CDMA2000 REVERSE-LINK SIMULATION MODEL DESIGN AND EVLUATION

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Abstract

This paper presents the design and implementation of a simulation model for the cdma2000 reverse link. The model includes all the radio configurations and their corresponding data rates in accordance with the IS-2000 specifications. The paper first presents a tutorial review of the traffic channel characteristics of the cdma2000 reverse link (subscriber to base station) and its physical layer performance by considered two types of rake receivers; ideal and non-ideal. The reverse link performance is measured based on its link budget specifications.

Introduction

Following the implementation of the forward link simulation models for the cdma2000 in collaboration with Cadence design Systems Inc, we have now completed the simulation model of the reverse link.

Cdma2000 is based on the existing IS-95 CDMA system that has been proposed by the Tele-communications Industry Association (TIA) TR45.5 committee [1]. The channels transmitted on the reverse link consist of: Access Channel, Enhanced Access Channel, Reverse Common Control Channel, Reverse Pilot Channel (R-PCH), Reverse Dedicated Control Channel (R-DCCH), Reverse Fundamental Channel (R-FCH), Reverse Supplemental Channel 1 (R-SCH1), Reverse Supplemental Channel 2 (R-SCH2), and Reverse Supplemental Code Channels (R-SCCH).

The first three are common channels used for the communication of Layer 3 and MAC (Medium Access Control) messages from the mobile station to the base station [2]. The focus in this paper is on the remaining channel types known as traffic channels.

These channels are allocated on a per user basis and are specified by six different Radio Configurations (RC) [1]. For reverse traffic operation in RCs 1 and 2, a single R-FCH and up to seven R-SCCH's can be utilized. These two RCs are designed for backward compatibility with the existing IS-95 CDMA system. As our main concern is the cdma2000 system, RCs 1 and 2 will not be discussed in this paper. For the reverse traffic operation in RCs 3 through 6, a R-PCH is required together with up to one R-DCCH, up to one R-FCH, and up to two R-SCHs. Currently, cdma2000 supports spreading rates 1 and 3 which correspond to chip rates of 1.2288 and 3.6864 Mcps respectively.

The cdma200 also supports two basic rates: rateset 1 (9.6 kbps) and rateset 2 (14.4 kbps). Lists of the spreading rates, ratesets, and the possible data rates for different RCs can be found in [1]. The data rates in RCs 3 and 5 are included in rateset 1, while the data rates in RCs 4 and 6 are included in rateset 2. Data is processed in 5 or 20 ms frames. The 5ms-frame option is not included in our implementation. The data rate on the R-FCH can be fixed or variable during transmission. The variable rates (e.g., 1500, 2700, 4800, 9600 bps for rateset 1) are changed on a frame by frame basis. The use of R-SCHs offers two additional higher rate channels. For RC 5, each supplemental channel can accept information rates up to 614.4 kbps.

Figure 1 shows a block diagram of the transmission system for the cdma200 reverse link. The functionality of the blocks shown in this Figure will be discussed in the following sections. In particular, the section on the receiver presents the design strategy for the non-ideal and ideal rake receivers. Finally, after a discussion of the simulation parameters and the link budget, the results are presented for both ideal and non-ideal receivers.
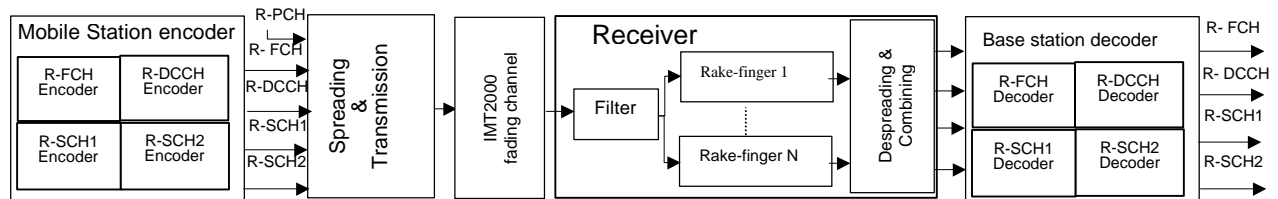

Figure 1: Block Diagram of the cdma2000 reverse link physical layer for traffic signal.

Mobile Station Encoder

The framing and encoding process is performed at the mobile station encoder for each reverse traffic channel. The encoding procedures for the Reverse Fundamental and Supplemental channels is shown in Figure 2. The first three blocks in this figure append bits to a frame of information bits. A single reserved or erasure indicator bit may be placed prior to the information bits.

The information bits are followed by the frame quality indicator (CRC bits) and the encoder tail bits. The CRC (Cyclic Redundancy Code) bits are used as an error detection mechanism at the receiver. Encoder tail bits are used to terminate the convolutional code.
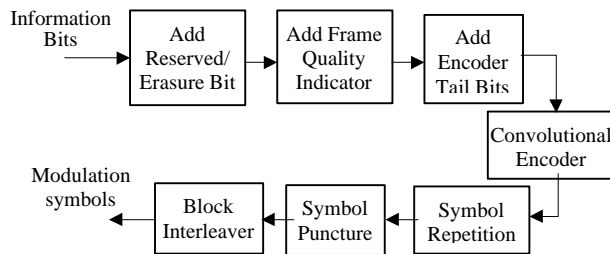

Figure 2: Reverse Fundamental and Supplemental

The bit allocations for the reserved bit, information bits, CRC, and encoder tail bits for the R-FCH and the R-SCH are specified in accordance with the data rate and the selected RCs [1].

Returning to Figure 2, after the framing procedures, the convolutional or turbo encoder codes its input at a higher symbol rate for error protection purposes. Symbol repetition and symbol puncturing further adjust the transmitted bit rate to the desired chip rate (1.2288 or 3.6484 Mcps) as specified by the RCs. The order of the symbols is then scrambled in the block interleaver to provide better protection against bursty errors. It should be noted that following the block interleaver, symbols on the R-FCH, R-SCH1, and R-SCH2 might be repeated. For instance, for the case of R-FCH and R-SCCH with a spreading rate of 3, the repetition factor is 3. The parameters associated with each of the blocks in Figure 1 for RC 3 through 6 can be found in [1].

The R-DCCH frame structure is similar to that of the R-FCH and R-SCH. The R-DCCH is used for the transmission of higher level data and control information from a mobile station to a base station. This channel can be enabled or disabled on a frame by frame basis. The datarate for the R-DCCH is fixed at 9600 or 14400 bps for 20ms frame.

Finally, the pilot channel (R-PCH) is an unmodulated spread spectrum signal used for initial acquisition, time tracking, rake receiver coherent reference recovery, and power control measurement. The R-PCH is transmitted with RCs 3 through 6. The mobile station inserts a Reverse Power Control Subchannel on the R-PCH. This subchannel carries the power control bit, which is sent to the base station for power control purposes.

Spreading and Transmission

The reverse channel signals for radio RC-5 (spreading rate 3) as shown in Figure 3, are orthogonally spread and combined using quadrature spreading.

Orthogonal codes are used to multiplex the reverse channels, i.e. R-FCH, R-DCCH, and R-SCHs. Each channel is spread by an orthogonal Walsh function. The orthogonal characteristics of the Walsh functions ensure that the channels do not interfere with each other. The specific Walsh functions used for different reverse channels are also shown in Figure 3. As indicated in this Figure, the Walsh functions are converted to symbols (-1, +1) and multiplied with the corresponding reverse channels.

The spread reverse channels are then scaled by relative gains, which will be discussed in the section on the Link Budget. After gain adjustment, the spread R-SCH2, R-PCH, and R-DCCH are combined to form the I-Channel. Similarly, spread R-FCH and R-SCH1 are combined to form the Q-Channel. This complex signal (I and Q channels) is then applied for quadrature spreading (see Figure 3).

Fading Channel

After spreading, the modulated traffic signal is then transmitted over multipath fading channels. As shown in Figure 1, the channel model used for our reverse link system is that specified by the IMT2000 for Vehicular Model A. This model takes into account both slow and frequency selective fast fading. The slow fading is modeled by lognormal shadow fading. The frequency selective fast fading is modeled by the superposition of multiple single flat faded paths with different arrival times and average powers. The average power and arrival times are assumed to be fixed and are determined by the channel impulse response. Each path has a Rayleigh distribution, with the power spectrum suggested by Jakes [3]. Figure 4 shows the six-path

fading channel with its corresponding relative power (G_i) and delay parameters.

After the fading channel, white Gaussian noise (WGN) is added to simulate the effect of overall interference in the system, including thermal noise and inter-cell interference.
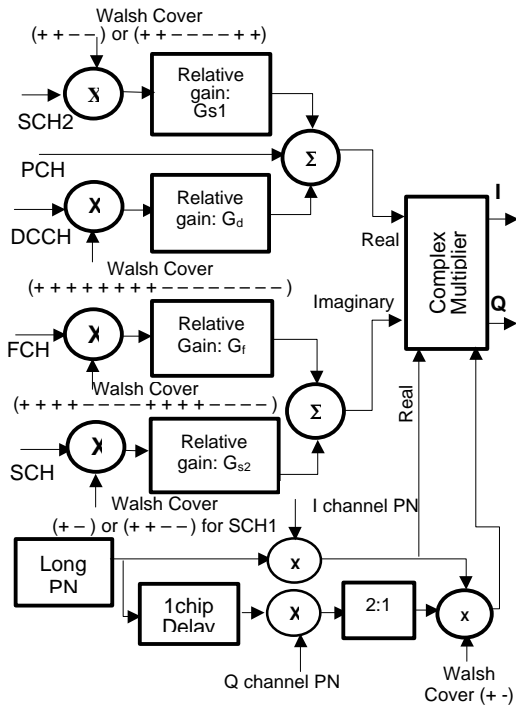

Figure 3: I and Q Mapping for RC 5

The dominating interference in CDMA systems tends to be inter-cell due to the possibility of the systems having a unity reuse factor (if traffic is very heavy in adjoining cells). The carrier-to-interference ratio (C/I) is often used to denote this inter-cell interference, and can have values of 0 dB or less.

Receiver Design

The receiver for the reverse link model consists of a rake receiver followed by a channel despreader. The rake receiver is a coherent receiver that attempts to collect the signal energy from all received signal paths that carry the same information. The rake receiver therefore can significantly reduce the fading caused by these multiple paths. The channel despreader takes the outputs from the rake receiver and recovers the channel data, by despreading the outputs using the appropriate

Walsh function. The first stage in the receiver model is the receiver filter. This filter has the same parameters as the transmitter filter.

The next stage is to bring all the rake fingers into time alignment for combining. The received signal at the receiver is a composite signal made up of the sum of multiple reflections of the transmitted signal. Each reflection has a different delay, amplitude, and phase shift. The separation of the composite signal into individual time aligned signals occurs when the composite signal is delayed by a different delay for each path. Therefore, a single complex signal input becomes a complex vector output, with a vector length equal to the number of fingers in the rake receiver. Two types of rake receivers have been considered: rake receiver with fade channel estimation and, ideal rake receiver. The following provides a brief description of the rake receiver design.
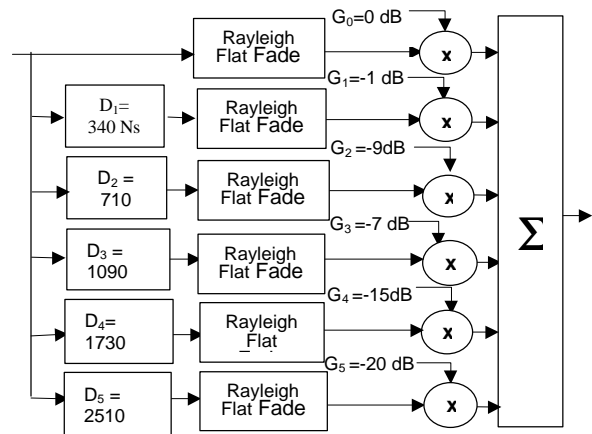

Figure 4: Frequency selective fading channel

The number of fingers in the rake receiver depends on the bandwidth of the received signal. The number of fingers denotes the number of resolvable paths that are received – in other words, N fingers implies that N reflections of the transmitted signal arriving at the receiver with different delays may be detected and combined. In our simulation model, a four or a six finger rake receiver can be selected depending on the transmitted chip rate. Since we are considering a higher chip rate of 3.6864Mcps, the six finger rake receiver is applied for our measurements.

The rake receiver in our model includes a timing feedback loop to adjust the delays applied to the composite received signal. In our receiver design,

assumptions have been made that the receiver knows the multipath delays and thus, the time alignment on the reflected paths is such that all the finger inputs are delay adjusted at the start of the second frame. In addition, we have also implemented an ideal rake receiver where the fading channel coefficients are made available at the receiver.

The pilot symbols are also used to estimate the time correction for each finger. Within each finger there are three paths; an early path, an on-time path, and a late path, which are taken from different samples in the down sampling of the signal to the chip rate. Each of path has the complex PN sequence removed and is de-spread using the pilot W_0 Walsh sequence. The de-spread symbols represent the pilot symbols with channel correction applied. The complex magnitude of symbols on each path are used to calculate a timing correction of once per frame. The timing correction feedback loop means that the rake receiver does not deviate too far from the correct timing for time aligned fingers, and for correctly de-spread data. In addition, within each rake finger, the recovered Pilot symbols are also used to estimate and compensate the amplitude and phase shifts introduced in the fading channel.

The data-chip outputs from each finger of the rake receiver are fed into the channel de-spreader block, which separates the data into individual channels using channel Walsh functions. The receiver model assumes that the short PN sequence starting position is known by the base station receiver, and so it is locally generated and delayed by one frame to match up with input data. The outputs of the individual fingers, after being combined (using a maximal ratio combining approach) are demodulated, and then forwarded to the decoder block.

The decoders for the channels are the reverse of the encoders shown in Figure 1, with the exception of the fundamental channel. The fundamental channel uses blind rate detection to determine the variable data rate. The fundamental decoder first removes the long code (using the inverse of long code). The data is then formed into frames and each frame is de-interleaved, and the output from the de-interleaver is fed into each individual channel decoding path. Each path consists of a de-puncture block that inserts zeros into the data stream where encoded data was punctured. Then, after the removal of any symbol repetition, the error-correcting process begins using a soft-decision Viterbi decoder. The CRC is then checked and removed together with any reserved bit.

Simulation Set up and Link Budget

Having discussed the operation for each block in Figure 1, the reverse link model has been implemented accordingly using SPW (Signal Processing Works-ystem) simulation tools[1]. Subsequently, to measure the performance of the reverse link, the next step is to allocate powers to each individual traffic channel. Bear in mind that CDMA systems rely heavily on strict power control to effectively manage the channel capacity of the system. Each mobile has its own power control to handle the path loss and aggregate interference. In cdma2000 reverse link, a link budget control has been specified by the standard to handle the power allocation on every transmitted channel [1]. These specifications, which are briefly discussed in the following, have been incorporated in our simulation model

The reverse link power budget is based on the equations specified in the cdma2000 Physical Layer [1]. In the equations, mean power is referenced to the nominal CDMA Channel bandwidth of 1.23 MHz for a spreading rate of 1 and 3.69 MHz for a spreading rate of 3. For simplicity, the Code Channel is used to represent either the R-FCH, the R-SCH1, the R-SCH2, or the R-DCCH.

The output power of each Code Channel is set by the mobile station relative to the output power of the R-PCH. Therefore, the first task is to determine the output power of the R-PCH, P_{pilot} using open loop power estimation. Then, the output power of every Code Channel, P_{code} can be calculated, based on P_{pilot} and the stored parameters in the mobile station. The calculated P_{code} is then applied to the Relative Gain block shown in Figure 3, so that every Code Channel can be adjusted to its desired output power for transmission. In our performance evaluation, the mean pilot output power is calculated assuming there are no closed loop power corrections.

For the measurements Eb/Nt which is defined as the ratio of the combined received energy per bit to the effective noise power spectral density at the receiver base station antenna connector has been used. The Eb/Nt on the Traffic Channel is calculated from the sum of all the individual Eb(i)/Nt(i) ratios for each of the code channels. For example, for R_FCH,

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$$\{Eb / NT\}_{R-FCH} = \sum_{i=0}^{N-1} [Eb(i)]_{R-FCH} / Nt(i)$$

where N is the number of reflected paths in the transmission channel. The calculations of Eb's and Nt's are given below:

$$\{EB(i)\}_{R-FCH} = \frac{(path\_loss) \cdot (pwr\_fch) \cdot (G_i)}{bit\_rate}$$

In the above equation, pwr_fch is the fundamental power calculated from the link budget and G_i is the relative power of the ith path. For instance, as shown in Figure 4, for the six-paths IMT-2000 vehicular Model A these powers are defined as: $G_0 = 0$ dB, $G_1 = -1$ dB, $G_2 = -9$ dB, $G_3 = -10$ dB, $G_4 = -15$, and $G_5 = -20$ dB.

Similarly, the total effective noise Nt (i) is obtained as,

$$Nt(i) = Io * (\sum_{j=0}^{N-1} G_j) + Nt \qquad i = 0,1,\dots N-1, \quad j \neq i$$

where I_0 is defined as the total power spectral density of a single user in the cell and is calculated from the following equation,

$$I_o = \frac{(total\_power) \cdot (path\_loss)}{chip\_rate}$$

Nt is the interference power in (W/Hz) and is obtained from the power spectral density (PSD) of the band limited white noise, I_{oc}. This is defined in the dBm as one of the user selectable parameters of the reverse link model. Thus, for a given I_{oc},

Nt is then applied to obtain the variance of the Additive white Gaussian noise (AWGN) by taking into consideration the channel over sampling rate.

Results

The simulation parameters and calculations of the signal-to-noise ration were described in the previous section. These parameters can be set by the user to perform tests under various transmission conditions.

$$Nt = \frac{10^{(Ioc- 30)/10}}{chip - rate}$$

The results presented in this paper are based on a single

user transmission and concentrate mainly on RC 5 of the cdma2000 reverse link. The carrier frequency was set to 1.9 GHz. For every set of experiments the mean output channel powers were calculated by the reverse link model in accordance with the link budget. In the link budget the user sets the Power Spectral Density (PSD) of the received signal. Then, according to the link budget equation, the model first calculates the average power of the pilot channel, P_{pilot}. Subsequently, the P_{pilot} is used to obtain the average powers for each of the code channels that has been selected for transmission (i.e., R-FCH, R-SCH1, R-SCH2, R-FCH, or R- DCCH).

In these experiments all the initial values and relative gain adjustments in the link budget were set to zero. In the first set of experiments, all five traffic channels were included in the traffic signal. The bit rate for the R-FCH was 9.6 kbps (fixed) and, for each supplemental channel, 19.2 kbps. The PSD of the received signal at the mobile station antenna connector was set to -76.5. The Eb/Nt values for each channel, which are based on calculated powers, were then estimated for a given PSD of the Gaussian noise (I_{oc}) for the average path-loss of 100 dB. Figure 5 shows the calculated Eb/Nt versus the PSD of Gaussian noise for R-FCH and R-SCH1 (please note that only the Eb/Nt for R-SCH1 is shown as both supplemental channels have the same Eb/Nt value).
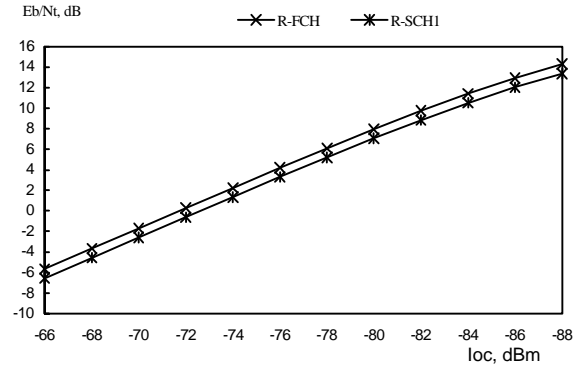

Figure 5: Calculated Eb/Nt versus I_{oc}

The results, in terms of bit error rate (BER) and frame error rate (FER) versus Eb/Nt, are presented in Figure 6. The vehicular speed was set at 100 km/hr using a six-path frequency selective fading channel (see Figure 4), and lognormal fading (path-loss = 100 dB).

Similar experiments were also carried out under the same test environments using a six finger ideal rake receiver. The results, in terms of FER and BER (frame error rate) for all three channels, are shown in Figures 7 and 8, respectively.

Looking at the results depicted in Figures 7 & 8, and compared with the results in Figure 6, we note that there is almost a 13dB difference in Eb/Nt between the ideal and non-ideal rake receivers. In our experiments we have observed that the BER/FER performance between the two receivers becomes much smaller at lower vehicular speeds. This may be due the fact that at lower speeds, the accuracy of the fade estimation of the non-ideal receiver is considerably enhanced; thus helping to resolve the fading paths more efficiently.
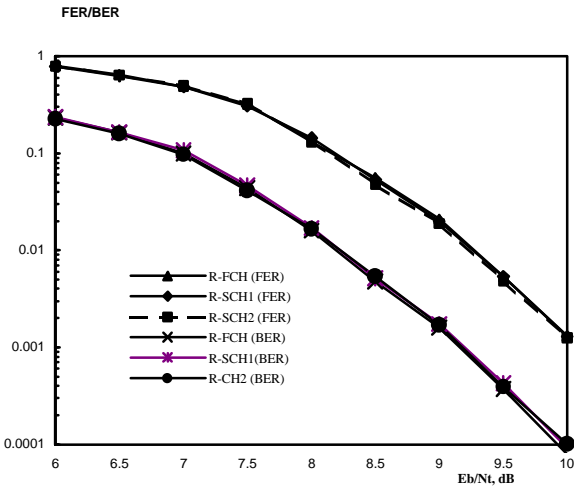
FER/BER

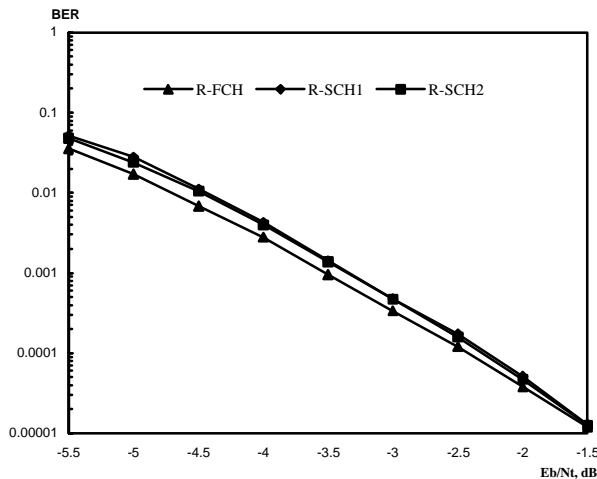Figure 6: FER/BER versus Eb/Nt for R-FCH, R-SCH1, and R-SCH2.

BER

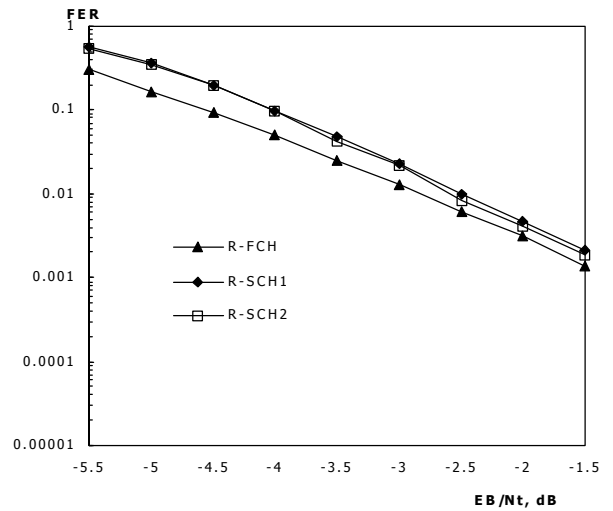Figure 7: BER versus Eb/Nt for R-FCH, R-SCH1, and R-SCH2 using ideal rake receivers

FER

Figure 8. FER versus Eb/Nt for R-FCH, R-SCH1, and R-SCH2 using ideal receivers

Conclusion

After a brief review of the cdma2000 reverse link, a simulation model design for testing and measurement was presented. In this model the powers for each code channel are allocated in accordance with the IS-2000 link budget specifications. The simulations were then carried out using two types of receivers; ideal and non-ideal. The performance of both receivers was compared within a limited number of tests for RC 5.

References

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2. TIA/EIA/IS-2000.3-A, "Medium Access Control (MAC) Standard for cdma2000 Standards for Spread Spectrum Systems", March 2000.
3. W. C. Jakes, Microwave Mobile Communications. John Wiley and Sons, INC, , New York (1974).