Multi-cell WCDMA Signal Processing Simulation

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Abstract

Third generation (3G) wireless systems are being developed to increase system capacity and support innovative broadband multimedia services. Wideband CDMA (WCDMA) is one such system where the air interfaces need to support services with different bit-error rates, delay, and rates. We have developed a multi-cell simulation platform implementing user mobility and detailed radio channels to study the impact of mobile users, fading and propagation effects, and other-cell interference on waveform level processing. Our study aims at analyzing and improving algorithms at the link level (interference cancelation) and system level (power control and handoff) for WCDMA systems.

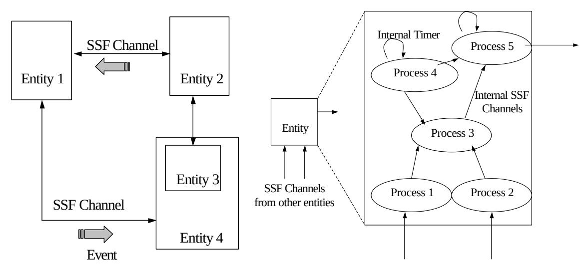

Figure 1. Basic SSF framework : SSF Entities communicate over channels through events. Processes inside entities define the dynamics

1. Introduction

Emerging Third-generation (3G) mobile radio networks intend to provide a multitude of services, especially multimedia and high-bit-rate packet data. Wideband code division multiple access (WCDMA) has emerged as the mainstream air interface solution for these 3G networks. Enhancements to the physical layer are among the most interesting and tangible directions for 3G research. However, system complexity dictates the need for simulation tools to evaluate and improve designs. Physical layer network simulation typically requires two main components: the calculation of the received signal at each network node and the receiver signal processing for bit detection. Both these classes of signal processing require complex calculations, and thus dominate the total computational effort. Careful consideration has to be given to the efficiency and accuracy of the implementation of these computations.

Beyond efficiency and accuracy, the other important goal of a simulator must be the ease with which researchers can write and incorporate modules that implement new and better algorithms. In turn, this translates into clear class organization, easy overloading of methods and the ability to add to the library of functionality. In this paper, we describe WIPPET$_{\text{signal}}$[1], a virtual testbed for parallel simulation of WCDMA networks. We will discuss its computational demands and parallelization problems, and also introduce certain preliminary results.

WIPPET$_{\text{signal}}$ is implemented in the Scalable Simulation Framework (SSF) [1] that has been designed with the goal of reducing the time required to construct new simulation models. SSF shifts much of the work to the design of models rather than low-level programming of customized simulator software. Careful model design enables reuse of a growing database of objects for creation of more advanced simulations. SSF provides a single, unified interface for discrete-event simulation (the SSF API). Object-oriented models that utilize and extend the framework can be portable across SSF-compliant simulation environments. SSF makes it possible to build models that are efficient and predictable in their use of memory, able to transparently utilize parallel processor resources, and scalable to very large collections of simulated entities [1]

In SSF, physical and conceptual objects in the telecommunication domain are modeled as *entities*. Entities are con-

[1]Wireless Propagation and Protocol Evaluation Testbed for WCDMA signal processing

nected to and interact with each other via channels, called SSF *inChannels* and *outChannels*. SSF channels are the only means of dynamic interaction between entities. Information units, called *events*, flow through SSF channels. An output SSF channel of one entity may connect to the input SSF channel of another entity, or may connect to itself, thus creating *internal* SSF channels. *Processes* inside an entity define its dynamic behaviour. Figure 1 illustrates the basic framework of SSF where the entities interact with each other. This collection of classes thus allows for modeling an arbitrary structure of connected entities that represent a complex simulation model.

2. System Model and Requirements

WCDMA shares the common elements of CDMA systems, including rake reception, transmitter power control, soft handoff and multiuser detection. A detailed comparison of IS-95 CDMA and WCDMA is given in [6]. The important improvement of WCDMA is the introduction of inter-cell asynchronous operation and the pilot channel associated with each data channel. The pilot channel makes coherent detection possible on the reverse link. Furthermore, it makes it possible to adopt interference cancelation and adaptive antenna array techniques.

We will restrict our discussion to those physical aspects of WCDMA that are relevant to WIPPET$_{\text{signal}}$. The basic physical resource is the code/frequency plane. In addition, on the uplink, different information streams may be transmitted on the I and Q branches. Consequently, a physical channel corresponds to a specific carrier frequency, code, and, on the uplink, relative phase (0 or π/2). WCDMA physical channels can be classified as *dedicated* or *common*. There are dedicated and common channels for both the *uplink (reverse link)* and the *downlink (forward link)*. The two uplink dedicated physical channels are the uplink Dedicated Physical Data Channel (uplink DPDCH) and the uplink Dedicated Physical Control Channel (uplink DPCCH). The DPDCH and the DPCCH are I/Q code multiplexed within each radio frame, although in this version of WIPPET$_{\text{signal}}$, we are use a time multiplexed pilot channel [3]. The downlink Common Pilot Channel (CPICH) is a fixed rate downlink physical channel that carries a pre-defined bit/symbol sequence. The WCDMA scheme employs long spreading codes for which Gold sequences of length 2^{18-1} and 2^{41-1} are used for downlink and uplink respectively. Both are truncated to form a cycle of a 10-ms frame. For channelization, orthogonal codes are used. Orthogonality between codes with different spreading factors can be achieved by tree-structured orthogonal codes as described in [2].

The performance of radio receivers primarily depends on signal propagation and multiuser interference. Radio reception quality can exhibit very large fluctuations in space and time. Sources of these fluctuations include changes in distance between receiver and transmitter, changes in environment or terrain, and changes in the activity of other transmitters. Accurate evaluation of a wireless network requires a radio channel model that captures these spatial and temporal variations, i.e. distance fading, shadow fading, fast fading, and interference. There is a vast body of literature on the measurements and modeling of propagation in various environments at various frequencies; for a review, see [5, 7]. While the design of WIPPET$_{\text{signal}}$ allows the use of site-specific propagation models, in our research we focus on statistical characterization of the wireless network, and thus we limit the discussion to stochastic propagation models. Currently, WIPPET$_{\text{signal}}$ implements distance loss, shadow fading and Rayleigh fading for chip level simulation.

WIPPET$_{\text{signal}}$ also implements a number of algorithms as part of the transceiver. The modular structure allows for direct comparison of receiver performance and the ability to create other types of transceivers. Currently, WIPPET$_{\text{signal}}$ implements two kinds of receivers that are discussed in this paper.

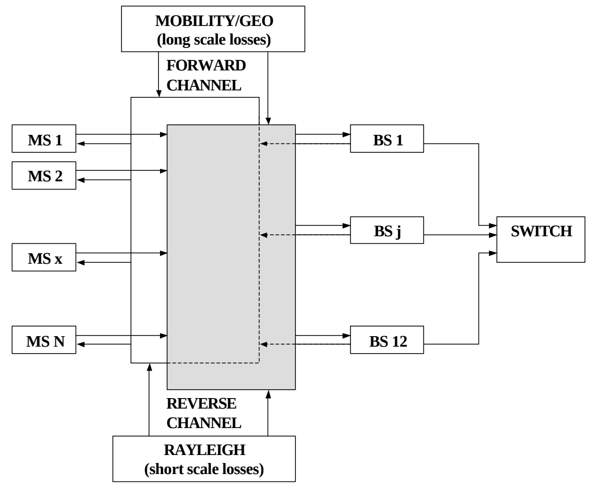

Figure 2. WIPPET$_{\text{signal}}$ **modules in analogy to the real WCDMA system**

3. WIPPET$_{\text{signal}}$ Design

Figure 2 shows the entities of WIPPET$_{\text{signal}}$ and their basic connectivity through SSF channels. A wireless network consists of mobile stations (MSs), base stations (BSs), and mobiles switching centers (MSCs). A MS is connected to a BS through the air interface (a radio link). A BS is connected to a MSC through a microwave link or an optical fiber link. Error free SSF channels also exist between the BSs and MSs to implement WCDMA protocol messages for power control and handoff commands.

Radio Channel Processing

In WIPPET$_{\mathrm{signal}}$ the Rayleigh Fading for all possible signal paths in the system (reverse link and forward link) are calculated in the `RAYLEIGH` [2] entity. WIPPET$_{\mathrm{signal}}$ uses an approximation to Clarke's model [4], which avoids going through the computationally intensive method of calculating the power spectral density (PSD) and then using the inverse fast fourier transform (IFFT) to obtain the correlated Rayleigh values. For a Rayleigh random process, the autocorrelation function is ${J_0}^2(2\pi f_d \tau)$, where J_0 is the zero-order Bessel function of the first kind and τ is the shift variable. WIPPET$_{\mathrm{signal}}$ uses an approximation to this function by using the monotonic and periodic properties of negative powers and cosine function respectively. The filtered Gaussian noise method is used to generate the amplitude and phase attenuation. The frequency transform function of the filter is given by

$$G(f) = \frac{1}{\sqrt{\pi}} \cdot \left(f_d^2 - f^2\right)^{-1/4} \quad |f| < f_d \tag{1}$$

where f_d is the Doppler frequency shift. The corresponding impulse response function has the closed form as

$$g(t) = \xi \left(2\pi f_d |t|\right)^{-1/4} J_{\frac{1}{4}} \left(2\pi f_d |t|\right) \tag{2}$$

where ξ is the normalizing coefficient to keep $|g(t)| = 1$. Interpolation techniques are used in which a high-rate interpolation filter follows a low-rate prototype filter whose impulse response is given by an approximation of equation (2). This implementation is further improved with a polyphase subfilter implementation.

In WIPPET$_{\mathrm{signal}}$, long scale (Distance and Shadowing) effects for all the possible MS-BS pairs in the system (reverse link and forward link) are modeled in `MOBILITY`. A separate MATLAB program was written to generate the Manhattan geographical model and associated path loss matrix. Figure 3 illustrates the output for a 12 cell geography. The program takes distance resolution, correlation distance, variance of shadow fading, etc., as inputs and generates a path loss matrix and stores it in a file. The wrap-around in the model makes sure that there are no boundary mobiles, and hence all BS have interference from all directions. This allows us to collect statistics from all possible BSs rather than just from a central BS which is surrounded by one to two tiers of cells.

In WIPPET$_{\mathrm{signal}}$, interference is modeled in the `CHANNEL` entity, which is closely coupled with the `RAYLEIGH` and `MOBILITY` entities which provide the propagation effects. The radio channels incorporate waveform level simulations. Waveforms are modeled by a sampled time system with sampling interval Δ. In general, T_c, the duration of one CDMA chip, is a multiple of Δ; however, to reduce the computational requirements, our experiments have employed one sample per CDMA chip. Further, time offsets between transmitted signals are always an integer number of chips. Similarly, the multipath delays of each radio channel and the asynchronism of each base station are always an integer number of chips. Thus, for our purposes, a waveform of duration nT_c is simply a complex I/Q vector of length n. For antenna i of transmitter x, and antenna j of receiver y, multipath component l has an associated channel gain $G_{x,i,y,j,l}$ and delay $\tau_{x,i,y,j,l}$. When transmitter x sends signal $C_x(t)$, the corresponding received signal cpmponent at antenna j of receiver y is given by

$$s_{x,y,j}(t) = \sum_{i=1}^{T_x} \sum_{l=1}^{L} \sqrt{P_x} G_{x,i,y,j,l} C_x(t - \tau_{x,i,y,j,l}) \tag{3}$$

where T_x and L are the number of transmitting antennas of x, and the number of multi-paths respectively. This signal $C_x(t)$ is the information symbol $b_x(t)$ spread by a chip sequence. Slot by slot power control dictates that the transmitter power P_x of transmitter x is held constant over the transmission of a single slot for the reverse link. The composite received signal at receiver y is obtained by summing equation (3) over all transmitters. For a single transmitter antenna and a single receiver antenna, the complex baseband

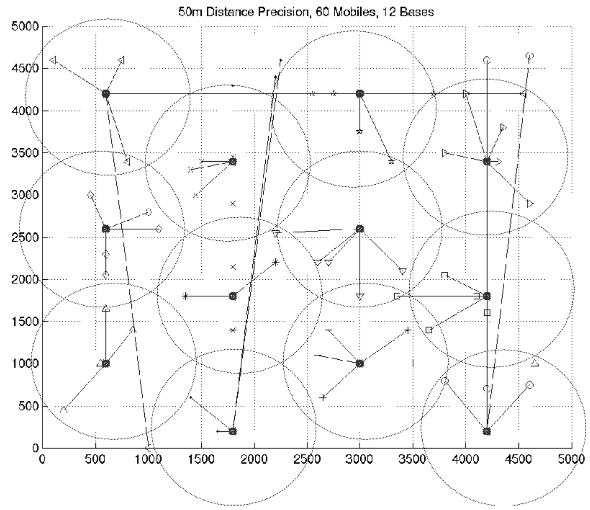

Figure 3. Manhattan geography contains streets and avenues modeled as one dimensional lines constructed by discrete points on which the MSs move

[2] The names of WIPPET$_{\mathrm{signal}}$ entities that appear in `typewriter` font match exactly the entity name as they appear in the source code of WIPPET$_{\mathrm{signal}}$.

received signal is

$$s_y(t) = \sum_{l=0}^{L-1} s_{x,y,l}(t) + \sum_{x' \neq x} \sum_{l=0}^{L-1} s_{x',y,l}(t) + \omega(t) \quad (4)$$

where $s_{x,y,l}(t)$ is the received signal on the lth path for the desired user x and all other users ($x' \neq x$) and AWGN $\omega(t)$ cause the multi-access interference and noise.

Transceiver Processing

WIPPET$_{\mathrm{signal}}$ supports multiple WCDMA transceiver modules that can be inherited as part of the simulation. The transceiver functionality of the `MOBILE`, `BASE` and `SWITCH` entities is encapsulated in another sub-module. The current version of WIPPET$_{\mathrm{signal}}$ implements all stages of reverse link data (DPDCH/DPCCH) transmission and reception and forward link common pilot (CPICH) transmission and reception. This section describes the implementation of transceiver design in WIPPET$_{\mathrm{signal}}$.

WIPPET$_{\mathrm{signal}}$ uses the recently researched channel estimation filter called the Weighted Multi Slot Averaging (WMSA) filter [3]. A coherent rake receiver using equal gain combining (EGC) is used. The first step in detection process used in WIPPET$_{\mathrm{signal}}$ is a matched filtering operation on each path using the chip sequence for user x. From equation (4), for the mth symbol in the nth slot, the matched filter output for path l of user x at receiver y is given by

$$r_{x,y,l}(m,n) = \sqrt{2P_x(n)}G_{x,y,l}(m,n)b_x(m,n) + w(m,n) \quad (5)$$

where $P_x(n)$ is the average transmitted power in the nth slot which is constant over the slot, $G_{x,y,l}(m,n)$ is the complex path gain of the lth path, $b_x(m,n)$ is the transmitted symbol and $w(m,n)$ is the sum of all the multi-access interference (MAI) including self interference from other paths and background noise. Each slot starts with N_P time multiplexed pilot symbols. The instantaneous channel estimate $\widetilde{\eta}_{x,y,l}(n)$ for the nth slot, and the coherent rake combiner output sample $\widehat{r}_{x,y}(m,n)$ for the mth symbol in the nth slot is obtained by using N_P pilots of the same slot as

$$\begin{aligned} \widetilde{\eta}_{x,y,l}(n) &= \frac{1}{N_P} \sum_{m=0}^{N_P-1} r_{x,y,l}(m,n) \\ \widehat{r}_{x,y}(m,n) &= \sum_{l=0}^{L-1} r_{x,y,l}(m,n) \widetilde{\eta}^*_{x,y,l}(m,n) \end{aligned} \quad (6)$$

Another version of the WSMA channel estimation filter takes two consecutive slots to estimate the channel. Further details are provided in [3].

When the pilot and data symbols have the same power, the estimated SIR $\lambda_{x,y}(n)$ of user x at receiver y for the nth slot is given by the following set of equations:

$$\begin{aligned} \widehat{S}_{x,y,l}(n) &= \left| \frac{1}{N_m} \left(\sum_{m=0}^{N_P-1} \widehat{r}_{x,y,l}(m,n) + \sum_{m=N_P}^{N_m-1} \widehat{r}_{x,y,l}(m,n) \right) \right|^2 \\ \widetilde{I}_{x,y,l}(n) &= \frac{1}{N_P} \sum_{m=0}^{N_P-1} \left| r_{x,y,l}(m,n) - \widetilde{\eta}_{x,y,l}(n) \right|^2 \\ \widehat{I}_{x,y,l}(n) &= \alpha\, \widetilde{I}_{x,y,l}(n-1) + (1-\alpha) \widetilde{I}_{x,y,l}(n) \\ \lambda_{x,y}(n) &= \sum_{l=0}^{L-1} \frac{\widehat{S}_{x,y,l}(n)}{\widehat{I}_{x,y,l}(n)} \end{aligned} \quad (7)$$

where $\widehat{S}_{x,y,l}(n)$ is the instantaneous signal power measured over the interval of $N_m \geq N_P$ symbols for path l and $\widehat{I}_{x,y,l}(n)$ is the average MAI plus noise power following a first order linear filter with a factor $\alpha < 1$ used for averaging. A qualitative study of the SIR-based TPC used by WIPPET$_{\mathrm{signal}}$ for reverse link for coherent DS-CDMA systems appears in [11].

WIPPET$_{\mathrm{signal}}$ also implements a pilot symbol assisted coherent multistage interference canceler (COMSIC) with three stages as given in [9, 10]. The user ranking is done after despreading using matched filters (MFs), and is updated every slot. At each stage, there are K channel estimation and interference replica generation units (CEIGUs). At base y, let $I_{x,y,l,p}(n)$ be the generated replica, at the pth stage of the xth user spread signal which is associated with the lth path and the nth slot. At each stage the MAI from $K-1$ users is subtracted from the received composite signal $r(t)$. The MAI from higher ranked users $(1 \leq u \leq x-1)$ and the lower ranked users $(x+1 \leq u \leq K)$ is given by:

$$\begin{aligned} I_{u,y,p}(n) &= \sum_{l=1}^{L-1} I_{u,y,l,p}(n) \\ I_{u,y,p-1}(n) &= \sum_{l=1}^{L-1} I_{u,y,l,p-1}(n) \end{aligned} \quad (8)$$

The output of the CEIGU is given by:

$$\begin{aligned} r_{x,y,l,p}(n) = r(n) - \beta \Bigg[&\sum_{i=1}^{x-1} \sum_{j=1}^{L-1} I_{i,y,j,p}(n) + \\ &\sum_{i=x+1}^{K} \sum_{j=1}^{L-1} I_{i,y,j,p-1}(n) \Bigg] \end{aligned} \quad (9)$$

where β is an interference rejection control (IRC) factor used to reduce the error of the generated interference replica due to channel estimation error and data decision error [8].

Event Flow

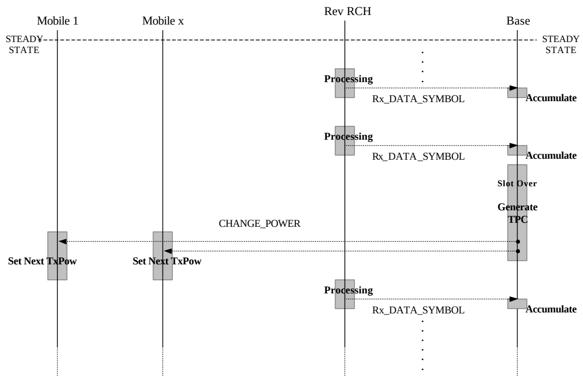

Figure 4. Power Control flow in WIPPET$_{\text{signal}}$: The BSs estimate the SIR of each of their MS and compare it with a target level. An error free feedback is sent over to the MS which increase or decrease their transmit power level by a constant factor

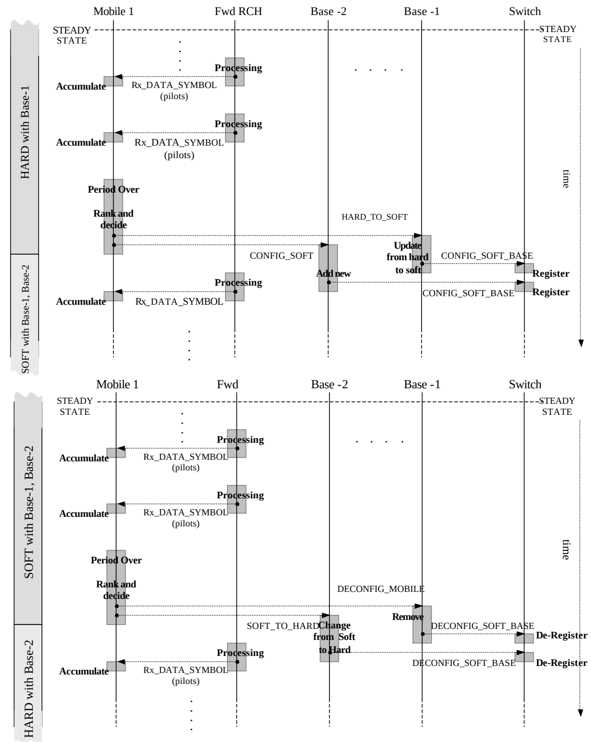

Figure 5. Soft Handoff Initiation and Termination flow in WIPPET$_{\text{signal}}$: The MS receives simulation data, based on which the MS, BSs and the Switch exchange protocol messages which initiates and terminates the soft-handoff

The WIPPET$_{\text{signal}}$ entity `MOBILE` creates and sends out information bits to the BS via the reverse channel (RCH) which simulates the DPDCH/DPCCH. A BER statistic is created at the BS to characterize the performance of the system. The MS also demodulates the CPICH for each BS, to calculate average power levels and make decisions about initiation and termination of soft handoffs. During the time the MS is in soft handoff, the power of the MS is increased only if all the *active* BSs command it to increase power. The WIPPET$_{\text{signal}}$ `BASE` acts as a service provider and maintains states for each MS it serves. For all the MSs that are in normal state (this BS is their only active BS), the BS makes a hard decision on the data and makes BER calculations locally. For MSs that are in soft state, i.e. have more than one active BS, all the active BSs create soft data, but make no decisions based on it. This soft data is then forwarded to the WIPPET$_{\text{signal}}$ `SWITCH` entity, where the various contributions are combined and a final hard decision made.

In WIPPET$_{\text{signal}}$, SSF events can be simulation data events traveling via the `CHANNEL` module where propagation and interference effects are incorporated, or protocol messages that travel on error free channels. Figure 4 gives an illustration of one of the setups where the simulation data is constantly received as Rx_DATA_SYMBOL (spreaded DPDCH/DPCCH) events from the `CHANNEL`. A feedback based on the estimated SIR is encapsulated in a CHANGE_POWER protocol message event on an error free SSF channel for the MS to increase or decrease its transmit power for the next slot. This feedback can also be delayed by some amount to analyze the effect of protocol delay on the performance of the system. Similarly, figure 5 illustrates soft handoff initiation and termination. Based on the criterion for soft-handoff, the BSs switch between candidate and active sets during the simulation. The MS receive simulation data as Rx_DATA_SYMBOL (spreaded CPICH) events from the `CHANNEL`, which is accumulated. After every slot, the MS ranks the BSs in decreasing order of their current average power levels and makes a decision on whether to upgrade a candidate BS to an active BS. Once this decision is made, the MS sends a protocol message HARD_TO_SOFT to its currently active BSs. It also sends another protocol message CONFIG_SOFT to the new active BS, which is told of the long code state and the timing of this MS, so that it can start decoding it. The active BSs send protocol messages CONFIG_SOFT_BASE to the `SWITCH` which establishes a setup where it awaits soft data from these two BSs which can be combined and BER calculated for the MS. Termination of this soft handoff means that the MS reverts to a normal connection with one of the BSs.

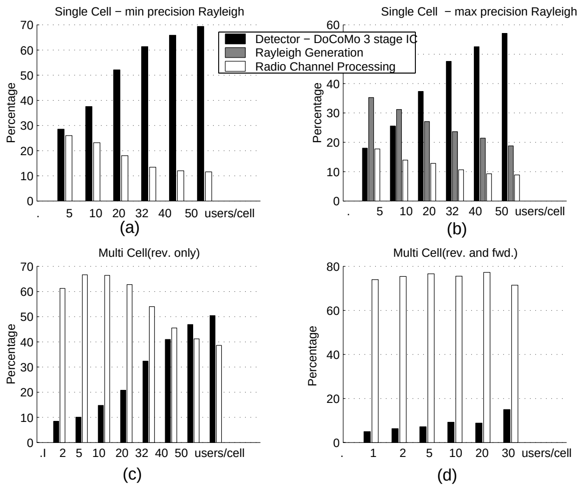

Figure 6. Relative complexity : The complexity of the IC3 detector exceeds all other processing except in the multi cell (fwd. and rev.) case(d)

4. Complexity, Parallelization and Speedups

WIPPET$_{\text{signal}}$ is a computationally intensive simulation and the two main components of these calculation are *Radio Channel Processing* and *Bit Detection*. The former involves the calculation of the received signal at each of the receivers in the system. This processing is done in the CHANNEL where information from all transmitters is gathered, the phenomena of propagation (short and long-scale channel effects) and interference are incorporated and the signals are delivered to the receivers. We will discuss the complexity of the NTT DoCoMo 3 stage interference canceler *IC3*[9] as a special case of the latter.

We have used the GNU profiler, *gprof* and profiled the simulator to learn where the program spends its time. The profiling has been done with various parameters like detector types, number of multipaths and number of users to establish the complexities of the radio channel processing vs. bit detection in a single and multi cell environment with *MF* and *IC3* detectors for one and two multipath channels. The effect of increasing the precision of the Rayleigh fading generator by increasing the number of fading samples from one per symbol to one per chip has also been evaluated. Figure 6 gives bar graphs for one multipath and IC3 detectors. The top two graphs are (a): 1 cell, spreading factor (SF) 64 and 1 rayleigh sample per symbol; and (b): 1 cell, SF 64 and 1 rayleigh. Figures 6(a) and 6(b) clearly show that the detector outweighs the other modules. Figure 6(c) with 12 cells(rev. only), and SF 64 shows that the detector starts outweighing the channel as the number of MS increase. Figure 6(d) with 12 cells(fwd. and rev.), SF 64 shows that the complexity of *radio channel processing* is much higher than other modules in the multi cell system.

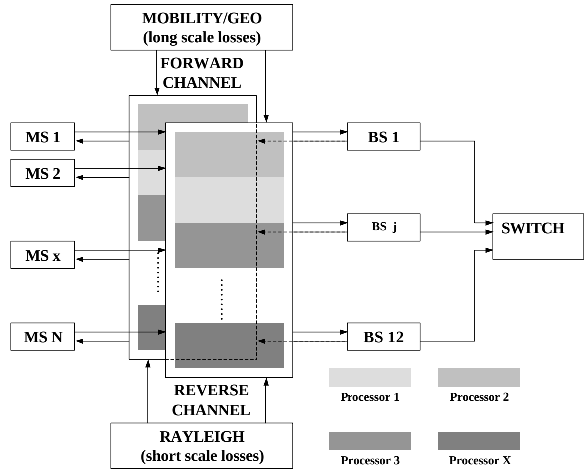

Figure 7. WIPPET$_{\text{signal}}$ **per-event parallalization scheme**

Parallel simulation performance is measured in terms of execution time speedup and efficiency based on experiments performed in a multi-processor environment. SSF allows for two types of parallelization schemes:

- Entity parallelization (Optimal partitioning)
- Per-event parallelization

Entities in a serial SSF simulation are *aligned* to one common *timeline*. This means that all the processing that has to take place at a particular SSF instant is done in all the entities, and only then does the simulation proceed to the next simulation instant. Entity parallelization utilizes parallel processors to align entities or groups of entities to different timelines, which parallelizes the simulation. Empirical methods to obtain optimal *load balancing* requires a long period of tuning and analysis, especially for complex models. In this case, parallelization works well unless there are many *cross-processor events* and small windows for processor *synchronization*. However this scheme is not suitable to WIPPET$_{\text{signal}}$ due to the fact the CHANNEL entity will always cause frequent cross-processor events because of its connectivity with all other entities.

Instead, WIPPET$_{\text{signal}}$ is parallelized using the per-event parallelization scheme as the computation of composite signals in the CHANNEL for each of the receivers is a classical problem in parallel computation. As is evident from equation (3), the same kind of computation is done for all the receivers. Only two elements in the equation change for different receivers; the channel gain $G_{x,i,y,j,l}$ and the delay $\tau_{x,i,y,j,l}$ for each signal component (x, i, y, j, l). Once all

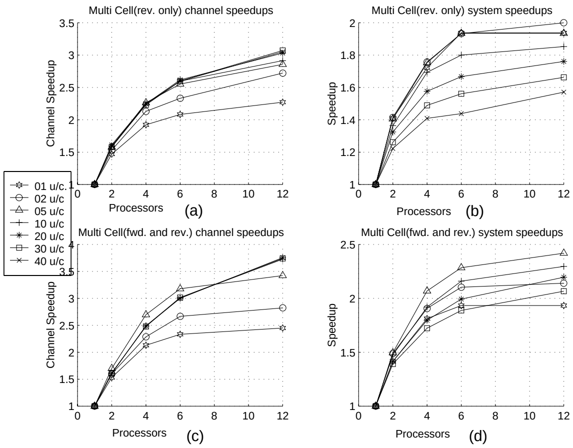

Figure 8. Multi cell Channel speedups in (a) and (c) when the transceiver is absent. (b) and (d) give the system speedups when the transceiver is present. (a) and (b) have only the reverse channel, (c) and (d) have both the reverse and forward channel

the transmitter contributions are received, and channel gains set up, the computation of the composite signal at one received node is **NOT** dependent on the result of the computation of the composite signal at some other receiver node. The implementation of this parallelization is illustrated in Figure 7. The receivers for the reverse and forward links are divided into groups. One processor handles two groups (one from the MS and one from the BS).

Figure 8 gives the simulation speedups for the multi cell system with 2 multipaths, spreading factor 64 and only channel (Figures 8(a) and 8(c)) or the entire system (Figures 8(b) and 8(d)). Since only the channel is parallelized in WIPPET$_{\mathrm{signal}}$, it is observed that the speedups when the detector is absent are better than when it is present. The difference is more prominent in cases when the complexity (i.e. time consumption) of the detector starts increasing for higher number of users in the multi cell(rev. only) (Figures 8(a) and 8(b)) cases. Also, in the multi cell(fwd. and rev.) (Figures 8(c) and 8(d)) cases, since the channel dominates the computation, better speedups are observed than the multi cell(rev only) cases. Single cell simulations can also be parallelized for cases when the receiver BS has more than one receiving antenna.

5. Validation

WIPPET$_{\mathrm{signal}}$ has been validated on a sub-system level basis (unit testing) and an end-to-end system basis to make sure that the statistics and results are representative of the actual system characteristics. The performance of the fader

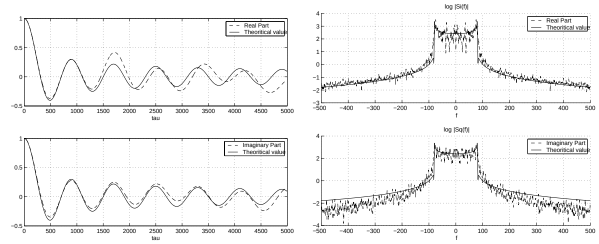

Figure 9. Rayleigh Fader Correlations and PSD : [left] The auto correlation of the real and imaginary component. [right] The corresponding spectral densities

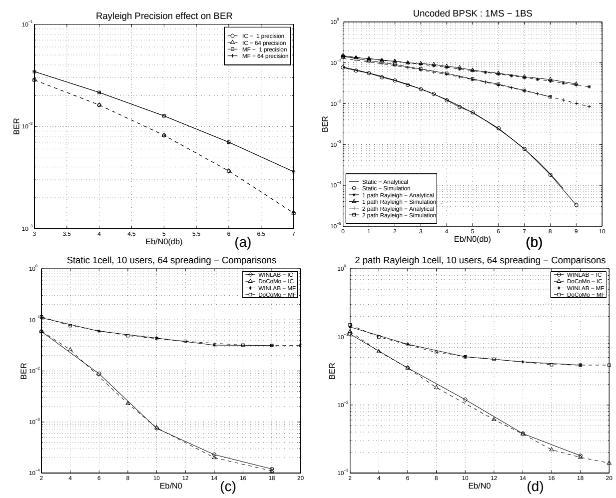

Figure 10. End-to-end BER validation for Rayleigh precision, Uncoded BPSK and comparisons with NTT DoCoMo measurements

was evaluated by running the fader for 100,000 samples at a sampling frequency of $64K$ symbols/s and a Doppler frequency of 80 Hz. Figure 9[left] plots the auto correlation of the real and imaginary component. Only the first 5000 values have been plotted, though the correlation was calculated for all the entire [-100,000 100,000] range. The Bessel function is also plotted to give a measure of error of the fader. The autocorrelation results were then passed through a Kaiser Window and the logarithmic version of the FFT is plotted in Figure 9[right]. Since all Rayleigh faders are stochastically independent of each other, the results are representative of all the faders in the system.

End-to-end BER experiments were performed to validate the performance of the Rayleigh fader for minimal precision (1 sample per symbol). Figure 10(a) gives an illustration of the error rates for full (1 sample per chip) versus minimum precision. Figure 10(b) gives the simulation and an-

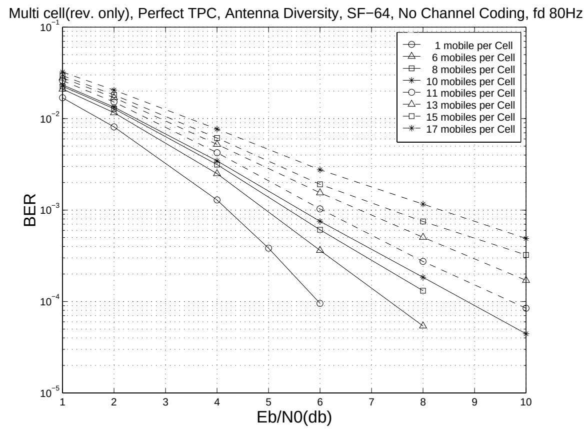

Figure 11. Multi cell(rev. only) results specific to a particular combination of WCDMA physical layer and transceiver parameters

alytical results for a single MS and BS for uncoded BPSK [12]. Validation was also performed for multiuser single cell setups and the results were checked against the ones calculated by NTT DoCoMo for the same setups. Figures 10(c) and 10(d) illustrate the BER for a 10 user uncoded BPSK single cell system with a spreading factor 64 for a single path time invariant and 2path (80 Hz) Rayleigh setups respectively. The results for the simulation results at WINLAB for the DoCoMo 3 stage interference canceler and matched filter closely the results obtained from NTT DoCoMo for the same cases. This validated the end-to-end transmitter-channel-receiver design for WIPPET$_{\text{signal}}$ and made sure that every module was working as per the specifications. Other experiments with static 1 path BPSK with soft Viterbi decoding were also performed and results matched against analytical bounds.

6. Sample Results and Conclusions

WIPPET$_{\text{signal}}$ is a configurable WCDMA physical layer simulation. Various parameters like SIR target, noise PSD, number of MS, number of receiving and transmitting antennas, multipath profile(delay and power), coding polynomials, interference cancelation, Perfect TPC E_b/N_0, soft handoff dynamic range, etc. can be configured at runtime. This allows the user to set the simulation up with specific parameters and observe the results. An example of this process is given in Figure 11 which gives the results for a multi cell(rev. only) system with perfect TPC, antenna diversity, spreading of 64, no channel coding and 80 Hz Doppler with 2 paths. WIPPET$_{\text{signal}}$ gives a handle over critical parameters that allow the user to do simulations on parallel processors and arrive at system results like BER and FER based on signal processing WCDMA simulations.

Acknowledgments

The work is partially supported by NTT DoCoMo. We thank Prof. Narayan B. Mandayam (WINLAB), Prof. Andrew T. Ogielski (Dartmouth) and Mr. Kenichi Higuchi (NTT DoCoMo) for their valuable inputs and motivation for this project.

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