Performance Analysis of the WCDMA End-To-End Physical Layer

1B. O. Omijeh, 2M.I.Udoh
1Department of Electronic & Computer Engineering
2Centre for Information and Telecommunications Engineering University of Port Harcourt, Nigeria

ABSTRACT

In this paper, the performance analysis of a WCDMA End-to-End Physical Layer has been achieved. The goal for the next generation of mobile communications system is to seamlessly integrate a wide variety of communication services such as high speed data, video and multimedia traffic as well as voice signals. The technology needed to tackle the challenges to make these services available is popularly known as the Third Generation (3G) Cellular Systems. One of the most promising approaches to 3G is to combine a Wideband Code Division Multiple Access (WCDMA) air interface with the fixed network of Global System for Mobile communications (GSM). In this paper, a signal simulator was implemented according to the physical layer specification of the IMT-2000 WCDMA system. The data is transmitted in a frame by frame basis through a time varying channel. The transmitted signal is corrupted by Multiple access interference which is generated in a structured way rather than treating it as Additive White Gaussian Noise (AWGN). The signal is further corrupted by AWGN and Rayleigh fading at the front end of the receiver. Simple rake diversity combining is employed at the receiver. The bit error rate was investigated at the downlink for different channel conditions. Performance improvement due to error correction coding scheme was observed. The simulator developed can be an invaluable tool for investigating the design and implementation of WCDMA systems.

Keywords: 3GPP, WCDMA, RAKE DIVERSITY, AWGN, GSM

1. INTRODUCTION

Wideband Code Division Multiple Access (WCDMA) is a 3rd generation Mobile Communication System that uses Code Division Multiple Access (CDMA) technology over a wide frequency band to provide high-speed multimedia and efficient voice services. The WCDMA infrastructure is compatible with GSM mobile radio communication system. The objective of this work, is to present the wideband CDMA air interface scheme that is currently being developed by the standardization organizations in Europe, Japan, the United States, and Korea for third-generation communication systems. And also, to develop a simulated design model that allows the evaluation of different variables in the wireless communication system, such as the properties of the channel, which are affected by environmental factors in the design [1-2].

The motivation for what came to be known as WCDMA was both increased information rate, so as to ensure the capability of transmitting multimedia traffic, and enhanced robustness to multipath fading, an attribute which ultimately results in higher capacity [3-4].

The Physical Layer

The physical layer offers data transport services to higher layers. The access to these services is through the use of transport channels via the MAC sub-layer. The physical layer is expected to perform the following functions in order to provide the data transport service:

- Error detection on transport channels and indication to higher layers
- FEC encoding/decoding of transport channels
- Multiplexing of transport channels and demultiplexing of Coded Composite Transport Channels (CCTrCHs)
- Rate matching of coded transport channels to physical channels, Mapping of coded composite transport channels on physical channels, Power weighting and combining of physical channels,
- Modulation and spreading/demodulation and dispersing of physical channels
- Frequency and time (chip, bit, slot, frame) synchronization.
- Radio characteristics measurements including FER, SIR, Interference Power, etc., and indication to higher layers, - Inner - loop power control.
- RF processing,
- Synchronization shift control
- Beam forming
- Hybrid ARQ soft-combining for HS-DSCH and E-DCH. http://www.3gpp.org

The WCDMA system uses two types of radio channels; Frequency Division Duplex (FDD) and Time Division Duplex (TDD). The FDD radio channels are primarily used for Wide Area Voice (audio) channels and data services. The TDD channels are typically used for systems that do not have the availability of dual frequency bands. In this duplex method, uplink and downlink transmissions are carried over the same frequency band by using synchronized time intervals. Thus time slots in a physical channel are divided into transmission and reception part. [5-6]

There are two main types of Wideband CDMA schemes: network asynchronous and network synchronous. In network asynchronous schemes the base stations are not synchronized,
while in network synchronous schemes the base stations are synchronized to each other within a few Micro-second. [7-8]

**WCDMA Key Features [5]:**

The key operational features of the WCDMA radio interface are listed below.

- Support of high data rate transmission: 384 kbps with wide area coverage, 2 Mbps with local coverage.
- Built in support for future capacity and coverage enhancements like adaptive antennas, advanced receiver structures and transmitter diversity.

**Performance Enhancing Schemes**

A number of performance enhancing schemes has been proposed for the WCDMA systems. They include adaptive receiving antennas, transmit diversity schemes, and advanced receiver structures.

**Transmit Diversity Schemes:** Transmit diversity schemes at the downlink employ multiple transmit antennas at the base station. They provide performance enhancement similar to that with multiple antennas at the mobile station receivers. These schemes are attractive since they transfer the complexity, lower sampling rates, and lower performance requirements. However, 3G systems was introduced to support real-time voice applications at toll quality and support real-time multimedia and high data rate of internet and mobile data applications with qualities comparable to high-speed wire-line systems such as digital subscriber loop (DSL). Hence, the simulation of 3G systems is significantly more challenging than that of 2G. 3G systems are expected to be more power efficient and smaller in size [9].

Zeba Khan Rafi (2015) showed that the bit error rate performance of UWB systems is degraded as energy is spread out by multipath fading. In the case of DS-UWB systems, since the spreading factor is relatively small for high data rates as compared with that of traditional DSSS systems, they are highly exposed to inter pulse interference (IPI) and energy spread. There is therefore a need to compensate the multipath fading effects and the use of a RAKE receiver is the solution.

**Adaptive Antennas:** Adaptive antennas at the receiver can increase the capacity and coverage of the system. Connection dedicated pilot bits can be used in both the links for employing adaptive antennas.

**3. SYSTEM ANALYSIS AND DESIGN**
This section describes the simulator designed to evaluate the Bit Error Rate (BER) at the downlink of a Wideband CDMA (WCDMA) system. Data is transmitted in a frame by frame basis over a time varying multipath channel. Receiver design incorporates rake diversity combining. Additive White Gaussian Noise (AWGN) + Rayleigh fading is added at the front end of the rake receiver. Multiple Access Interference (MAI) is generated in a structured way rather than treating it as

3.1 Modeling of Data, Channel and Chip-Matched Filtering

\[
S_k(t) = \sqrt{2P_k} \sum_{i=0}^{L-1} b_{k,i} x c_k(t - i T) \quad (1)
\]

where, \(P_k\) = transmitted power of kth user; \(b_{k,i}\) \(\in\) \{+1, -1\} is the \(i^{th}\) transmitted bit in a stream of \(L\) bit
\[ C_k(t) = \sum_{n=0}^{N-1} C_{k,n} \pi (t - nT_c) \quad (2) \]

It should be noted that the transmitted signal \( S_k(t) \) corresponds to \( y_1 \) in the Matlab simulation programs. Equation (2) is a spreading waveform with \( C_{k,n} \in \{+1, -1\} \) and \( \pi (t) \) being a rectangular pulse of duration \( T_c = T/nT_c \) as there are \( N \) chips per bit. The received signal due to the superposition of the attenuated and delayed signals of the \( K \) users is given by:
\[ r(t) = \sum_{k=1}^{K} w_k x S_k(t - \zeta_k) + v(t) \]  

(3)

where \( W_k \) is the complex amplitude with which the \( k \)th signal is received and includes the effect of channel attenuation and the phase offset; \( \zeta_k \) is the relative delay with respect to a reference at the receiver. This received signal at the channel output \( r(t) \) corresponds to \( y_{\text{noisy}} \) in the Matlab simulation programs. The noise component \( v(t) \) is assumed to be Gaussian with zero-mean and double-sided spectral density of \( N_0/2 \). This received signal is fed into a chip matched filter whose output is as follows:

\[
(n+1)T_c \quad \text{r}(n) = \int r(t) \, dt \quad (4)
\]

A discrete observation vector \( \tilde{r}_i \) is formed at bit \( i \) by sampling the integrator output and collecting \( N \) successive chip-matched filter outputs given by:

\[
\tilde{r}_i = [f[i], f[i+1], \ldots, f[i+N-1]]^T \quad (5)
\]

Each observation vector \( \tilde{r} \) can be viewed as a linear combination of 2K signal vectors, corresponding to 2 from each of the \( K \) users due to the past and the current bits. So \( \tilde{r} \) can be written as:

\[
\tilde{r}_i = AWb_i + vi \quad (6)
\]

with \( vi = N(0, k) \), where \( A \) is the \( N \times 2K \) matrix signal vectors, which depends on spreading codes of each user; \( W \) is the \( 2K \times 2K \) diagonal matrix of complex amplitudes; \( b_i \) is the \( 2K \times 1 \) vector of \( K \) users’ previous and current data bits; and the \( N \times 1 \) vector \( K \), is the noise covariance. The matrices \( A, W \) and \( b_i \) are expanded below.

\[
A(\zeta) = [a_{1}^{\zeta}(\zeta) \; a_{2}^{\zeta}(\zeta), \ldots, a_{K}^{\zeta}(\zeta), a_{K+1}^{\zeta}(\zeta)] \quad (7)
\]

Let \( a_{k}^{\zeta}(\zeta) = (1 - y_k) c_{k}^{\zeta}[q_k] + y_k c_{k}^{\zeta}[q_k+1] \quad (8) \)

and \( a_{K+1}^{\zeta}(\zeta) = (1 - y_k) c_{k}^{\zeta}[q_k] + y_k c_{k}^{\zeta}[q_k+1] \quad (9) \)

The \( N \times 2K \) matrix \( A(\zeta) \) has a column corresponding to two adjacent bits of each user given that \( q_k \in \{0, 1, \ldots, N - 1\} \) and \( y_k \in \{0, 1\} \), where \( c_{k}^{\zeta}[q_k] \) and \( c_{k}^{X}[q_k] \) are the spreading codes shifted by integer in multiples of chips delays and \( \zeta \) is the relative delay with respect to a reference at the receiver.

\[
C_k^{\zeta}[q_k] = [c_k, N-1-k \ldots c_k, N-1] \quad (10)
\]

\[
C_k^{X}[q_k] = [0 \ldots 0 c_k, 0 \ldots c_k, q_k-1] \quad (11)
\]

Expanding \( A(\zeta) \) in equation (7) by substituting equations (8) and (9) yields:

\[
A(\zeta) = \{(1-y_1) c_{1}^{\zeta}[q_1]+y_1 c_{1}^{\zeta}[q_1+1]\} \\
(1-y_1) c_{1}^{X}[q_1]+y_1 c_{1}^{X}[q_1+1] \ldots \\
(1-y_K) c_{K}^{\zeta}[q_K]+y_K c_{K}^{\zeta}[q_K+1] \\
(1-y_K) c_{K}^{X}[q_K]+y_K c_{K}^{X}[q_K+1] \quad (12)
\]

where \( y_i = S_i^2 \) is the code-matched filter detector output vector. Equation (12) is an expression of \( N \times 2K \) matrix of relative time delays encountered by multiple signals in a channel with respect to the receiver during transmission and reception. When signals are transmitted, they undergo varied delays \( \zeta_k \) in the channel due to multipath fading effects. They arrive at the receiver input at different instants.

Similarly,

\[
W = \text{diag}[w_1, \ldots, w_k] = \begin{bmatrix} w_1 \; 0 \; \ldots \; 0 \\
0 \; w_1 \; \ldots \; 0 \\
0 \; 0 \; \ldots \; 0 \\
\vdots \; \vdots \; \ddots \; \vdots \\
0 \; 0 \; \ldots \; 0 \; w_k \\
0 \; 0 \; \ldots \; 0 \end{bmatrix} \quad (13)
\]

Therefore, \( b_i = [b_{i,1}, \; b_{i,2}, \ldots, b_{i,k}]^T \)

Where \( b_{i,k} \) is the \( k \)th bit of the \( k \)th user.

The chip matched filter block generates an output for every chip waveform, which is then vectored and fed into the channel estimation block. Maximum likelihood (ML) channel estimation uses a fixed preamble which is known at the receiver. The preamble bits are sent across the channel in the initial part of a transmission. The ML channel estimation block uses the resulting output from the channel in the form of the chip matched filter vector and the knowledge of the preamble bits is used to estimate the channel parameters (amplitude, and delay information). The multi-user detector uses the chip matched filter outputs and the matrix which conveys the delay and amplitude information to detect the bits of all the users.
3.2 Simulated Model using Simulink

Simulink, developed by Math Works, is a graphical programming environment for modeling, simulating and analyzing multidomain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.

Fig. 2 below is the simulated WCDMA model with AWGN channel of the End-to-End Physical layer. It further computes the delay between the transmitted and received signals in the model. Fig. 3 is the simulated WCDMA MODEL with AWGN+MULTIPATH FADING channel, further more it analyzes the effect of delay on the model by introducing the unit delay block before modulation, after modulation, before demodulation and after demodulation.

![Simulink Model Diagram](image-url)

Fig. 2: The WCDMA-AWGN Channel Model For The Downlink Physical Layer.
Functions of Subsystems

a. WCDMA DL Tx Channel Coding Scheme: The WCDMA DL Tx Channel Coding Scheme subsystem processes each transport channel independently according to the transport format parameters associated with it. The different transport channels are then combined to generate a coded combined transport channel (CCTrCH). The CCTrCH is then sent to the WCDMA Tx Physical Mapping subsystem.

b. WCDMA Tx Physical Mapping: This subsystem implements the following functions:
   - Physical channel segmentation
   - Second interleaver
   - Slot builder

The output of this subsystem constitutes a dedicated physical channel (DPCH), which is passed to the WCDMA BS Tx Antenna Spreading and Modulation subsystem.

c. WCDMA BS Tx Antenna Spreading and Modulation: The WCDMA BS Tx Antenna Spreading and Modulation subsystem performs the following functions:
   - Modulation
   - Spreading by a real-valued orthogonal variable spreading factor (OVSF) code
   - Scrambling by a complex-valued Gold code sequence
   - Power weighting & Pulse shaping

d. WCDMA Channel Model: The WCDMA Channel Model subsystem simulates a wireless link channel containing additive white Gaussian noise (AWGN) and, if selected, a set of multipath propagation conditions.

e. WCDMA UE Rx Antenna: The received signal at the WCDMA UE Rx Antenna subsystem is the sum of attenuated and delayed versions of the transmitted signals due to the so-called multipath propagation introduced by the channel. At the receiver side, a Rake receiver is implemented to resolve and compensate for such effect. A Rake receiver consists of several rake fingers, each associated with a different received component. Each rake finger is made of chip correlators to perform the despreading, channel estimation to gauge the channel, and a derotator that, using the knowledge provided by the channel estimator, corrects the phase of the data symbol. The subsystem coherently combines the output of the different rake fingers to recover the energy across the different delays.

f. WCDMA Rx Physical Channel Demapping and Channel Decoding Scheme: The WCDMA Rx Physical Channel Demapping and the WCDMA DL Rx Channel Decoding Scheme subsystem decode the signal by performing the inverse of the functions of the WCDMA DL Tx Channel Coding Scheme subsystem.
4. RESULTS AND DISCUSSION

This section contains the results obtained after series of test carried out, experimentation and simulations.

Findings and Discussion

- The Subsystem coherently combines the output of the different rake fingers to recover the energy across the different delays.
- WCDMA systems use Interference suppression at the receiver and multiple antennas at the transmitter.
- Orthogonality among channels is preserved better at the downlink.
- When a signal is received over a multipath fading channel, the amplitude distribution of the spread spectrum becomes more and more specular as the spread bandwidth increases. This is irrespective of the fading statistics of the received waveform.
- The effect of any residual measurement inaccuracy is less in a wideband system than it is in a narrow band system, that is for a given power control error, the decrease in capacity experienced by a narrowband CDMA is greater than that seen by a WCDMA system.
- Pilot bits assists coherent demodulation and channel estimation
- With WCDMA, a user's information bits are spread over an artificially broadened bandwidth. The job is done by multiplying them with a pseudorandom bit stream running several times as fast. It increases the bit-rate of the signal (and the amount of bandwidth it occupies) by a ratio known as the spreading factor, namely, the ratio of the chip rate to the original information rate. The scheme can also resolve different propagation paths, turning multipath distortion from a destructive nuisance into a helpful ally.
- At the receiver output, the amplitude of the de-spread signal is increased by the spreading factor relative to interfering signals. In the process, those interfering signals are diminished and simply add to the background noise level. In other words, correlation detection uses the spreading factor to raise the desired user signal from the interference. The effect is called processing gain.

Table 1 BLER, BER, AND SAMPLE Rate Computation Associated With Each Transport Channel

<table>
<thead>
<tr>
<th>SAMPLE RATE</th>
<th>SIMULATION TIME</th>
<th>BLER CALCULATION</th>
<th>ERROR RATE CALCULATION</th>
<th>ERROR RATE CALCULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BLER CALCULATION</td>
<td>BLOCKS</td>
<td>BLER</td>
</tr>
<tr>
<td>0.001</td>
<td>0.1</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.2</td>
<td>0</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.3</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.4</td>
<td>0</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.5</td>
<td>0</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.6</td>
<td>0</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.7</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.8</td>
<td>0</td>
<td>58</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.9</td>
<td>0</td>
<td>65</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>1</td>
<td>0</td>
<td>73</td>
<td>0</td>
</tr>
</tbody>
</table>

From Table 1, it is observed that, increasing the Simulation time at progressive intervals and constant sample rate has no effect on the bit error rate results, hence the WCDMA system can be said to be less prone to errorr
Table 2: Effects of Unit Delay in the WCDMA End-To-End Downlink Physical Layer

<table>
<thead>
<tr>
<th>SAMPLE RATE</th>
<th>SIMULATION TIME</th>
<th>EFFECT OF DELAY BEFORE MODULATION</th>
<th>EFFECT OF DELAY AFTER MODULATION</th>
<th>EFFECT OF DELAY BEFORE DEMODULATION</th>
<th>EFFECT OF DELAY AFTER DEMODULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>0.1</td>
<td>0</td>
<td>0.2458-1.046i</td>
<td>-1.589+1.257i</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.2</td>
<td>0</td>
<td>0.09683-0.07827i</td>
<td>-3.034+0.9746i</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.3</td>
<td>1</td>
<td>-0.4157+0.6866i</td>
<td>-2.554+1.232i</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.4</td>
<td>0</td>
<td>-0.5775-1.489i</td>
<td>-2.718-2.944i</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.5</td>
<td>1</td>
<td>1.914+0.01616i</td>
<td>6.211+2.297i</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.6</td>
<td>0</td>
<td>0.05651-0.8623i</td>
<td>-0.1342+3.655i</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.7</td>
<td>0</td>
<td>-0.1341</td>
<td>-0.414</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.8</td>
<td>1</td>
<td>0.706</td>
<td>3.49</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>0.9</td>
<td>0</td>
<td>0.334</td>
<td>0.414</td>
<td>0</td>
</tr>
<tr>
<td>0.001</td>
<td>1</td>
<td>0</td>
<td>0.7356</td>
<td>-3.12</td>
<td>0</td>
</tr>
</tbody>
</table>

From Table 2, the following deduced:

Introducing the unit delay block before and after modulation has an impact on the system as can be seen from the values obtained.

Introducing the unit delay block before demodulation also has an impact on the system, however after demodulation the effect of delay on the system is subdued.

![Fig.4: Effect of Delay before Modulation](image1)

![Fig.5: Effect of Delay after Modulation](image2)

![Fig.6: Effect of Delay before Demodulation](image3)

![Fig.7: Received DPCH Signal](image4)
Fig 4-6 show the effect of delays before and after modulation and demodulations respectively. Fig.7 shows that there were more distortion and delay interval due to multipath fading.

Fig.8: Rake Combined DPCH

Fig.9: Derotated DPCH Signal

Fig.10: Before Spreading Spectrum

Fig.11: Before Pulse Shaping Spectrum

Fig.8 shows less distortion and delay interval due to rake receiver. Fig 9 Receiver compensates for the attenuation caused by the channel by correcting the phase of the data symbol.

Fig.10: Before Spreading Spectrum: Output characterized by a Rayleigh probability distribution
Fig. 12: Power Spectrum/Tx Signal by the WCDMA BS Tx Antenna

Fig. 13: Power Spectrum/Rx Signal by the WCDMA UE Rx Antenna

Fig. 14: Real part: Data is spread by a real-value orthogonal signal code for channel separation

Fig. 15: Imaginary Part: Data is scrambled by a complex-valued Gold code sequence
5. Conclusion

The simulation of Wireless Communication System allows the evaluation of different variables in the system, such as the properties of the channel, which are affected by environmental factors in the design. One of the most challenging parts of the design of wireless Cellular communication systems is the design of the baseband physical layer. The baseband physical layer algorithms are designed to establish and maintain a reliable radio link between base stations and user terminals. These baseband algorithms are designed to overcome propagation effects, interference effects, and degradation effects resulting from nonlinearities and noise in the hardware implementation.

The development of the WCDMA wireless communication system physical layer link, which was carried out successfully, can be used as a simulation Model for the design and development of WCDMA wireless cellular communication system. Comparing the performances of narrowband CDMA and WCDMA methods of simulations, it was shown that the later was more efficient than the former. This shows that WCDMA is much better for the design and implementation of 3G wireless communication systems than the narrowband CDMA.

REFERENCES


