated within the wrap-around layout. It is expected that the antenna characteristics, propagation models, etc. that are used in other modules of SEAMCAT will also be used here. The calculation of the distance between mobiles and base stations in the wrap-around layout is described in Uplink part P of this annex.

2.5 Soft Handover

A user may simultaneously be connected to multiple BS's in CDMA based systems (soft handover). Since soft handover affects the amount of power transmitted by each BS to a certain user, it is necessary to determine whether the user is served by a single BS or multiple BS's. The actual determination of the soft handover state of a user and the corresponding channel power requirements may get complicated. Hence, a simplified soft handover algorithm is presented next, which captures the essence of soft handover effects while avoiding implementation of complex algorithms.

Base stations that are connected to a user are included in the "active set" of that user. A base station is initially selected to be in the "active set" based on the strength of its pilot signal versus the interference background. Each base station broadcasts a certain fixed percentage of its maximum power on the pilot channel. The interference background consists of the non-orthogonal energy received on the other channels of the base stations within the active set and the total broadcast power of the base stations that are not in the active set. The BS selection criterion, "pilot Ec/Io" is then defined as

$$\left(\frac{E_c}{I_0}\right)_i = \frac{pilot\_frac \times P_{Max,i} / W}{FN_{th} + \sum_{allj} P_j / W + I_{ext} / W}$$

(1), with the following definitions:

–E_C= *chip energy received from ith BS*
–I_O = *spectral density of total received interference*
–*pilot_frac* = *fraction of BS power allocated to pilot*
–$P_{\max,i}$= *maximum receivable power from ith BS (max BS transmit power*path loss)*
–W = *system bandwidth*
–P_j= *total received power from jth BS*
–F = *mobile station noise figure*
–N_{th} = *thermal noise power density*
-I_{ext} = *external interference (out of system)*

Based on this selection criterion, the following simplified soft handover algorithm can be employed to assign soft handover states to each user:

For each user:

i. Add the BS with the strongest corresponding Ec/Io to the active set

ii. Add the BS with the second strongest corresponding Ec/Io to the active set if its Ec/Io is within 4 dB of the strongest Ec/Io

Then the soft handover state of a user becomes the number of BS's in its active set, which is either one or two. Note that in actual systems, the active set of a user may have more than 2 BS's. However, in order to develop a unified methodology that can simulate various implementations of CDMA based systems and to avoid overwhelming complexity, this simplified approach is suggested. Several standards (including UMTS) present similar methodologies for simulations.

2.6 Power Control

As far as SEAMCAT is concerned, the actual CDMA power control algorithm looks merely like a black box that maps link quality to channel power. However, the mapping is not simply one-to-one. Depending on the conditions of the mobile user, the same link quality can map to different channel power requirements. A key parameter that determines the condition of a user is called the "geometry". Geometry is defined as:

$$G = \frac{P_{active}}{N_0 + P_{other} + I_{ext}}$$

(2); with the following definitions:

P_{active} = *Total power received from BS's in the active set*
N_O = *Thermal noise*
P_{other}= *Total power received from BS's not in the active set*
I_{ext} = *External Interference (out of system)*Note that the higher the geometry, the more favorable the user's condition is.

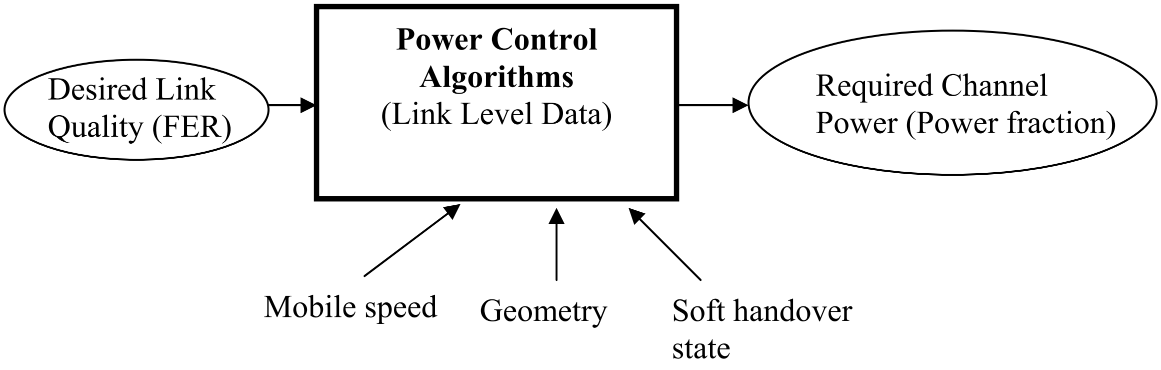


Figure 2: Power Control Module (high level)

As shown in the figure 2, in addition to geometry, mobile speed and soft handover state of the user are also needed to map a particular link quality to the channel power requirement. All these factors determine the appropriate mapping of a particular link quality to the channel power requirement. For example, stationary users may require less power than moving users to attain the same link quality. Similarly, users connected to several BS's at the same time (soft handover) may require less power than users connected to a single BS to achieve the same link quality. Furthermore, users in favorable locations (high geometry) may again require less power than users that are in unfavorable locations (low geometry). Hence, link level data includes different mappings (look up tables) between link quality and required power for different mobile speeds, geometries and soft handover states. Furthermore, in order to remove the dependency on the total BS power (may vary from system to system), the power requirements are reported as normalized power fractions (fraction of the total BS power). Consequently, the link level data is used in modeling power control in a variety of conditions such as different mobile speeds, geometrical user distributions, soft handover characteristics and amplifier output power ratings.

The fractional power levels found in the link level data are defined for each user (channel) as:

$$\frac{E_c}{I_{or}} = \frac{P_{traff\_active}/W}{P_{total\_active}/W} = \frac{P_{traff\_active}}{P_{total\_active}} \quad (3)$$ with the following definitions:

P_{traff_active}: Total received traffic channel power from BS's in the active set

P_{total_active}: Total power received from BS's in the active set

Note that P_{total_active} is the sum of the total received power from the BS's in the active set including their pilot, overhead and all traffic channels. Whereas P_{traff_active} includes only the traffic channel power that is received from the BS's in the active for the particular user. In other words, a user's E_c/I_{or} shows the fraction of the total received power that is used for voice communication with that user. Based on this definition, the amount of traffic channel power received from a BS for a particular user can be derived from the E_c/I_{or} requirements reported in the link level data.

If user has only 1 BS in the active set (simplex), the power received from the BS is:

$$P_{traff}=P_{total\_active} \times E_c/I_{or} . \quad (4)$$

If user has 2 BS's in the active set (2-way soft handover), power received from one of the BS's is then:

$$P_{traff}=(P_{total\_active} \times E_c/I_{or})/2. \quad (5)$$

Note that symmetry between the two soft handover legs (links with BS's in the active set) is assumed. Therefore, when a user is connected to two BS's, it receives equal power from each link. The determination of the traffic channel power levels for each user cannot be done in a single step. The inherent assumption in equations 4 and 5 is that P_{total_active} is known. However, P_{total_active} itself is the sum of the pilot, overhead and all traffic channel power levels received from the BS's in the active set. Therefore, an iterative process is required to determine the individual traffic channel received power levels.

Figure 3 shows how the power control loop operates. The initial step is to initialize each BS in the cell layout by assigning total broadcast power levels. A figure around 70% of maximum BS power is appropriate. Note that for the simulated BS's, the total BS power will be updated at each iteration by the power control loop. After enough iterations, the power levels will converge to the correct values. If the BS's in a surrounding tier are replaced with artificial interference generators (see figure 1), the broadcast levels for those BS's will not be updated by the power control loop. It is suggested that these BS's are initialized at the same power level as the simulated BS's and updated after each iteration of power control based on the average power of the simulated BS's.

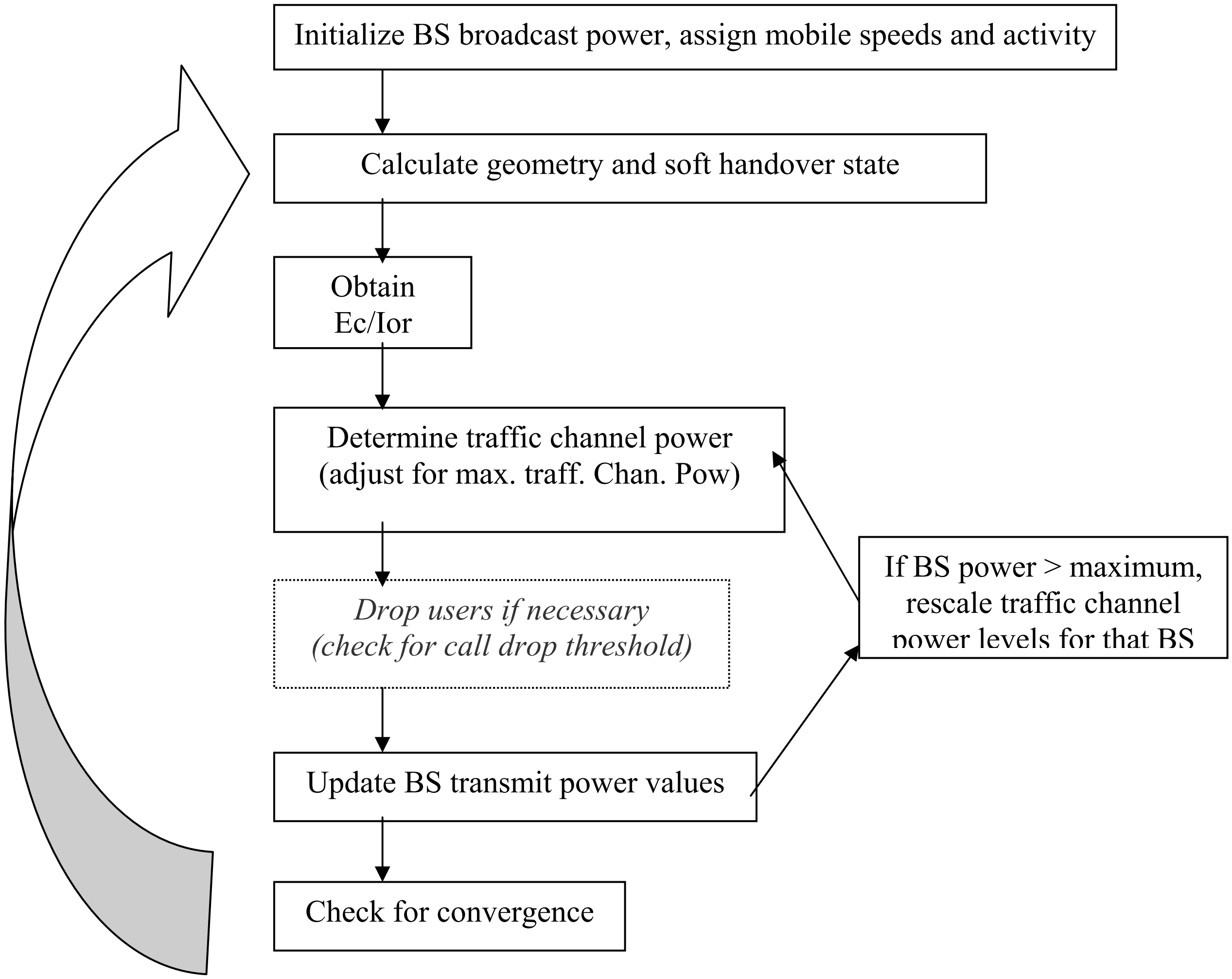


Figure 3. Power Control Loop

Once the initialization is complete, geometry and soft handover state for each user can be calculated based on the initial values of the BS broadcast levels. Then the E_c/I_{or} requirement for each active user can be obtained from the link level data using its mobile speed assignment, calculated geometry and soft handover state. Equations 4 and 5 can then be used to get the received traffic channel power levels for each user. Path loss information can then be used to determine the corresponding transmit channel power levels. However, the calculated transmit traffic channel power levels should be checked against the maximum allowable traffic channel power and transmit/receive levels should be adjusted if necessary. As a result of such an adjustment, a user may not meet its E_c/I_{or} requirement. Based on a "call drop threshold", such a user may be removed from the system if it meets the following criterion:

$$\textit{Achieved } E_c/I_{or} < E_c/I_{or} \textit{ requirement} - \textit{Call drop threshold (dB)}. \quad (6)$$

Note that the call drop threshold should be set such that dropping a call is limited to extreme circumstances (thresholds less than 2dB are not recommended) and kept mostly as a safety measure to avoid a single user hogging the BS resources. In an actual system, calls are not dropped at the instant they fail to meet their link quality target. The system will tolerate quality degradation up to certain durations and at the same time avoid a single user to sacrifice the overall system performance by consuming all the BS resources (max. traff. chan. pow. setting). In fact, for systems that employ sufficient control of maximum traffic channel power, call drops may be avoided completely within the power control loop. Eventually, users not meeting their E_c/I_{or} target will be evaluated when the success rate of the system is calculated.

Once the transmit traffic channel levels are calculated, the broadcast power of each BS should accordingly be updated. If the total broadcast power of a BS turns out to be greater than its maximum allowable level, all traffic channels served by that BS should be scaled down so that the maximum BS power constraint is met. The scaling factor that should be applied to the traffic channel power levels can easily be calculated as:

$$Scaling = \frac{P_{\max} - (pilot\_frac \times P_{\max}) - (overhead\_frac \times P_{\max})}{P_{calculated} - (pilot\_frac \times P_{\max}) - (overhead\_frac \times P_{\max})}, (7)$$

where $P_{\max}$ is the maximum allowable BS power and $P_{\text{calculated}}$ is the actual calculated BS broadcast power (including pilot and overhead). Scaling is only done if $P_{\text{calculated}} > P_{\max}$ and it is done only on the traffic channels; pilot and overhead power levels remain at a constant percentage of the maximum allowable BS power. Note that for channels that go through the scaling, achieved E_c/I_{or} levels may not match the required E_c/I_{or} levels. Therefore, call drop criterion (if used) shown in equation 6 should also be checked after the scaling. The process is outlined in figure 3.

This process describes a single iteration of the power control loop. After all the traffic channel power levels are determined and the BS levels are updated, the process should be repeated (with the new, more accurate BS broadcast levels). Convergence of the traffic channel power levels should be checked at the end of each iteration. The loop can be terminated once the traffic channel power of every simulated user in the network converges to the desired precision.

Note that signaling and other errors in power control are considered in the link level simulations. System level simulations do not consider additional errors and assume that each user is served with the required power level that is determined from link level data, provided that the BS has enough power to do so and the maximum traffic channel limit is not exceeded.

2.7 Output

The power control loop terminates when every BS broadcast power converges and traffic channel power level for every user is calculated. Therefore, both the BS output power and the success rate for the cell of interest (center cell in figure 1) can be calculated. BS output power is the sum of the power in pilot, overhead and all traffic channels. Success rate is the percentage of calls that do not suffer quality degradation. The following process can be used to calculate both output metrics:

i. Power control loop is terminated (traffic power converges for every user)
ii. Final BS transmit power levels are calculated (sum of all traffic, pilot and overhead)
iii. Total BS broadcast power for the cell of interest is determined

(For each active user in the cell of interest)
iv. Final geometry is calculated based on BS power levels calculated in ii.
v. Traffic E_c/I_{or} target is determined based on geometries calculated in iv.
vi. Achieved E_c/I_{or} is calculated based on BS power levels calculated in ii.
vii. Success criterion is checked

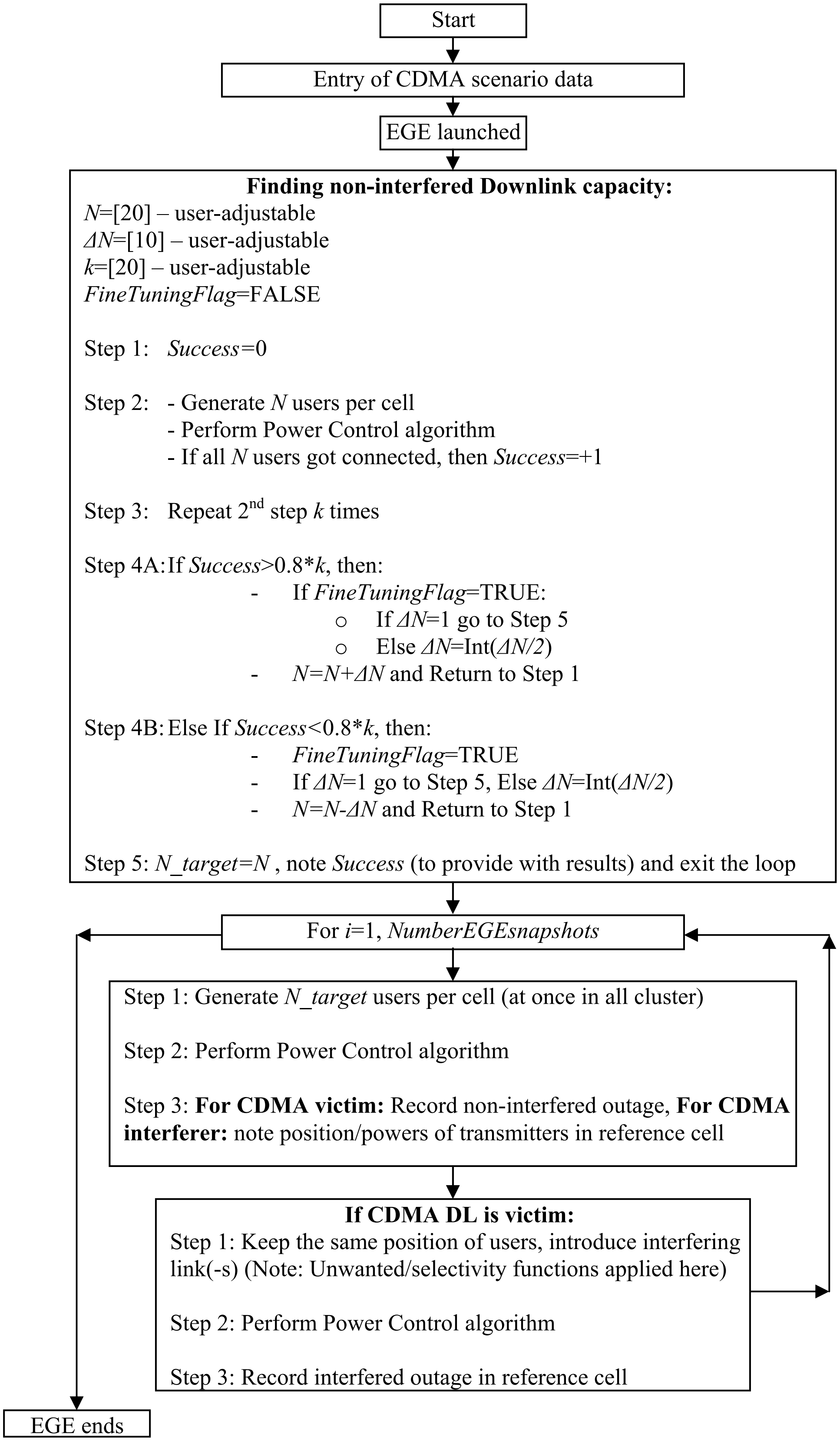
$$\left(\frac{E_c}{I_{or}}\right)_{\text{achieved}} \overset{?}{\geq} \left(\frac{E_c}{I_{or}}\right)_{\text{target}} - \text{Success Threshold (dB)} \qquad (8)$$

viii. Success rate is determined for the cell of interest

Success Threshold is usually a small figure such as 0.5dB. Users who miss their E_c/I_{or} targets by more than the threshold suffer link quality degradation. Note that if call drops occurred within the power control loop (according to equation 6), they should also be considered when success rate is determined:

$$\text{Success Rate} = \frac{\#\,\text{users meeting success criterion}}{\text{Total}\,\#\,\text{of active users including call drops}} \qquad (9)$$

Part A.2: CDMA Downlink software implementation in SEAMCAT-3



```
Finding non-interfered Downlink capacity:
N=[20] – user-adjustable
ΔN=[10] – user-adjustable
k=[20] – user-adjustable
FineTuningFlag=FALSE

Step 1:  Success=0

Step 2:  - Generate N users per cell
         - Perform Power Control algorithm
         - If all N users got connected, then Success=+1

Step 3:  Repeat 2nd step k times

Step 4A: If Success>0.8*k, then:
             - If FineTuningFlag=TRUE:
                   o If ΔN=1 go to Step 5
                   o Else ΔN=Int(ΔN/2)
             - N=N+ΔN and Return to Step 1

Step 4B: Else If Success<0.8*k, then:
             - FineTuningFlag=TRUE
             - If ΔN=1 go to Step 5, Else ΔN=Int(ΔN/2)
             - N=N-ΔN and Return to Step 1

Step 5: N_target=N , note Success (to provide with results) and exit the loop
```

Step 1: Generate *N_target* users per cell (at once in all cluster)

Step 2: Perform Power Control algorithm

Step 3: **For CDMA victim:** Record non-interfered outage, **For CDMA interferer:** note position/powers of transmitters in reference cell

If CDMA DL is victim:

Step 1: Keep the same position of users, introduce interfering link(-s) (Note: Unwanted/selectivity functions applied here)

Step 2: Perform Power Control algorithm

Step 3: Record interfered outage in reference cell

Setup:

Calculate and store Thermal Noise:

$$Nt_W = 10^{\left(\frac{((-173,977+10\cdot\log_{10}\left(SYSTEM\_BANDWIDTH*10^6\right)+RECEIVER\_NOISE\_FIGURE)-30}{10}\right)}$$

Layout cells

Capacity finding

This step is done before start of actual simulation, and only if “simulate non interfered capacity” flag is checked in cdma system setup. The purpose of this is to find the non interfered capacity of a system with the current configuration. The capacity is found by gradually filling system with users while measuring system outage. For every number of users a certain number of trials are run and then the number of “successful” trials is compared to a predefined success criterion. In current version only the number of trials is configurable by user – success criterion is fixed at 80%. This means that optimal capacity of a downlink system is defined as the capacity which system is able to serve without any outage in 80% of trials. Note that this step can be quite time consuming.

The following pseudo code describes how the non interfered capacity of a downlink system is found:

Note: This method runs recursively

```
Find Non Interfered Capacity function {
  For (Number of Trials) {
            Reset System
            For (1 -> (Users per cell * Number of cells)) {
                  Generate new user
                  Randomly drop user in system
                  Determine and store distance to all BS (based on Wrap-Around model)
                  Determine and store pathloss to all BS
                  Select active list based on pathloss
                  If (new user is voice inactive) -> {go to next user}
                  Else proceed with:
                        User tries to connect to BS in active list
                        If user is unable to connect -> {
            user is dropped and next user is generated
            }
                        Else
                              For BS’s in users active list {
                                    If (Current Transmit power > Maximum Transmit power)
                                          BS power scaling is activated
                              }
            }
            Balance Downlink System
Note number of dropped users during this trial

      }
      Note successRate (Number of trials where number where no users where dropped)
If (successRate > (number of trials * success criteria)) {
      If (fine tuning) {
            If (ΔN == 1) {
                        Capacity found = true
                        Exit;
                  }
            Else {
```

```
                  ΔN = Ceil (ΔN / 2);
                  }
            }
      Users per Cell += ΔN
      Return "Find Non Interfered Capacity" //Recursive call using new values
      }
Else if (successRate < (number of trials * success criteria)) {
      Fine tuning = true
      If (ΔN == 1) {
            Capacity found = true
            Exit;
      }
      Else {
            ΔN = Ceil (ΔN / 2);
      }
      Users per Cell -= ΔN
Return "Find Non Interfered Capacity" //Recursive call using new values
}
Else {//Success Criteria is fulfilled
      Capacity Found = true
      Exit
      }
}
```

Non interfered capacity

This procedure is executed once at the beginning of every snapshot, and is used to initialize CMDA system, and determine initial outage.

```
Initialize and balance downlink system {
            For (All cells in cluster) {
                  Initialize Cell Power levels
            }
      For (1 -> Capacity of system) {
            Add new user to system
            Generate new user
                  Randomly drop user in system
                  Determine and store distance to all BS (based on Wrap-Around
model)
                  Determine and store pathloss to all BS
                  Select active list based on pathloss
                  If (new user is voice inactive) -> {go to next user}
                  Else proceed with:
                        User tries to connect to BS in active list
                        If user is unable to connect -> {
            user is dropped and next user is generated
            }
                        Else
                              For BS's in users active list {
                                    If (Current Tx power > Maximum Tx power)
                                          BS power scaling is activated
                              }

      }
      For (All voice active users in system) {
            If($\frac{Ec}{ior}req$ > -3db) ->     User is dropped

                  }
            Balance Downlink System
      }
```

Interfered Capacity

This procedure is invoked on a filled system, after adding external interferers.

```
For (All voice active users in system) {
Calculate and store distance and path loss to external interferers. Distance is
“linear” (i.e. not using “wrap-around” formulas).
Recalculate Geometry and look up link level data
If($\frac{Ec}{ior}req$ > -3db) ->     User is dropped
}
Balance Downlink System
```

Balance Downlink System

This is a pseudo code implementation of the internal downlink power balance algorithm, called from other parts of the CDMA system.

```
For (All voice active users in system) {
            Calculate total interference experienced by this user
            Recalculate Geometry and look up link level data
     If ($\frac{Ec}{ior}req$ > -3db) ->     User is dropped

            If (User does not meet $\frac{Ec}{ior}req$) -> User id dropped
}
powerConverged = false
While (not powerConverged) {
      powerConverged = true
      For (All BS in cluster) {
                  if (Number of served users > 0) {
                        if (current transmit power > maximum transmit power) {
                              Scale Traffic Channel Power

            powerConverged = false
                        }
                  }
            }
      }
```

Scale Traffic Channel Power

Method invoked on a single BS object by power balance algorithm. Pseudo implementation is below:

```
Calculate scaling factor:
//Lucent EQ7:
If (Current Transmit Power > Maximum Transmit Power) {
            Scaling = Maximum Power in Watts / Current Power in Watts
            For (All active connections to this BS) {
                  Scale traffic power for this link according to scale factor
      }
}
```

Test $\frac{Ec}{Ior}$ requirement for specific user

When evaluating whether or not system is capable of serving a specific user, the following procedure is invoked:

```
Calculate Achieved $\frac{Ec}{Ior}$ as: $P_{Traf_{dBm}} - P_{TotalActive_{dBm}}$
//Lucent EQ6:
Meets $\frac{Ec}{Ior}$ = (achieved $\frac{Ec}{Ior}$ >= (required $\frac{Ec}{Ior}$ - Call Drop Threshold))
```

Calculation of Geometry for specific user

```
//          Lucent EQ2:
            If (User is in Soft Handover and also in AWGN channel) {
                  c1 = $P_{Rx_{1st\_link\_in\_active\_list}}$
                  c2 = $P_{Rx_{2nd\_link\_in\_active\_list}}$
                  Absolute Geometry =     (c1 / (c2 + thermal Noise + total interference)) +
                                          (c2 / (c1 + thermal Noise + interference))
                  Geometry = 10 * log10 (Absolute Geometry)

            } else {
            Absolute Geometry = $P_{Rx_{active\_list}}$ / (thermal Noise + total interference)
                      Geometry = 10 * log10 (Absolute Geometry)
            }
```

Part B. CDMA Uplink Modeling

Part B.1: Concept Description

CDMA Uplink Power Control Methodology for SEAMCAT (VOICE ONLY)

Based on October 2003 contribution of Qualcomm (CEPT Doc. STG(03)13 Rev.1)

1. Introduction

SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) is a generic radio compatibility analysis software tool developed within the frame of the CEPT Working Group Spectrum Engineering (SE). It quantifies the interference level in scenarios involving victim and interfering radio systems, by taking into account the statistical nature of received signals. An important goal of SEAMCAT is to address any interference scenario irrespective of the type of radio systems involved. However, the current version of SEAMCAT does not support the analysis of interference scenarios involving CDMA networks, which build the basis for future 3G public mobile networks. Therefore, the SEAMCAT Technical Group (STG) decided in its first meeting on 10-11 July 2003, to upgrade SEAMCAT with CDMA simulation capability. In addition, the basic principals regarding modeling the CDMA transmit power control (TPC) in SEMCAT were agreed and the companies interested in this subject were invited to make contributions before the next STG meeting. The aim of this document is to provide a description of necessary CDMA power control algorithms to be included in SEAMCAT.

2. Methodologies for co-existence assessment

There are two approaches to analyzing the co-existence of different radio systems: a deterministic link budget approach and a statistical Monte-Carlo approach. The link budget approach is used to assess the effect of the interfering system on a single link of the victim system. This approach can only assess one link at one time instant and usually assumes that this link is for a user which just meets the target C/I levels, whereas the load is at some assumed maximum level. Hence, it may not be indicative of the average link in the network. Furthermore, it may not give enough insight into the relative likelihood of the occurrence of that scenario. For these reasons, a statistical approach is needed to calculate the power levels across the cells of a network which is used by randomly distributed mobile users running different services. The Monte Carlo model is a useful approach for a statistical treatment of interference problems to gain a complete picture beyond simply obtaining mean changes to system characteristics. The Monte-Carlo aspect of the model is used to randomize the mobile users' positions (both victim and interfering), locations (e.g. indoor or outdoor), speeds, and services. It also accounts for stochastic fading between transmitters and receivers. The system power levels can be calculated based on a distribution of users which are randomly placed, reflecting reality. Assessing many distributions lends insight into the statistical characteristics of the interference effects, as defined by power rises and drop calls.

3. The Monte-Carlo model

There are two different types of Monte-Carlo model that could be employed: a 'static' model, also referred to as a 'snapshot' model, and a 'dynamic' model. In a cellular network, calls will frequently arrive and leave the network during a given period of time. This causes fluctuating traffic and power levels. Principally, it is possible to carry out a dynamic Monte-Carlo taking into account this fluctuating traffic in real time. It can account for dynamical statistical characteristics; however it is extremely time consuming to run. In cases, where many scenarios need to be investigated, such long runtimes could become restrictive. Therefore, the snapshot model is preferred in such cases. This model sets up a random distribution of users based on one instant in time in connection with a network configuration and considered service characteristics. A set of statistics which accurately reflects these scenarios is derived by simulating several such snapshots.

4. CDMA Simulation Methodology in SEAMCAT

SEAMCAT is a simulation test-bed based on the snapshot model. To investigate the coexistence of a CDMA mobile radio network with another radio technology in SEAMCAT, a snapshot of both victim and interfering systems is modeled at each event generation in SEAMCAT, which generates transmit power, interference levels as well as the probability of link success of the victim system for a given number of users at a time instant. It captures a snapshot of the user powers in the network and the number of user links which can be successfully carried given these powers. In order to analyze the impact of the interfering network on the victim one, the success rates of the victim network in the presence and absence of the interfering system are compared.

Power control is a crucial mechanism in CDMA mobile radio networks, which needs to be modeled in SEAMCAT. Power control is a cross-layer process involving physical and link control layer techniques as well as signaling. Because it is not reasonable, and might be not feasible, to model all these details in SEAMCAT, we adopt here an approach widely used for the simulation based evaluation of CDMA network performance. In this approach, performance characteristics of individual links to be used in the power control module of SEAMCAT are generated a priori from link level simulations. This usually includes several mappings between requested link quality (e.g. block error rate, BLER) and required transmit power of mobile stations/base stations. For generating such mappings in form of “look up tables”, link level simulations involve multipath fading, physical layer transceiver algorithms, e.g. modulation/demodulation and coding/decoding, as well as power control procedures. Different mulipath fading channels (e.g. the ITU channel models) are used to model various configurations, e.g. indoor, outdoor, pedestrian, vehicular, etc. Power control procedures take into account different errors occurred in the power control loop (see Section 8).

5. Deployment Scenarios

Only the macro-cellular environment is considered in this document. Cell sites are laid out in a hexagonal grid. Sites with omni-directional antennas are placed in the middle of the cells as depicted in Fig. 1 and sites with tri-sector antennas are placed at the edge of the cells, where each site covers three cells. Fig. 2 shows one of these cell sites (small hexagons in dashed lines)[1]. The inter-site distance (ICD) is D. The cell radius R is equal to $D/\sqrt{3}$ in the omni-antenna case and is equal to $D/3$ in the tri-sector antenna case. Both suburban scenario and urban scenario can be modeled with this cell configuration. The scenarios differ only in propagation conditions and in the cell radius. A wrap around cluster is used to reduce the number of cells required in the simulations and consequently to enable faster simulation run times. The number of cell sites in the cluster is assumed to be 19 (19 cells in the case of omnia-antenna and 57 cells in the case of tri-sector antenna), which appears to be appropriate for SEAMCAT simulation purposes, however the center cell site only is used to calculate the effects of interference, In spite of this fact, it is essential to consider the intra-system interference caused by other cells in the cluster for an accurate modeling of power control. I.e. the precise transmit power of all active mobile stations in the wrap-around cluster has to be calculated in the uplink power control loop. The implementation of cell wrap-around is presented in Appendix B.

---

[1] Note that the arrows in Fig 2 demonstrate the antenna orientation of each cell.

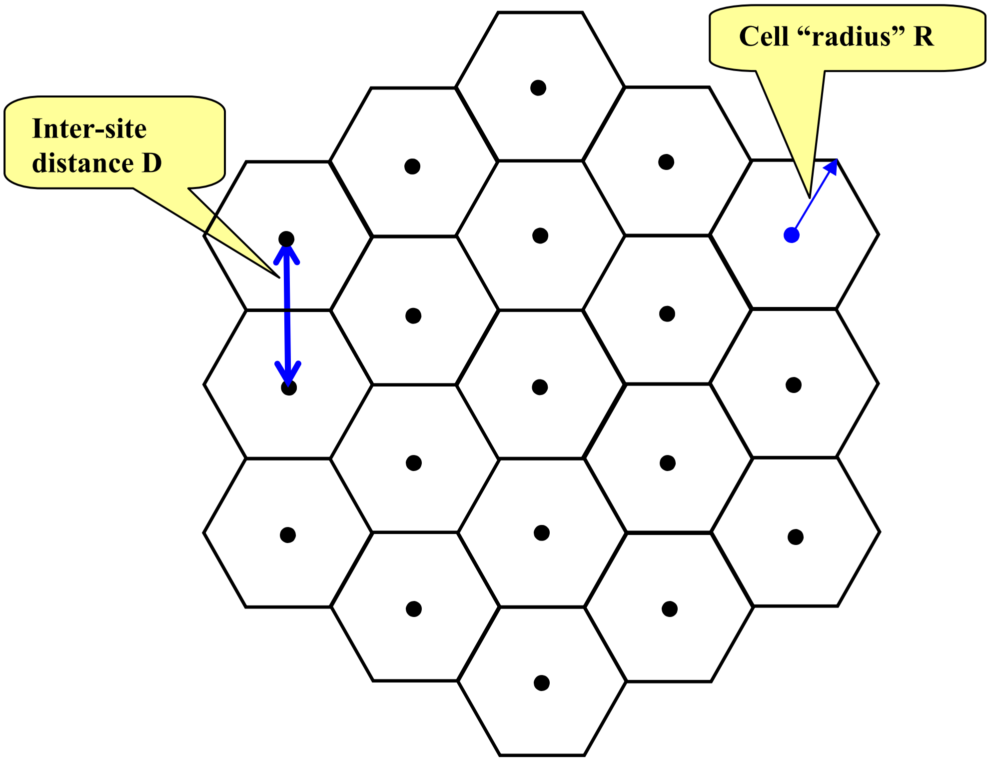


Figure 1: Macro-Cellular CDMA Network Deployment with Omni Antenna

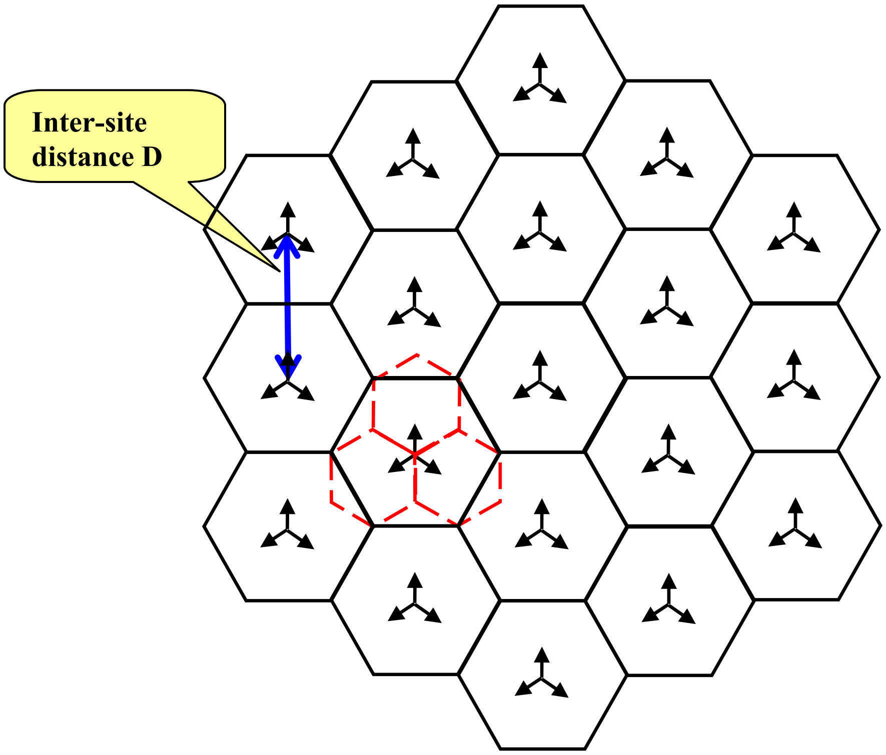


Figure 2: Macro-Cellular CDMA Network Deployment with Tri-Sector Antenna

6. Implementation of Cell Wrap-Around

To analyze the behavior of a cellular network without inducing any artifacts due to boundary effects limitations, it is necessary to consider an infinite cellular network. In this case one cannot perform simulation techniques because the network model is not finite. It is necessary to apply a way of simulating and analyzing the infinite network using a finite model. Wrap-around is a model developed for this purpose. By embedding a finite repeat pattern (cluster) from the infinite hexagonal lattice on a torus, we define in fact a mapping of all the clusters forming the lattice into a generic cluster. In other words, the cell layout is wrap-around to form a toroidal surface. In order to be able to perform this mapping, the number of cells in a cluster has to be a rhombic number $\rho_{i,j}$, defined by two "shifting" parameter i and j as

$$\rho_{i,j} = i^2 + j^2 + i \cdot j$$

A toroidal surface is chosen because it can be easily formed from a rhombus by joining the opposing edges. We propose to use $\rho_{i,j} = 19$ (i=3 and j=2) for SEAMCAT. To illustrate the cyclic nature of the wrap-around cell structure, the cluster of 19 cells is repeated 8 times at rhombus lattice vertices as shown in Figure 3. Note that the original cell cluster remains in the center while the 8 clusters evenly surround this center set. From the figure, it is clear that by first cutting along the blue lines to obtain a rhombus and then joining the opposing edges of the rhombus a toroid can be formed. Furthermore, since the toroid is a continuous surface, there are an infinite number of rhombus lattice vertices but only a select few have been shown to illustrate the cyclic nature.

In the wrap-around model considered, the signal or interference from any mobile station to a given cell is treated as if that mobile station is in the first 2 rings of neighboring cells. The distance from any mobile station to any base station can be obtained as follows: Define a coordinate system such that the center of cell 1 is at (0,0). The path distance and angle used to compute the path loss and antenna gain of a mobile station at (x,y) to a base station at (a,b) is the minimum of the following:

a. Distance between (x,y) and (a,b);

b. Distance between (x,y) and $(a + 3D/\sqrt{3}, b + 4D)$;

c. Distance between (x,y) and $(a - 3D/\sqrt{3}, b - 4D)$;

d. Distance between (x,y) and $(a + 4.5D/\sqrt{3}, b - 7D/2)$;

e. Distance between (x,y) and $(a - 4.5D/\sqrt{3}, b + 7D/2)$;

f. Distance between (x,y) and $(a + 7.5D/\sqrt{3}, b + D/2)$;

g. Distance between (x,y) and $(a - 7.5D/\sqrt{3}, b - D/2)$,

where D is the inter-site distance.

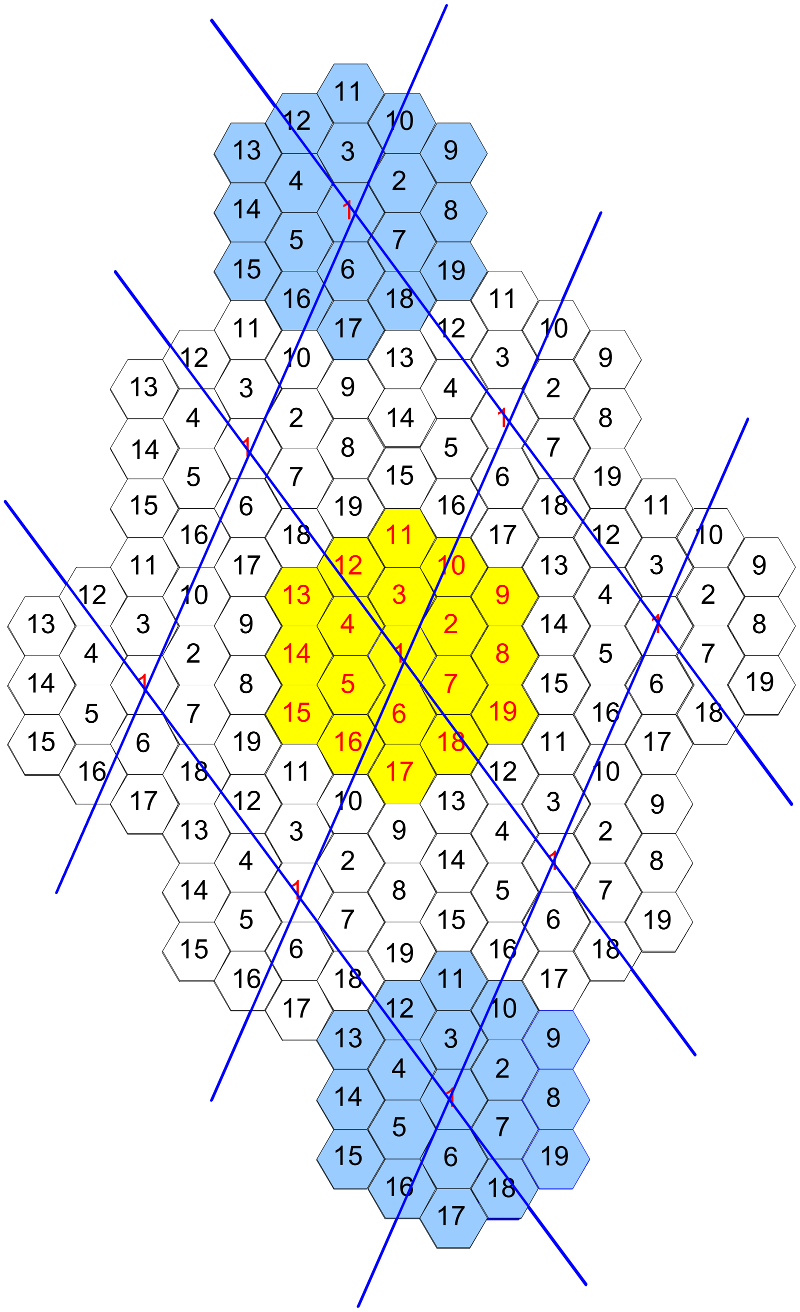


Figure 3: Wrap-around with '9' clusters of 19 cells showing the toroidal nature of the wrap-around surface

7. Path-loss Model

The propagation path loss modeling will make use of standard SEAMCAT propagation models.

Mobile station antenna gain is denoted by G_{MS} and base station antenna gain denoted by G_{BS} (for both omni antenna and sector antenna). The received power P_{RX} at either the mobile or base station in relation to the transmit power P_{TX} is given by

$$P_{RX} = P_{TX} - \max\left(P_{L\_fading} - G_{MS} - G_{BS}, MCL\right) \qquad \textbf{EQ 1}$$

where MCL is the minimum coupling loss, defined as the minimum distance loss including antenna gain measured between antenna connectors.

8. Power Control and Handover Modeling

In CDMA networks, closed-loop fast transmit power control (TPC) is supported in uplink. The base station estimates the signal-to-interference ratio (C/I), measured in bit energy-to-noise density ratio E_b/N_0, and compares it to a target value (*E_b/N_0_target*). If the estimated C/I is below *E_b/N_0_target*, the base station commands the mobile station to increase the transmit power; if the measured C/I is above *E_b/N_0_target*, it commands the mobile station to lower its power. The fast transmit power control works at a frequency of f Hz (1500 Hz for WCDMA and 800 Hz in CDMA2000 1x), thus the TPC commands are transmitted at 1/f s time intervals (0.667 ms for WCDMA and 1.25 ms for CDMA2000 1x).

In reality, the fast TPC is not ideal because of issues such as

- inaccuracies in the C/I estimates
- transmit power control signaling errors
- delay in the transmit power control loop

Links level simulations take these errors into account and reflect their impacts on the link quality figures in the look up tables to be input to the power control module of SEAMCAT. Therefore, we assume a simple C/I based fast closed-loop TPC of traffic channels for uplink in the following.

Power Control

In the uplink, each mobile station perfectly achieves the target C/I, *E_b/N_0_target*, during the power control loop convergence, assuming that the maximum transmit (TX) power, *max_MS_Tx_Pw*, is not exceeded. Those mobile stations not able to achieve *E_b/N_0_target* after convegence of the power control loop are considered in outage.

Local-mean Signal-to-interference power ratio in the uplink, $(C/I)_{UL}$, is calculated by multiplying the received signal power S by the processing gain G, and dividing the result by the total interference power I_{total}

$$\left(\frac{C}{I}\right)_{UL} = \frac{G \cdot S}{I_{total}} \qquad \textbf{EQ 1}$$

with

$$I_{total} = (1-\beta) \cdot I_{intra} + I_{inter} + I_{out} + N \qquad \textbf{EQ 2}$$

I_{intra} is the intra-cell interference power, i.e. the interference generated by those mobile stations served by the same base station as the considered mobile station. I_{inter} is the inter-cell interference power from other radio cells. I_{out} is the interference power coming from the interfering system. N is thermal noise (as well as spurious interference) contained in the receiver bandwidth, *W*, and β is an interference reduction factor due to the use of interference mitigation signal processing techniques in the uplink, e.g. Multi User Detection. No such interference mitigation technique is assumed in these considerations, therefore $\beta = 0$.

Assuming a mobile station power control range in the order of *MS_PC_Range* dB; the minimum TX power is therefore *max_MS_Pw_Tx – MS_PC_Range* dBm.

Soft and Softer Handover

The handover model proposed is a simplified soft handover. We assume that all base stations transmit with the same pilot power in downlink. Therefore, P_{L_fading} (path loss plus the shadow fading) is the only criterion for selecting the base stations belonging to the active set of a mobile station.

We assume that active set for a mobile station consists of two base stations; the base station with the strongest signal, i.e. the lowest P_{L_fading}, and the base station with the second strongest signal if its signal strength is within *Handover_Margin* dB of the strongest signal (in other words its P_{L_fading} is within *Handover_Margin* dB of the lowest P_{L_fading}).

In the case that base stations with omni-antenna are used at the cell sites, selection combining among the base stations in active set is performed and the base station with the strongest signal is selected as the serving base station of the mobile station. In the event of base stations with tri-sector antenna, similar procedure is applied, if the two sectors in the active set belong to different cell sites, else a maximal ratio combining is realized by summing the received signal powers. In the later case, the sum of received C/I values in two sectors should meet the C/I requirements specified by the link level simulation data. Because during softer handover, the mobile station is usually in the overlapping coverage area of two adjacent sectors of the base station, it is reasonable to assume that it has symmetric links to both sectors in the active set. As a consequence, each sector needs to fulfill one half of the C/I requirement.

9. Voice Activity Factor

This factor, *Act_Factor*, is modeled by a random variable χ which has the binomial distribution, i.e. χ takes the value 1 with probability *Act_Factor* and takes the value 0 with probability 1- *Act_Factor*.

10. Simulation Procedures

The following procedures can be used for system loading during simulation and preparation of simulation outputs.

11. System loading

To determine the number of active mobile stations *Act_MS* in the network:

1. Set up:
   I. Average traffic load in terms of a predefined number of users per cluster: *N_UL*
   II. standard deviation of log-normal shadowing $\sigma_{shadowing}$
   III. voice activity factor *Act_Factor*
   IV. target maximum noise rise over the thermal noise in the network η*_target*
   V. target C/I (E_b/N_0*_target*) to fulfill service requirement depending on configuration and mobility (provided by link level simulations)

VI. maximum transmit power of mobile station *max_MS_Pw_Tx*

VII. power control range – *MS_PC_Rang*:

VIII. In the case that the CDMA uplink is the victim link, add the received power from the interfering system to the thermal noise power

2. For each snapshot:

I. put down uniformly mobile stations at pseudo-random locations across the network and distribute speed among them

II. Add a new mobile station in the set of active users in the network

- ➢ compute average path-loss from the mobile station to the base station of each cell by (EQ 1)
- ➢ generate a log-normal pseudo-random value to add to each of the path losses to model shadow fading (EQ 2)
- ➢ perform a pseudo-random weighted coin-toss to determine voice activity, where 1 occurs with probability *Act_Factor*
- ➢ compute required received power at the base station to meet E_b/N_0*_target*, given interference from pre-existing mobiles and other sources (EQ 4 and EQ 5)
- ➢ compute required transmit power of the mobile station (EQ 3)
- ➢ adjust the required transmit powers of the all existing mobile stations perturbed by addition of the new mobile station
- ➢ continue the adjustment until the convergence of power control loop is achieved. A convergence criterion could be that the variation of two consecutive transmit powers of each mobile station is within a predefined threshold.
- ➢ compare the number of active mobile stations, *Act_MS*, with *N_UL*
    - ▪ if *Act_MS* ≥ *N_UL* terminate the addition of a new mobile station in the network
    - ▪ else measure the average noise rise over the thermal noise η and compare it with the target noise rise limit η_target
        - o if η_target is reached, terminate the addition of a new mobile station in the network
        - o else add a new mobile station and go to step II

12. Outage calculation

Two conditions are counted as outage.

1. A mobile station, which is not able to transmit the required amount of power to meet the received E_b/N_0*_target* due to maximum power limitations. This mobile is counted as part of the specified traffic load *N_UL*. However, the mobile is assumed to be transmitting no power.

2. In the case of *Act_MS* < *N_UL*, no more mobile stations can be added to the set of active users because of noise rise limits. In this event, *N_UL* - *Act_MS* outages are counted.

13. Simulation output

When the CDMA uplink is the victim link, a similar analysis is performed with and without the interference from the interfering link. Outage probability with and without the interference source is reported.

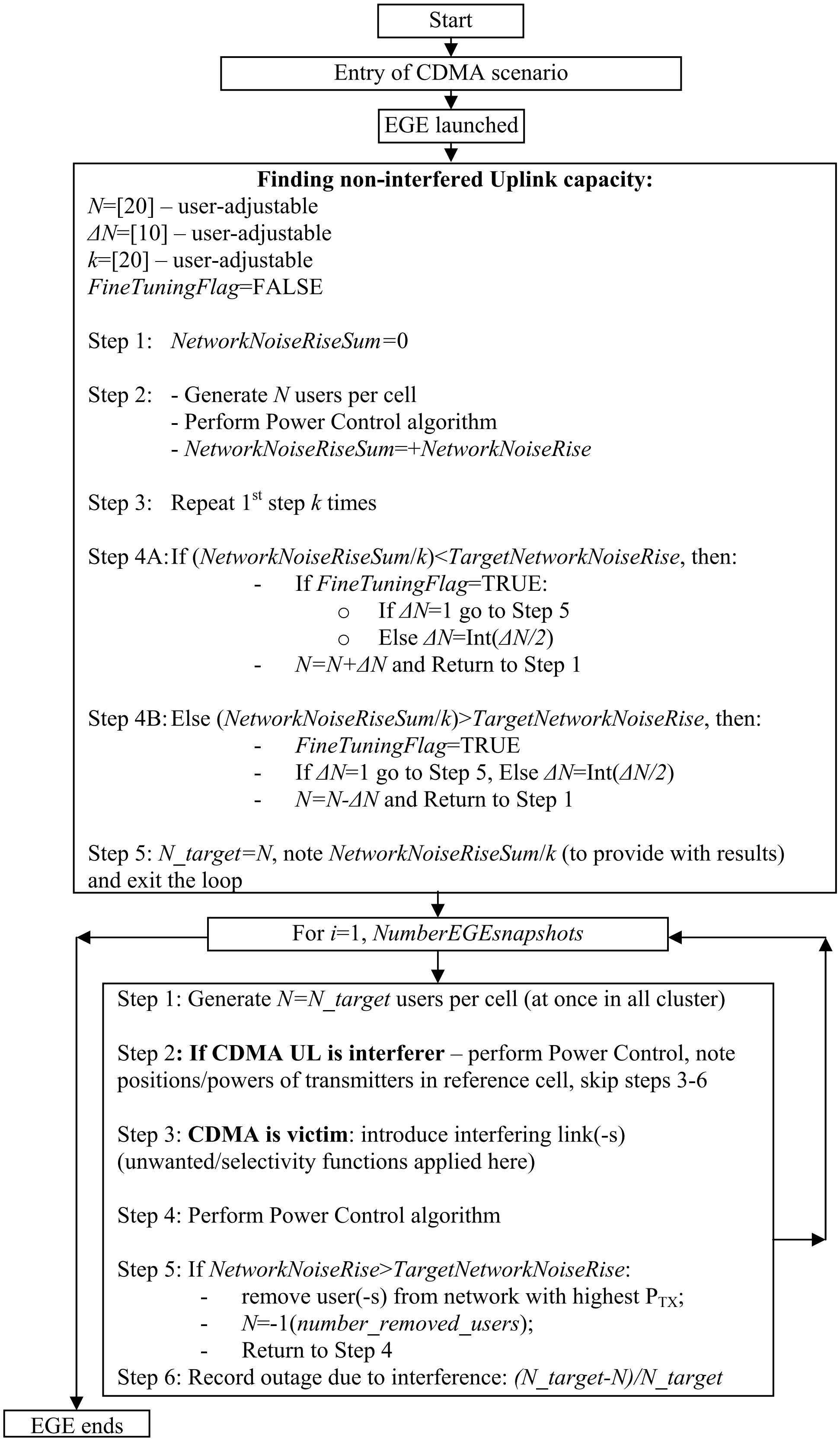
When the CDMA uplink is the interfering link, the total received power at the receiver in the victim link, due to the transmit power of all the active mobile stations in the three cells of the center cell site of the CDMA cluster, adjusted for spectral masks, etc., is counted as the interfering power in the victim link. It is not necessary to keep track of outages in this case, unless the victim link is also a CDMA system.

14. References

1. 3GPP TR25.942 v6.0.0, 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; RF System Scenarios (Release 6)

2. 3GPP2 TSG-C.R1002, 3rd Generation Partnership Project 2; 1xEV-DV Evaluation Methodology

Part B.2: CDMA Uplink software implementation in SEAMCAT-3



Finding non-interfered Uplink capacity:

```
N=[20] – user-adjustable
ΔN=[10] – user-adjustable
k=[20] – user-adjustable
FineTuningFlag=FALSE

Step 1:   NetworkNoiseRiseSum=0

Step 2:   - Generate N users per cell
          - Perform Power Control algorithm
          - NetworkNoiseRiseSum=+NetworkNoiseRise

Step 3:   Repeat 1st step k times

Step 4A: If (NetworkNoiseRiseSum/k)<TargetNetworkNoiseRise, then:
            -  If FineTuningFlag=TRUE:
                  o  If ΔN=1 go to Step 5
                  o  Else ΔN=Int(ΔN/2)
            -  N=N+ΔN and Return to Step 1

Step 4B: Else (NetworkNoiseRiseSum/k)>TargetNetworkNoiseRise, then:
            -  FineTuningFlag=TRUE
            -  If ΔN=1 go to Step 5, Else ΔN=Int(ΔN/2)
            -  N=N-ΔN and Return to Step 1

Step 5: N_target=N, note NetworkNoiseRiseSum/k (to provide with results)
and exit the loop
```

For *i*=1, *NumberEGEsnapshots*

```
Step 1: Generate N=N_target users per cell (at once in all cluster)

Step 2: If CDMA UL is interferer – perform Power Control, note
positions/powers of transmitters in reference cell, skip steps 3-6

Step 3: CDMA is victim: introduce interfering link(-s)
(unwanted/selectivity functions applied here)

Step 4: Perform Power Control algorithm

Step 5: If NetworkNoiseRise>TargetNetworkNoiseRise:
        -  remove user(-s) from network with highest P_TX;
        -  N=-1(number_removed_users);
        -  Return to Step 4
Step 6: Record outage due to interference: (N_target-N)/N_target
```

EGE ends

Setup:

Calculate and store Thermal Noise:

$$Nt_W = 10^{\left(\frac{((-173,977+10\cdot\log_{10}\left(SYSTEM\_BANDWIDTH*10^6\right)+RECEIVER\_NOISE\_FIGURE)-30}{10}\right)}$$

Calculate and store system processing gain, G:

$$G = \frac{Bandwith_{\mathrm{Receiver}}[MHz]}{ServiceBitRate[kbps]}\cdot 10^3$$

Layout cells

Capacity finding

This step is done before start of actual simulation, and only if “simulate non interfered capacity” flag is checked in CDMA system setup. The purpose of this is to find the non interfered capacity of a system with the current configuration. For uplink case the algorithm uses an approach similar to downlink case, but instead of measuring outage, the total network noise rise over thermal noise of reference cell is used as an indicator of system load.

Note that this step can be quite time consuming. The measured noise rise is summed throughout number of trials and the average is compared to user defined threshold in order to fine tune capacity.

The following pseudo code describes how the non interfered capacity of an uplink system is found:

Note: This method runs recursively

```
Find Non Interfered Capacity function {
  Network Noise Rise Sum = 0
  For (Number of Trials) {
            Reset System
            For (1 -> (Users per cell * Number of cells)) {
                  Generate new user
                  Randomly drop user in system
                  Determine and store distance to all BS (based on Wrap-Around
model)
                  Determine and store pathloss to all BS
                  Select active list based on pathloss
                  If (new user is voice inactive) -> {go to next user}
                  Else proceed with: {
                        User tries to connect to BS in active list
                        If user is unable to connect -> {
            User is dropped and next user is generated
            }
                        }
                  }
            Balance Uplink System
      Network Noise Rise Sum += Noise Rise of reference cell
      }
      //All trials has been completed
      If ((Network Noise Rise Sum / Number of Trials) < Noise Rise Threshold) {
            If (fine tuning) {
                  If (ΔN == 1) {
                        Capacity Found = true
                        Exit
                        }
                  } Else {
                              ΔN = Ceil (ΔN / 2)
                  }
            Users Per Cell += ΔN
```

```
        Return "Find Non Interfered Capacity" //Recursive call using new values
        }
    Else If ((Network Noise Rise Sum / Number of Trials) > Noise Rise Threshold) {
        Fine tuning = true
        If (ΔN == 1) {
            Capacity found = true
            Exit
        }
        Else {
            ΔN = Ceil (ΔN / 2);
        }
        Users per Cell -= ΔN
    Return "Find Non Interfered Capacity" //Recursive call using new values
  }
  Else {//Success Criteria is fulfilled (not very likely in uplink case)
        Capacity Found = true
        Exit
    }
}
```

Non interfered capacity

This procedure is executed once at the beginning of every snapshot, and is used to initialize CMDA system, and determine initial outage.

```
Initialize and balance uplink system {
    Reset System
    For (1 -> Capacity of system) {
        Add new user to system
        Generate new user
            Randomly drop user in system
            Determine and store distance to all BS (based on Wrap-Around model)
            Determine and store pathloss to all BS
            Select active list based on pathloss
            If (new user is voice inactive) -> {go to next user}
            Else proceed with:
                User tries to connect to BS in active list
                If user is unable to connect -> {
        user is dropped and next user is generated
        }
                }
            }
        Balance Uplink System
    }
```

Interfered Capacity

This procedure is invoked on a filled system, after adding external interferers.

```
For (All Base Stations in cluster) {
Calculate and store distance and path loss to external interferers. Distance is "linear" (i.e. not using "wrap-around" formulas).

While (Reference Cell Noise Rise > Target Noise Rise) {
    Balance Uplink System
    If (Reference Cell Noise Rise > Target Noise Rise) {
        For (Every dB Reference Cell Noise Rise is above Target) {
```

```
                  Remove the highest transmitting user
            }
}
```

Balance Uplink System

This is a pseudo code implementation of the internal uplink power balance algorithm, called from other parts of the CDMA system.

```
Power Converged = false
While (Not Power Converged) {
      Power Converged = true
      For (All Active users in system) {
            Power Control Result = User meets Signal to Interference Ratio function
            If (Power Control Result == 0) { //Power has been scaled and user is served
                  Power Converged = false
            }
      Else if (Power Control Result == -1) { //User is unable to meet requirement
                  Power Converged = false
                  Drop User from system
            }
      }
}
```

Signal to Interference Ratio function

```
      Power Control Value = 0
      //Active link is strongest signal in active list
      Achieved CI = Calculate Achieved CI for active link

//If user is in soft handover with two sectors of the same mast (softer handover), selection //combining is used:
  If (User is In Softer Handover) {
            Achieved CI = Logarithmic summation of achieved CI levels from active list
      }

      Difference = $\frac{Eb}{N_0}$ - Achieved CI

If (abs(difference) < Power Convergence Threshold) {
                  //Difference is within threshold -> power is not scaled
                  Power Control Value = 1;
      }
Else {//Power is scaled
                  //If power is already max
                  If (Current Transmit Power == Max Transmit Power) {
                        If (Difference > Call Drop Threshold) {
//Difference between Max Transmit Power and the value we wished to scale to is
//larger than call drop threshold -> call is dropped (Power Control Value = -1)
                              Power Control Value = -1
                        } Else {
//Power is not scaled but user is still served
                              Power Control Value = 1
                        }
                  } Else {
//User is NOT transmitting at full power
```

```
                        Current Transmit Power += Difference;
                        If (Current Transmit Power > Max Transmit Power) {
                              //Power scaled to maximum allowed transmit value
                              Difference = Current Transmit Power - Max Transmit
Power;
                              If (Difference > Call Drop Threshold) {
//Difference between Max Transmit Power and the value we wished to scale to is
//larger than call drop threshold -> call is dropped
                                    Power Control Value = -1
                              } Else {
                                    Power Control Value = 0
                                    Current Transmit Power = Max Transmit Power
                              }
                        }
                  }
            }
Return Power Control Value
```