ADVANCED WCDMA RADIO NETWORK SIMULATOR

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ABSTRACT

If only good coverage is required in GSM networks, high frequency reuse factors can be used. In that case the network capacity is directly determined by the number of available time slots, and no advanced radio control algorithms are needed. If high capacity is required and fractional loading is used in GSM networks, advanced radio resource management algorithms are required. Sophisticated network simulators are needed for algorithm development in GSM base station systems. Also, finding out the capacity for accurate network planning is difficult without radio network simulators. In UMTS the need for an advanced radio network simulator will further increase because of new services, higher bit rates, multiplexing of services, and because of the possible asymmetric capacity requirement between uplink and downlink. Additionally, the UTRA WCDMA air interface is more dynamic than the GSM air interface, and therefore, optimised radio resource management algorithms need to be developed to fully exploit the WCDMA capabilities. The algorithm development for highly loaded dynamic networks is not possible without accurate modelling in computer simulations. In this paper the modelling principles of a WCDMA radio network simulator are presented.

1. INTRODUCTION

In UMTS radio access, UTRA (Universal Terrestrial Radio Access), there is a need for an advanced radio network simulator. UMTS introduces new services and higher bit rates. In addition, the UTRA WCDMA air interface will be very dynamic, and thus optimized radio resource management (RRM) algorithms need to be developed to fully exploit the WCDMA capabilities. In order to effectively study RRM algorithms sophisticated tools are needed. An advanced WCDMA radio network simulator is presented in this paper. The tool can be used to develop RRM algorithms, to obtain capacity and coverage estimates, to support network planning in optimizing and tuning the radio network parameters.

The paper is organised as follows. In Chapter 2, system level and link level tools and their interface is presented. In Chapter 3, the propagation modelling is shown and the usage of real propagation data is presented. In Chapter 4, the interference modelling is presented. Chapter 5 presents the traffic model and Chapter 6 the mobility models of the simulator. In Chapter 7, the radio resource management algorithms are briefly presented. Chapter 8 presents the simulator implementation and Chapter 9 the simulator application areas. In Chapter 10, conclusions are drawn.

2. SYSTEM AND LINK LEVEL TOOLS

Typically, the radio network simulations can be divided into two parts: link and system level simulations. A single simulator approach would be preferred but the complexity of such simulator - including everything from transmitted waveforms to multi cell network - is far too high with the required simulation resolutions and simulation times. For an accurate receiver performance evaluation a chip level or a symbol level simulation model is needed, i.e. at least 3.84 Mcps or 32 ksps time resolution. On the other hand, in the system level the traffic models and the mobility models require simulations of at least 10-20 minutes with a large number of mobiles and base stations. Therefore, separate link and system level simulators are needed. The link level simulators usually operate at symbol or chip level, while the system level simulators operate with the resolution determined by the feature that changes interference most often. In WCDMA the fast closed loop power control operating with 1.6 kHz frequency is the algorithm having the highest frequency, and therefore, 1.6 kHz frequency is used in this system simulator.

The link level simulator is needed to build such a model for the system simulator which is able to predict the receiver FER/BER performance, taking into account channel estimation, interleaving and decoding. The system level simulator is needed to model a system with a large number of mobile terminals and base stations, and algorithms operating in such a system.

Because the simulation is divided into two parts, a method to interconnect the two simulators has to be defined. Conventionally, the information obtained from the link level tool is linked to the system simulation by using a so-called average value interface describing the BER/FER performance by average E_b/N_o requirements. The average value interface is not accurate if there are fast changes in the interference due to, e.g. high bit rate packet users. This kind of approach suits well for static snap-shot simulations, but cannot be used when simulating systems with fast power control and high bit rate packet data. With the presented simulator, a so-called actual value interface (AVI) is used that provides accurate modelling of fast power and high bit rate packet data. [3]

Table 1. Link and system simulators (AVI=Actual Value Interface, RRM=Radio Resource Management)

	Link level	*System level*
Time resolution	1 sample/chip or per symbol	1 sample/slot (1.6 kHz)
Number of mobiles	1	>100
Number of base stations	1-3	>10
Fast fading	yes	yes
Receiver channel estimation	yes	via AVI
Interleaving, channel coding	yes	via AVI
Maximal ratio combining	yes	yes
Fast power control	yes	yes
SIR estimation	yes	error model from link level
Power control signaling errors	yes	error model from link level
Packet retransmission	-	yes
Path loss	-	yes
Slow fading	-	yes
Interference	Gaussian noise	real transmitters
RRM algorithms	-	yes
Mobility model	-	yes
Traffic model	-	yes
Simulated time span	1-5 min	20-60 min

3. PROPAGATION MODELLING

The transmitted signal attenuates because of pathloss, shadowing and multipath fading. The amount of the attenuation depends greatly on the environment. Obstacles, such as hills and buildings, create shadowing to radio connections. The most severe shadowing effects are in human made environment where high buildings cause steep boundaries to the signals received. The multipath fading is due to the multipath propagation of radio signals. Because the shadowing process is rather slow as compared to multipath fading, it is often referred to as slow fading. Locally, the mean value of shadowing can be generated from a log-normal deviation. Therefore, shadowing is often called as log-normal fading.

3.1. Path loss modelling

The pathloss model used in the simulator is separately defined for Manhattan micro cellular (outdoor-to-indoor) and macro cellular (vehicular) environments according to [2]. Also, measured propagation data can be used if real maps are available, see Figure 1.

3.2. Shadowing modelling

The shadowing modeling is adopted from [2]. The mean value for the long-term fading is 0 dB, and the standard deviation 6 dB in micro cells and 8 or 10 dB in macro cells. The decorrelation length is environment dependent. In the macro environment the decorrelation length of 20 meters is selected. In the micro cellular environment the selected decorrelation length is 5 meters. For more realistic simulation shadowing can be modeled so that the fading process is correlated between the base stations.

3.3. Fast fading modelling

In order to properly support the studies of RRM algorithms, the multipath propagation environment is modeled in the simulator. The WCDMA Rake receiver allows to separate multipath components. The number of multipaths and the path gains can be obtained from the channels models such as ATDMA or ITU.

3.4. Real propagation maps

In [2] the cellular models are regular hexagonal models for macro cellular environment and Manhattan model with equal size cell blocks and streets with micro cellular environment. In addition to those cellular models, real maps can be used with the simulator. The propagation data is generated by other tools, e.g. by Ray tracing, or by measurements, and imported to the simulator. An example of a real map from Helsinki City is shown in Figure 1. The propagation model is obtained from a network planning tool by ray tracing, and it is verified by measurements.

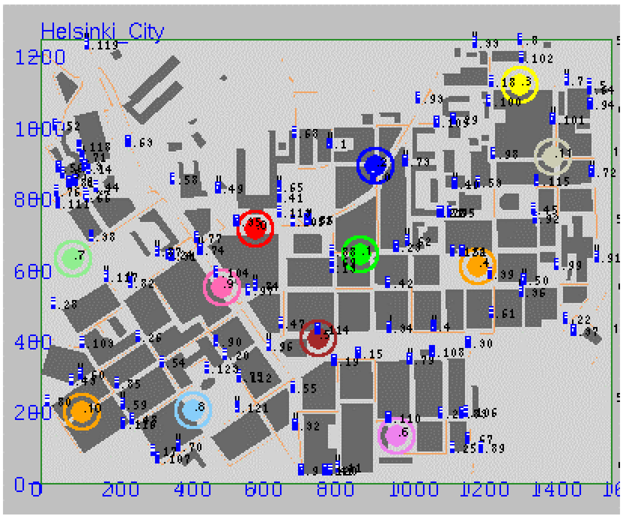

Figure 1. An example micro cellular layout and mobile locations. The circles are micro cell base stations with omni antennas.

4. INTERFERENCE MODELLING

The calculation of interference is an essential process of the system simulator. The better the interference modeling is, the more accurate results can be obtained. On the other hand, the interference calculation is very computer time consuming: the received interference has to be calculated every time when the interference situation changes due to the fast power control.

The total interference power $I_{bs(k)}$ received by a base station k is calculated as follows:

$$I_{bs(k)} = \sum_{\substack{n=1 \\ n\neq m}}^{N} \left[L_{n,k} \cdot \frac{\sum_{i=1}^{L} g_{i,n,k}}{\sum_{n=1}^{L} \hat{g}_{i,n,k}} \cdot p_{ms(n)} \right] \qquad (1)$$

where N is the total number of active mobile stations in the system and m is index for the observed user. $L_{n,k}$ is pathloss (attenuation due to distance and slow fading) between the base station k, and the mobile station n. $\sum g / \sum \hat{g}$ is the multipath fading normalized to having long term average equal to one and L is the number of multipath components. $p_{ms(n)}$ is the transmission power of the mobile n.

After the interference calculations, the uplink signal-to-noise ratio SNR_{ul} can be calculated for the user m connected to the base station k as

$$SNR_{ul(m,k)} = \sum_{i=1}^{L} \frac{G p_{ms(m)} a_i^2}{I_{bs(k)} + N} \qquad (2)$$

where G is the processing gain, a_i is amplitude attenuation of path i and L is the number of allocated RAKE fingers. In (2) it is assumed that the received signals are combined coherently with maximal ratio combining [6].

In downlink the effect due to orthogonal codes has to be considered. Because of the multipath propagation perfect orthogonality cannot be assumed. For optimal maximal ratio combining, the downlink signal-to-noise-ratio SNR_{dl} for a user m can be calculated as

$$SNR_{dl(m)} = \sum_{k=1}^{M} \Big(\sum_{i=1}^{L_k} \frac{G p_{bs(m,k)} a_{k,i}^2}{I_{ms(m)} - P_{bs(k)} a_{k,i}^2} \Big) \qquad (3)$$

where $I_{ms(m)}$ is the total interference power received by the mobile station m, M is number of base stations in the active set, $p_{bs(m,k)}$ is the transmitting power for the observed user from the base station k, $P_{bs(k)}$ is the total power transmitted from the base station k, $a_{k,i}$ is amplitude attenuation of the channel tap i and L_k is the number of allocated RAKE fingers from base station k.

5. TRAFFIC MODELLING

In the simulator the users are making calls and transmitting data according to the traffic models. The call generation process for real time services, such as speech and video, is made according to a Poisson process [2]. For speech, voice activity and discontinuous transmission have to be considered. For circuit switched data services, the traffic model is a constant bit rate model, with 100 % of activity.

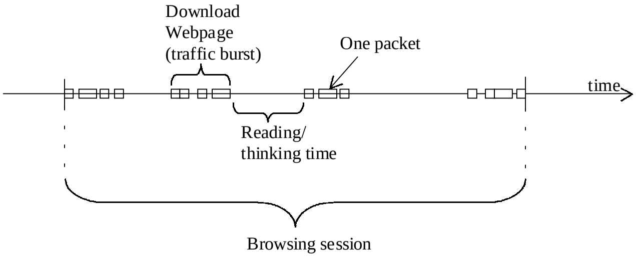

Figure 2. Word Wide Web traffic characteristic.

Figure 2 depicts a typical WWW browsing session [2]. A session consists of a sequence of packet calls that can be considered as web page downloading. The bursty nature of fixed network is modeled by assuming that one packet call constitutes of several packets. A packet service session contains one or several packet calls depending on the application. After the page is entirely downloaded to the terminal, the user spends a certain amount of time for studying the information. This time interval is called a reading time. If FTP type service is simulated, it is assumed that there is only one packet call per session.

The simulator supports mixed traffic scenarios where speech users together with packet data users can be simulated. For example, the speech load can be set to a certain number of Erlangs and the remaining best effort packet data throughput and delay can be studied.

6. MOBILITY MODELLING

In this dynamic simulator the users are moving in the simulation area according to the mobility model. In [2] separate mobility model is developed for micro cellular and macro cellular environments. When new users are generated in the macro cell simulation they are uniformly distributed over the simulation area. The direction to which a new users is moving is randomly selected when a new user is created. The direction of movement is updated for a user after every decorrelation length.

7. RRM ALGORITHM MODELLING

With the presented simulator radio resource management (RRM) algorithms can be studied efficiently.

Power control consists of fast closed loop, outer loop and open loop. The outer loop controls the SIR set point of the fast closed loop power control both in uplink and downlink, and open loop is used to set the initial transmission powers of the terminals.

Different soft handover algorithms are supported with modeling of the handover measurements, reporting, active set updates and statistics. In addition, the measurement inaccuracies and delays can be studied.

Also other radio resource management algorithms have been included, such as admission control, load control and packet scheduling.

The simulator supports realistic division of the RRM algorithms between the base station and the radio network controller, RNC, and the required signalling over Iub interface.

8. SIMULATOR IMPLEMENTATION

Due to the complexity of the simulator, an object oriented approach was selected. With the object oriented approach some computer efficiency is lost, but controlling of the software becomes much easier. Because of the high complexity, a lot of attention should be paid for defining and supporting good class structure. The WCDMA specific features such as soft handover and macro diversity further increase complexity of the simulator and class structures.

The most severe drawback from the high accuracy modeling is long simulation times. To make simulation reasonably fast, parallel processing techniques are utilized. With four POSIX threads speed-up in order of two was gained for those parts of the simulator that were calculated in parallel.

9. APPLICATION AREAS

The presented WCDMA radio network simulator can be used for capacity, coverage and quality analysis, RRM algorithm development, and to aid WCDMA network planning and optimization in various environments, with various mobile distributions and with different services.

The sophisticated RRM algorithms - such as handovers, load control, admission control, power control and packet scheduling - are important for the WCDMA radio network operation. The developed WCDMA radio network simulator supports development of all RRM algorithms. It should also be noticed that RRM algorithms depend heavily on each other, i.e. power control affects directly load control, handovers and packet scheduling. Therefore, the development of all RRM algorithms together is needed, and this WCDMA simulator supports the analysis of the interactions of the algorithms. The presented simulator supports the tuning and optimization of the parameters in RRM algorithms. Such tuning is important in providing the maximum capacity from the radio network.

The WCDMA radio network planning uses more simple interference and dynamical modelling than this WCDMA simulator but the network planning tools can be calibrated with the simulator. It is clear that any simulation tools need to be verified by the real measurements from the WCDMA test networks.

Figure 3, Figure 4 and Figure 5 give an example of distributions and traces that the simulator can provide. Figure 3 shows the measured uplink noise rise (interference relative to noise power) in a base station as a function of time. Figure 4 depicts the downlink total transmission power from the same base station as a function of time. Figure 5 gives an example of probability density function (PDF) of mobile station transmission power.

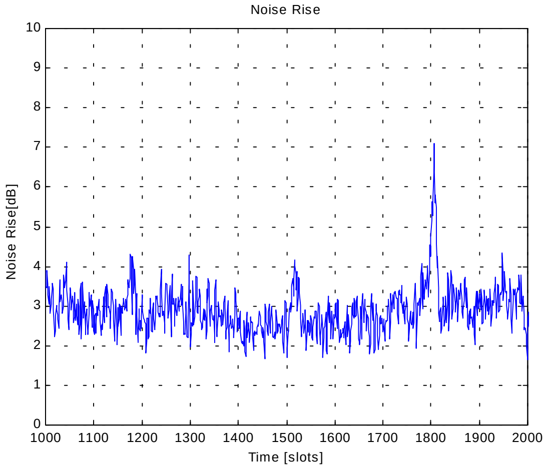

Figure 3. Measured noise rise in a base station as a function of time (in slots)

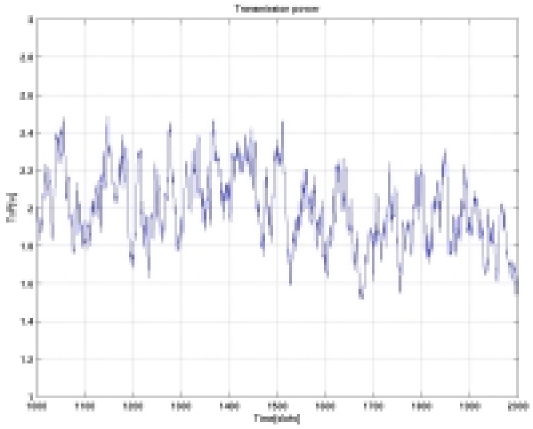

Figure 4. Trace of base station total transmission power as a function of time (in slots).

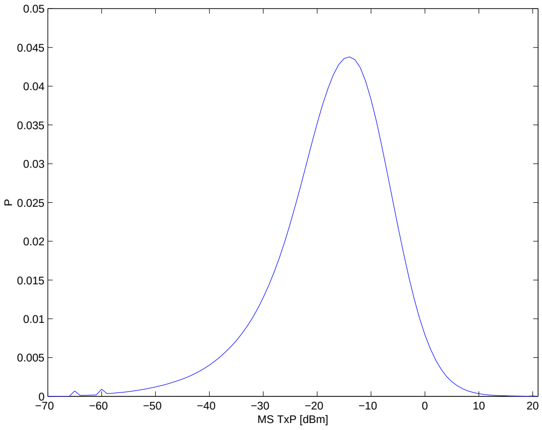

Figure 5. PDF for mobile station transmission powers. Transmission powers are measured slot by slot for all active users in the system.

10. CONCLUSIONS

An advanced WCDMA radio network simulator has been presented. This simulator can be utilized to develop the radio networks for fully exploiting the WCDMA capabilities, and to optimize the network for the operator needs. The accurate modelling of the radio network algorithms requires high time resolution and the simulation times are brought down by efficient parallel processing in multi-processor workstations.

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