CEPT WGSE PT SE21 **STG(03)13 r1**

SEAMCAT Technical Group **12 Oct 2003**

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Subject: **CDMA uplink Power Control Methodology in SEAMCAT (VOICE ONLY)**

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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.

2.1 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.

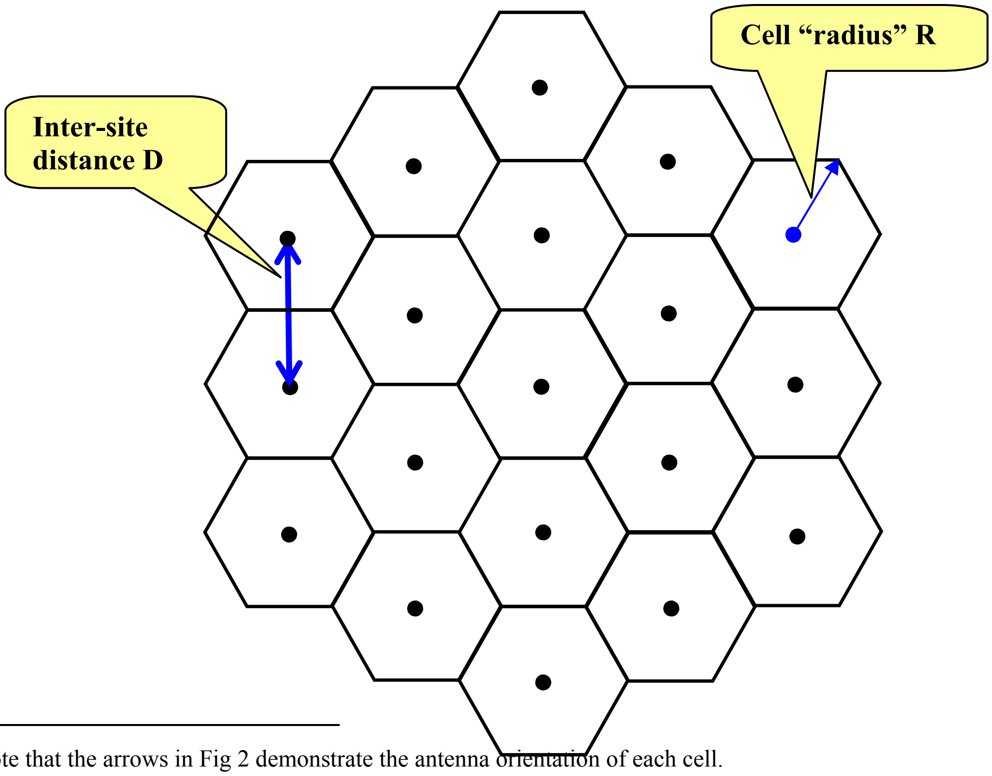
2.2 CDMA Simulation Methodology in SEAMCAT

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 5).

3 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.



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[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

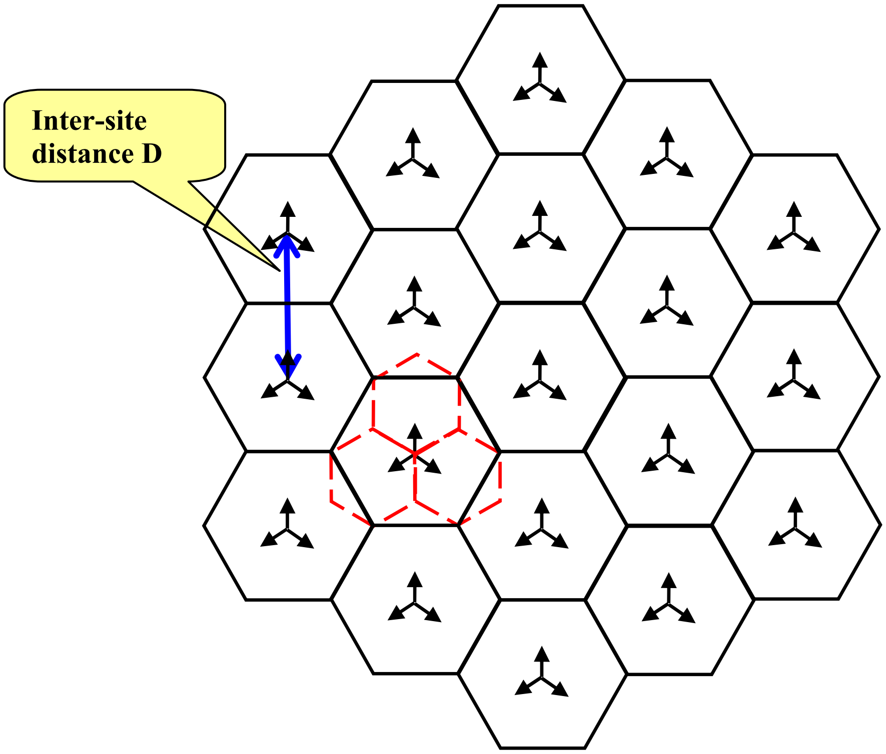

Figure 2: Macro-Cellular CDMA Network Deployment with Tri-Sector Antenna

4 Path-loss Model

The propagation pathloss used in this document is taken from [1] for 1900 MHz. This model is applicable for suburban and urban areas outside the high-rise core where buildings are of nearly uniform heights.

$$P_L = 40\left(1 - 4 \cdot 10^{-3}\right) \cdot Dhb \cdot \log(d) - 18 \cdot \log(Dhb) + 21 \cdot \log(f) + 80 \qquad \textbf{EQ 1}$$

where,

Dhb = the base station antenna height above the average rooftop in meters
f = the carrier frequency in MHz
d = the distance between the mobile and the base station in kilometers.

Note that this pathloss model is an exemplary one and every other model, e.g. the one currently applied in SEAMCAT, can be used instead of it.

A log-normally distributed shadowing (Log F) with standard deviation of $\sigma_{\text{shadowing}}$ dB $\left(LogF = \sigma_{\text{shadowing}} \cdot randn\right)$ is added to pathloss of EQ 1 to model fading effect.

$$P_{L\_fading} = P_L + LogF \qquad \textbf{EQ 2}$$

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

$$P_{RX} = P_{TX} - \max\left(P_{L\_fading} - G_{MS} - G_{BS}, MCL\right) \qquad \textbf{EQ 3}$$

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

5 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.

5.1 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}

$$\left(\frac{C}{I}\right)_{UL} = \frac{G \cdot S}{I_{total}} \qquad \textbf{EQ 4}$$

with

$$I_{total} = (1-\beta) \cdot I_{intra} + I_{inter} + I_{out} + N \qquad \textbf{EQ 5}$$

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.

5.2 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.

5.3 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*.

5.4 Simulation Procedures

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

5.4.1 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

    - if η_target is reached, terminate the addition of a new mobile station in the network

    - else add a new mobile station and go to step II

5.4.2 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.

5.4.3 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.

6 Reference

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

Appendix A: System Parameters

Table A-1

Parameter	Value
SIMULATION TYPE	Snapshot
DEPLOYMENT SCENARIO	
Macro-Cellular	Hexagonal layout, BS in the middle of the cell
Inter-cell distance	*D* (km)
Cell radius macro	0.755 *D* (km)
# of macro cells	19 with wrap around technique
Target noise rise over thermal noise	η_*target* (dB) (typical values 3dB for suburban and 6dB for urban)
PROPAGATION PARAMETERS	
Minimum coupling loss (including antenna again)	*MCL* (dB)
MS antenna gain (including losses)	G_{MS}
BS antenna gain (including losses)	G_{BS}
Log Normal fading standard deviation	$\sigma_{\text{shadowing}}$ (dB)
The base station antenna height above the rooftop	*Dhb* (m)
Carrier frequency	*f* (MHz)
Distance between MS and BS	*d* (km)
Pathloss	P_L (dB)
Pathloss with fading	$P_{L\ fading}$ (dB)
Transmit power	P_{TX} (dB)
Received power	P_{RX} (dB)
PC MODELLING	
# of snapshots	$> SANPSHOT_{min}$
#PC steps per snapshot	$> PC\_STEP_{min}$
step size PC	perfect PC
PC error	considered in link level simulations
margin in respect with target C/I	0 (dB)
Outage condition	E_b/N_0 target not reached due to lack of TX power OR for *Act_MS* < *N_UL*, noise rise limit is reached
HANDOVER MODELING	
Choice of cells/sectors in the active step	The base station with the strongest signal is selected as the serving base station
NOISE PARAMETERS	
BS receiver noise figure	*NF* (dB) (typical value 5dB)
Noise bandwidth	*W* (MHz) (4.096 MHz / 1.25 MHz)
Thermal noise power spectral density	-174.0 (dBm/Hz) (assuming T=290 K)
TX POWER	
Maximum MS TX power for speech	*MS_Pw_Tx* (dBm)
Power control range	*MS_PC_Range* (dB)
Minimum MS TX power for speech	*MS_Pw_Tx* - *MS_PC_Range* (dBm)
MOBILE STATIONS DISTRIBUTION	Random and Uniform across the cells
SIMULATED SERVICES	
bit-rate voice	*bit_rate_voice* (kbps)
Voice Activity factor	*Act_Factor* (%)
C/I target	$E_b\_N_0\_target$

Appendix B: 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 B-1. 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.

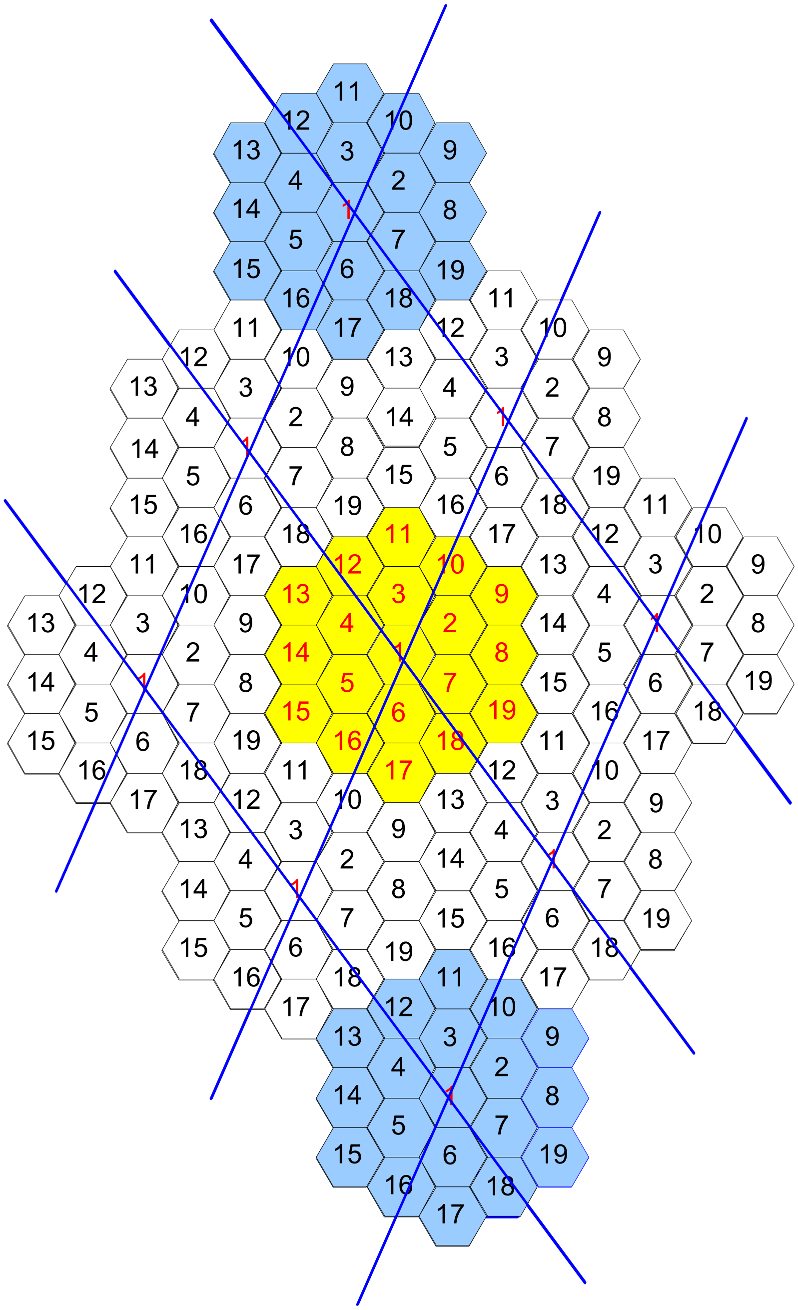

Figure B-1 Wrap-around with '9' clusters of 19 cells showing the toroidal nature of the wrap-around surface.