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PERFORMANCE ANALYSIS OF TD-SCDMA IN 3G

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ABSTRACT

The growing number of consumers utilizing the Internet, companies have foreseen a consumer demand for high-speed wireless access. Since current mobile cellular systems can transfer at most 115.2 kbps per user, a third generation of mobile cellular service has been under development by various organizations since 1997. This new generation of technology will support data rates up to 2 Mbps for stationary mobiles and up to 144 kbps for vehicular traffic.

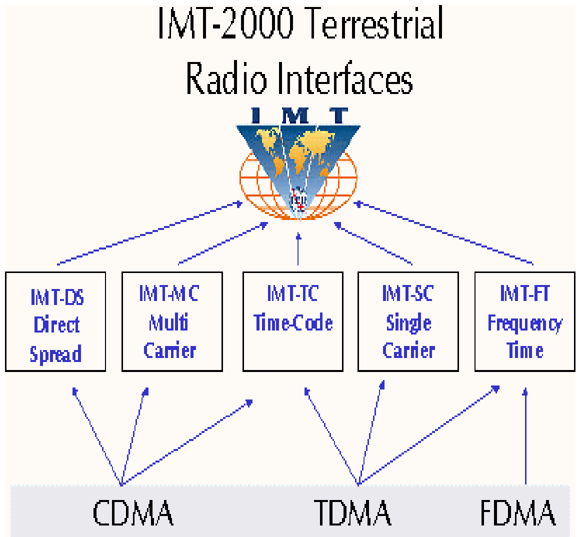
This project focuses mainly on TD-SCDMA. The standard that employs both code-division multiple access (CDMA) and time-division duplexing (TDD) to support both forward and reverse transmissions on one physical layer. This aspect, along with other common features of TD-SCDMA, will be studied and evaluated to determine if this new technology is a viable option for future commercial or military deployment.

INTRODUCTION

Cellular communications, since its commercial introduction in the United States in 1983, has undergone many changes to keep pace with advancing technology. Initially, AT&T developed the U.S. Advanced Mobile Phone System (AMPS) utilizing frequency modulation (FM) and frequency-division multiple access (FDMA) for multiple user access. Much thought and field testing had been put into releasing this standard since AT&T and Bell Laboratories had been researching and developing cellular technology as far back at 1958 [1]. Essentially, all future developments have relied heavily upon these results. With the rate of changing technology today, few companies can afford the amount of field-testing and research that was conducted by this company. A second generation of cellular communications, introduced in 1991, is the U.S. Digital Cellular (USDC), commonly called IS-54 (Interim Standard - 54). Instead of using FM and FDMA, IS-54 utilizes 4-DQPSK digital modulation and time-division multiple access (TDMA) for multiple user access. This was quite a departure from the AMPS standard, which uses analog signalling. For the same frequency spectrum and channel bandwidth, IS-54 has three times the user capacity of AMPS [2]. Soon after the inception of IS-54, a new standard was developed using similar digital technology. IS-95, commonly called CDMA (code-division multiple access), was introduced in 1993 and heralded in a new age for cellular communications. Whereas previous systems required cellular cluster planning and channel reuse schemes, CDMA required very little of this. CDMA uses Walsh functions, which are orthogonal to each other, and pseudorandom sequences to spread the spectrum of the transmitted signal because these sequences are orthogonal to each other, multiple users can use the same frequency band. A receiver can extract the desired signal if it has the proper code, and the orthogonality of the other sequences cause the interference to be almost zero.

TD-SCDMA is a joint venture between the Chinese Academy of Telecommunications Technology (CATT) and Siemens Information and Communication Mobile Group (Siemens IC Mobile). The concept for TD-SCDMA was originally submitted to the International Telecommunications Union (ITU) as a separate candidate submission for IMT-2000, but since then has also been incorporated into the Universal Terrestrial Radio Access - Time Division Duplex (UTRA TDD) proposal. The Chinese Ministry of Information Industry and Chinese Wireless Telecommunication Standard group (CWTS) were also instrumental in submitting this new technology for international review, but most of the technical information was originated by the previous two sources.

As stated in their objectives, the IMT-2000 project was instituted to promote support for harmonizing international frequency spectrums and developing compatible mobile telecommunications systems. This goal has not yet been fully realized, but the international community has narrowed development of 3G technologies into five distinct groups. Figure 1.1 illustrates the five main proposals and how they are distinct from one another.



The 3rd Generation Partnership Project (3GPP) currently holds the most recent specifications for 3G standards based on the GSM core network. All technical information contained within this thesis was obtained from this source.3GPP was formed in 1998 and maintains all technical specifications for UTRA FDD, UTRA TDD (including TD-SCDMA), WCDMA, GPRS, EDGE, and GSM. A second project, 3GPP2, was instituted at the same time and deals exclusively with CDMA2000 and ANSI/TIA/EIA-41.

SYSTEM OVERVIEW

As the name implies, TD-SCDMA utilizes time-division duplexing (TDD) along with synchronous CDMA to multiplex and spread a baseband signal. The TDD aspect allows one user several time slots for either uplink or downlink transmission, and the CDMA aspect allows multiple users to share the same physical channel and, hence, time slot. As a comparison with non-TDD systems, IS-95 users need access to two physical channels (two different frequency bands) to obtain both uplink and downlink transmission, occupying a total bandwidth of 2.5 MHz For TD-SCDMA, each physical channel can provide both uplink and downlink capabilities, occupying only 1.6MHz/carrier. (Note: for the remainder of this thesis all references to the physical channel imply the actual 1.6MHz frequency spectrum bandwidth occupied by the transmitted information) With the auction of radio frequency spectrums generating bids in the millions of dollars, a 43% saving in user bandwidth is significant.

Another key feature of TD-SCDMA is the ability to support information data rates of 12.2, 64, 144, 384, and 2048 kbps. Except in the case of 2048 kbps, individual users can achieve higher data rates by being assigned multiple CDMA codes. Alternatively, in the case of 2048 kbps no CDMA spreading is used and this is only a downlink capability and cannot be used for uplink. As previously mentioned, the current 2.5G cellular communications technology only supports data rates up to 115.2 kbps by using the same technique, but because IS-95B requires two physical channels this costs almost twice the bandwidth of one TD-SCDMA two-way channel. This also significantly reduces the number of users/cell available in IS-95B

SPREADING & MODULATION

Spreading of TD-SCDMA is similar to other CDMA systems in that TD-SCDMA utilizes orthogonal codes to allow multiple users on the same physical channel. For this standard, a variable sequence of up to sixteen orthogonal Walsh codes and a set of cell- specific scrambling codes are applied to a data sequence to spread the information data’s spectrum. Because the orthogonality of Walsh codes is destroyed in a multipath environment [7], this requires

TD-SCDMA to maintain both uplink and downlink phase and timing synchronization. Being time aligned is very important for CDMA, and without synchronization TD-SCDMA will not work.

TD-SCDMA also employs forward error correction (FEC) coding and the modulation techniques of QPSK and 8PSK to support data rates up to 2048 kbps. The most recent standard publication mentions an additional modulation technique of 16QAM, but this aspect is not fully discussed in the documentation. Table 2.1 illustrates the MPSK complex symbol representations currently used for modulation.

Table 2.1. Complex symbol representation for QPSK and 8PSK modulation.

QPSK	
Consecutive binary bit pattern	Complex symbol $\underline{d}_n^{(k,i)}$
00	+j
01	+1
10	-1
11	-j

8PSK	
Consecutive binary bit pattern	Complex symbol $\underline{d}_n^{(k,i)}$
000	cos(11π/8)+ jsin(11 π /8)
001	cos(9 π /8)+ jsin(9 π /8)
010	cos(5 π /8)+ jsin(5 π /8)
011	cos(7 π /8)+ jsin(7 π /8)
100	cos(13 π /8)+ jsin(13 π /8)
101	cos(15 π /8)+ jsin(15 π /8)
110	cos(3 π /8)+ jsin(3 π /8)
111	cos(π /8)+ jsin(π /8)

Orthogonal Variable Spreading Factors

To allow multiple users on the same physical channel without causing multi-user interference, each data waveform is spread by an orthogonal channelization code. This channelization code is generated from a set of Orthogonal Variable Spreading Factor (OVSF) codes and keeps the correlation of multiple signals on the same physical channel low. Without orthogonal coding, multiple signals on the same physical channel would interfere with each other and significantly increase the probability of bit error By employing an orthogonal coding scheme and maintaining the same transmitted power for all users, multiple signals can be on the same physical channel and not interfere with each other. Figure 2.1 illustrates the code-tree for OVSF

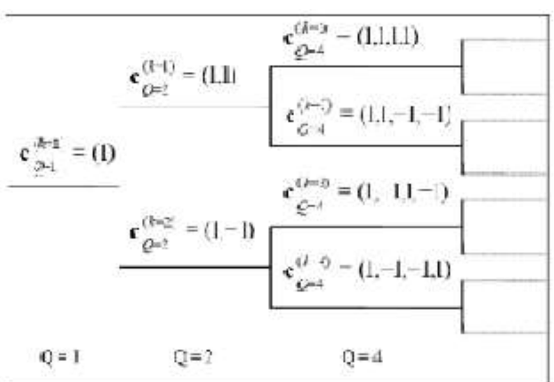


Figure 2.1. Channelization code tree for Orthogonal Variable Spreading Factor (OVSF) generation. After Ref. [8].

Spreading Factor(Q)	Number of symbols per burst transmission
1	3
2	1
4	8
8	4
16	2

Table 2.2. Number of symbols per burst transmission.

Cell-Specific Scrambling Codes

After channelization coding, each complex code is multiplied by a code- specific multiplier $w^{(k)}$

Where $$w_{Q_k}^{(k)} = e^{\frac{j\Pi p_k}{2}}, p_k = \{0,\ldots,Q_{k-1}\} \quad (2.1)$$

$$v = \{v_1, v_2, \ldots\ldots, v_{16}\} \ v_t = j^t v_t \quad v_t \in \{1 -1\}, i = 1, \ldots..16 \quad (2.2)$$

$$s_p^{(k)} = c^{(k)}_{1+[(p-1)\bmod Q_k]} . v_{1+[(p-1)\bmod Q_{\max}]}, k = 1 \ldots k_{code}, p = 1, \ldots., N_k Q_k \quad (2.3)$$

Where,

N_k is the number of *data* bits per time slot and

K_{Code} is the total number of users on the channel

Baseband Spread Signal:

Applying all the individual components from the previous sections, we find that the encoded data is spread according to the following formula:

$$d^{(k,i)} = \sum_{n=1}^{N_k} d_n^{(k,i)} w_{Q_k}^{(k)} \sum_{q=1}^{Q_k} s_{(n-1)Q_k+q}$$

$$Cr_0(t-(q-1)T_c-(n-1)Q_kT_c-(i-1)(N_kQ_kT_c+L_mT_c)) \quad (2.4)$$

Where,

$d^{(k,i)}$ is the transmitted complex-valued chip sequence, $d^{(k,i)}$ is the encoded User information data using FEC coding and Cr_0 is the impulse response for a root-raised cosine (RRC) filter. The index *i* is used to signify that the data sequence in one timeslot is divided into sections, and the reason for this will be explained in Section B. The purpose of the root-raised cosine filter will be discussed in more detail in the next section.

Pass band Modulation:

To transmit the baseband chip sequence described in the previous section, TD- SCDMA uses an IQ modulator as shown in Figure2.4.This modulator splits the complex chip sequence into its real and imaginary parts and pulse shapes the complex data impulses using identical root-raised cosine filters.

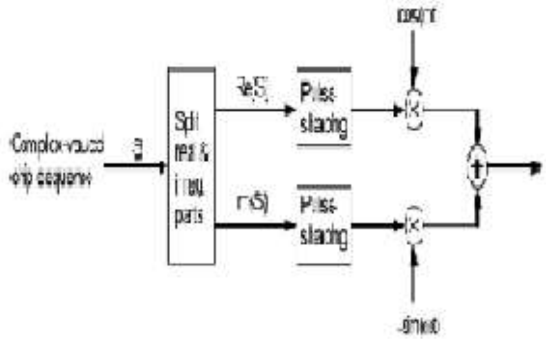


Figure 2.4. Modulation of baseband complex-valued chip sequence using raised root cosine filters for pulse shaping and an IQ modulator for heterodyning. From Ref. [8].

The root-raised cosine filters are implemented to reduce inter-symbol interference (ISI) in the channel by following Nyquist's pulse-shaping criterion [9]. Since TD- SCDMA is restricted in bandwidth to 1.6 MHz, any signal energy that spills over into adjacent frequency bands will cause interference. The principle behind raised cosine filtering is that the frequency response of the filter is essentially flat over the desired frequency band, has a sharp transition at the cut-off frequency, and is essentially zero in the stop band. Figure 2.5 illustrates the frequency response of a raised cosine filter, and the transfer function is given by,

$$H_{RC}(f)=\begin{cases} 1 & 0\leq|f|\leq\frac{(1-\alpha)}{2T_c} \\ \frac{1}{2}\left[1+\cos\left[\frac{\pi(|f|2T_c-1+\alpha)}{2\alpha}\right]\right] & \frac{(1-\alpha)}{2T_c}\leq|f|\leq\frac{(1+\alpha)}{2T_c} \\ 0 & |f|>\frac{(1+\alpha)}{2T_c} \end{cases} \qquad (2.5)$$

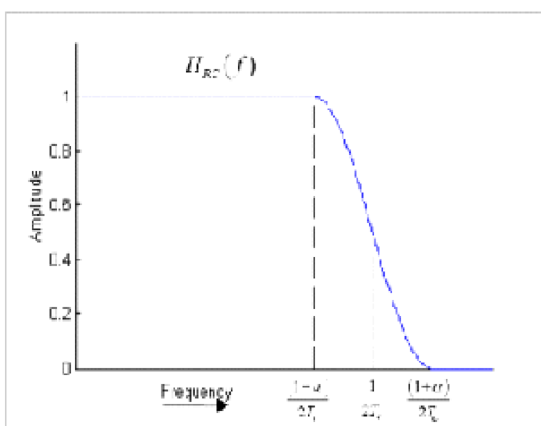


Figure 2.5. Frequency response of raised cosine filter. The value of T_c is the chip time and α is the roll-off factor.

By choosing an appropriate roll-off factor α, we can limit the amount of spill over. Since TD-SCDMA uses a chip rate of 1.28 Mcps, by applying a roll off factor of α=0.22 we can limit the baseband spectrum to ±0.7808 Mcps and a total pass band bandwidth of 1.5616 Mcps. This is the reason why TD-SCDMA matches the 1.28 Mcps chip rate with a bandwidth of 1.6 MHz

By placing matched RRC filters at the receiver and transmitter, we effectively create a raised cosine (RC) filter at the receiver. The only drawback of implementing raised cosine filters is that since the frequency response of the filter is almost a rectangular pulse for small α, the time response is similar to a sinc function $\left(\frac{\sin x}{x}\right)$.

This is taken from the fact that the inverse Fourier transform of a unit-step function in the frequency domain is a sinc function in the time domain. The problem lies in the fact that a sinc function is not physically realizable since the waveform is a non-casual function (the response at any point in time is dependent on both past and future inputs) and exists for all time (-∞, ∞). The standard procedure is to terminate the impulse three units before and after t=0 and delay the output three time units to make the function causal. Figure 2.6 illustrates the impulse response for the filter described above (before delaying the signal three time units), and the impulse response is given by

$$Cr_0 = \frac{\sin\left(\pi\frac{t}{T_c}(1-\alpha)\right)+4\alpha\frac{t}{T_c}\cos\left(\pi\frac{t}{T_c}(1+\alpha)\right)}{\pi\frac{t}{T_c}\left(1-\left(4\alpha\frac{t}{T_c}\right)^2\right)}, \quad \alpha=0.22. \qquad (2.6)$$

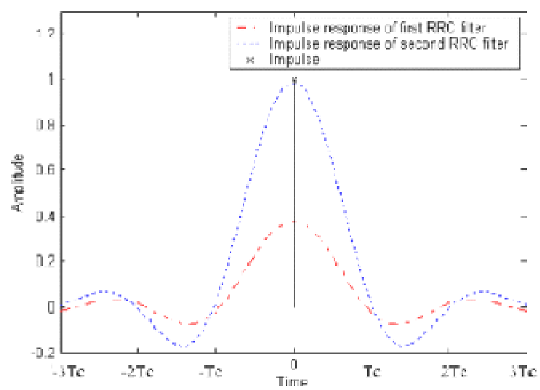


Figure 2.6. The impulse of response of a root-raised cosine filter (dot-dashed line) after being hit by an impulse (solid line). We can achieve the impulse response of a raised cosine filter (dotted line) if we pass the first waveform through a second RRC filter. In this case α=0.22.

By inspecting Figure 2.6, we see that passing the first RRC waveform through a matched RRC filter produces the output of a single RC filter. This is instrumental in reproducing the original input data stream at the receiver. The key to RC filtering is that the nulls of the waveform occur every T_C seconds. If two impulses occurring T_C seconds apart were passed through a raised cosine filter, the result would be as shown in Figure2.7. The actual output of the RC filter is taken by summing the individual impulse responses from the two inputs. Since the nulls of the two separate waveforms occur every T_C seconds, this means that the two signals will have no interference at the chip time T_C. By sampling the waveform every T_C seconds, the original impulse train can bereconstructed. This is how the raised cosine filter prevents ISI.

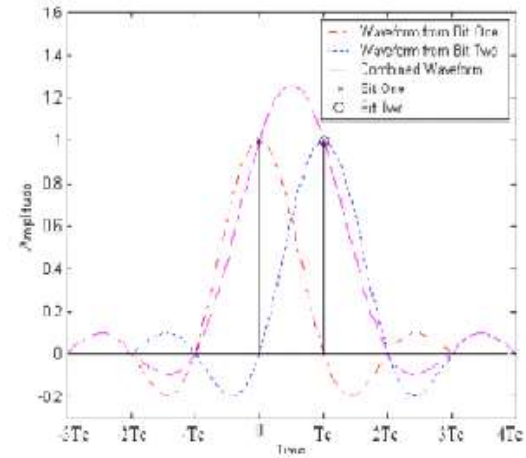


Figure 2.7. The output of a raised cosine filter after two incoming data bits. The impulse response after the first bit (dot-dashed line) and the second bit (dotted line) are combined to create the actual output waveform (dashed line).

TIME FRAME STRUCTURE

In the dedicated physical channel (DPCH/DCH), which contains the user information data, duplexing of the pass band signal is accomplished using TDD. The main unit for TD-SCDMA using TDD is a 10ms radio frame, which is divided into two 5ms sub-frames. These sub-frames are further subdivided into seven time slots, of which at least two are reserved for uplink and downlink transmissions and the other five can be either. Figure 2.8 illustrates an example of the most basic unit of TD-SCDMA

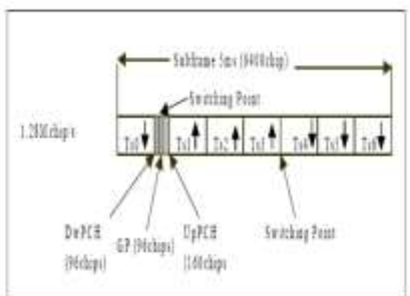


Figure 2.8. This is an example sub-frame for TDD (low chip rate option) with four downlink and three uplink time slots. From Ref. [10].

In this structure, the first time slot (Ts0) is dedicated for downlink and Ts1 is dedicated for uplink. In addition to the user data, two pilot channels and a small guard period are inserted at the switching point between the dedicated downlink and uplink time slots. The remaining five time slots (Ts2-Ts6) can be used for either uplink or downlink transmissions based on user demand.

In each sub-frame, the downlink pilot channel (DWPCH) and uplink pilot channel (UPPCH) are used to maintain synchronization and power control between the user and base station. By calculating the actual time difference between the transmitted downlink synchronization burst and the received uplink synchronization burst, the base station can estimate the propagation delay between itself and the user. This measurement can then be used to calculate the number of synchronization shift (SS) symbols that, when transmitted on the next available downlink time slot, will help maintain uplink synchronization. If re-synchronization is needed, on the next available downlink time slot the base station instructs the user to shift the data transmission by 1/8 chips or any multiple thereof. Since the orthogonality of the signal relies upon signal synchronization, without the DWPCH and UPPCH there would most certainly be interference between users on the same channel. Figure 2.9 illustrates the location of the SS symbol along with the transmitter power control (TPC) symbol. The user uses the TPC to instruct the base station to increase or decrease the transmitter power level as needed to reduce multi-user interference.

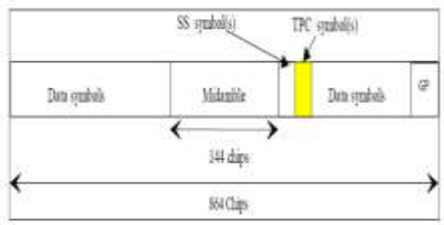


Figure 2.9. The location of the synchronization shift (SS) and transmitter power control (TPC) symbols within one time slot. From Ref. [11].

Each time slot, whether downlink or uplink, is 675µs long. A standard time slot is illustrated in Figure 2.10. In all cases, portions of the encoded and spread information data is contained within two 352 chip time blocks, separated by a 144 chip midamble, and followed by a 16 chip guard period. The purpose of the midamble block is to provide training sequences, which allow the base station to estimate the channel impulse response of all active users in a cell [11] and the user to identify an assigned channel. Each user within a given cell has a time-shifted version of the same midamble code, and each cell is assigned a different midamble code. By correlating the received cyclic sequence with a known reference, the radio frequency (RF) channel impulse response can be estimated. The base station receiver can then use this information to accommodate for fading channels.

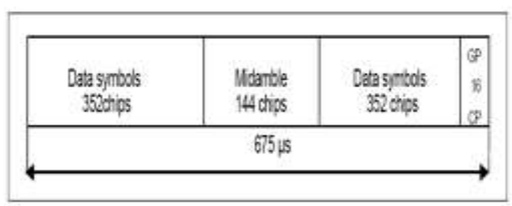


Figure 2.10. Burst structure for normal traffic time slot. From Ref. [10].

To separate multiple users on the same channel, TS-SCDMA employs CDMA using OVSF as described in the previously. This allows up to sixteen users per physical channel, which can be varied depending on the requested user data rates. Figure 2.11 illustrates one sub-frame and how up to 16 users (codes) can be transmitted on the same frequency band (1.6 MHz bandwidth).

In TD-SCDMA, each user can be assigned one or more OVSF codes depending on the requested user data rate and the number of users on each physical channel. We define each OVSF code of SF=16 on a given time slot as a resource unit (shown in Figure2.11 as the shaded block), and each user can have access to multiple RUs. In this manner, if a user was assigned two OVSF codes instead of one they would still have access to seven time slots, but instead of seven they now have fourteen available RU’s. By using packet data, this allows a user to transmit more symbols in a given unit of time to achieve higher information data rates.Table2.2 lists the uplink and downlink reference measurement channel data rates and spreading factors used in TD-SCDMA.

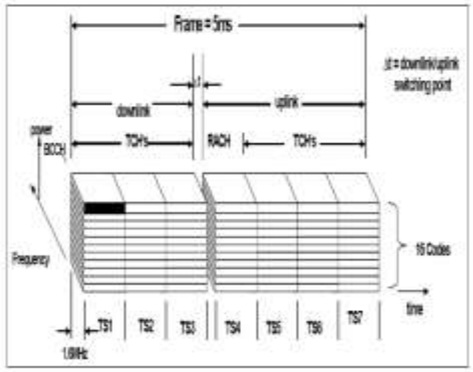


Figure 2.11. TDMA/TDD subframe for symmetric CDMA multi-user transmission of TD-SCDMA. The shaded block is one resource unit (RU). From Ref. [12].

Table 2.3. Sub-frame resource allocation for various user data rates.

Information Data Rate		12.2 kbps	64 kbps	144 kbps	384 kbps	2048 kbps
Downlink	Spreading Factor	SF=16	SF=16	SF=16	SF=16	SF=1
	OVSF Codes required	2	8	8	10	1
	Time Slots required	1	1	2	4	5
	Resource Units Allocated	2	8	16	40	80
Uplink	Spreading Factor	SF=8	SF=2	SF=2	1 SF=2 1 SF=8	X4
	OVSF Codes required	1	1	1	1	X4
	Time Slots required	1	1	2	4	X4
	Resource Units Allocated	2	8	16	40	X4

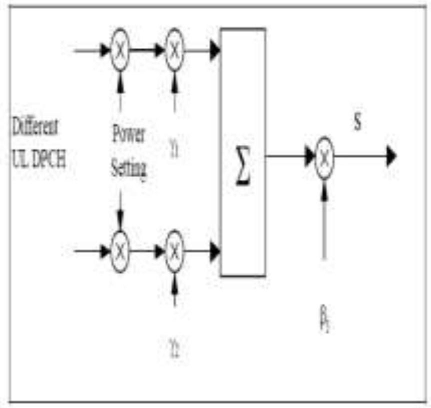


Figure 2.12. Combination of different physical channels in uplink. After Ref. [8].

To allow multiple users on the same physical channel, or allow one user the ability to transmit multiple OVSF codes on the same timeslot, the TD-SCDMA transmitter utilizes a multiplexer as shown in Figure 2.12. In this figure, the values γ are weight factors which vary according to the spreading factor used, and β represents the overall transmit power gain. Because the signals are orthogonal to one another there should be little to no interference between them at the receiver.

TRANSMISSION AND RECEPTION

As stated before, one of the main advantages of TD-SCDMA is that the transmit and receive frequencies are the same. TD-SCDMA utilizes TDD to duplex both downlink and uplink transmission on the same 1.6 MHz bandwidth carrier.

Physical Channels

TD-SCDMA employs two types of physical channels, dedicated physical channels (DPCH) and common physical channels (CPCH). Sections A and B of this chapter dealt mainly with the structure of the DPCH, whereas this section with deal more exclusively with the CPCH. The frame structure of the two channels is identical. The only difference between the two is that the DPCH carries user data information, whereas the CPCH carries control data information.

The CPCH is comprised of several transport channels, which includes but is not limited to, the broadcast channel (BCH), forward access channel (FACH), paging channel (PCH), random access channel (RACH), uplink shared channel (USCH), downlink shared channel (DSCH), and the high speed downlink shared channel (HS-DSCH). Many of these channels are formatted with FEC coding and use the same spreading technique as the DPCH. Because TD-SCDMA does not dedicate a separate 1.6 MHz frequency band for the CPCH, the control data is intermixed with the DPCH during specific time slots and OVSF codes. For example, the dedicated BCH is mapped onto the Primary Common Control Physical Channel (P-CCPCH) and is always transmitted on Ts0, the first dedicated downlink time slot using channelization codes $C_{Q=16}^{(k=1)}$ *and* $C_{Q=16}^{k=2}$ **.**The BCH contains the location of all other common transport channels, which can be intermixed throughout the radio frame on other RU's. Figure 2.13 illustrates the location of the P-CCPCH.

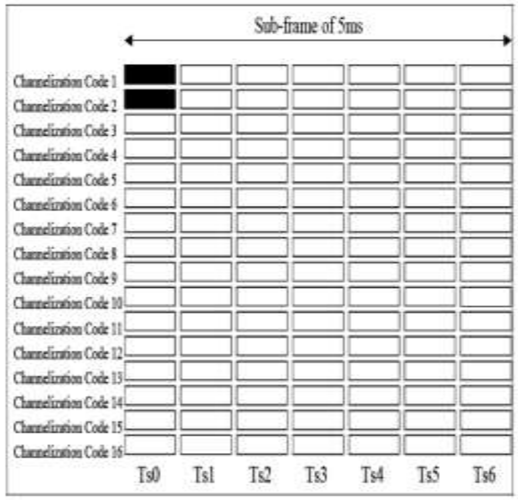


Figure 2.13. Location of the Primary Common Control Physical Channels (P-CCPCH 1 and 2) on the actual physical channel. The P-CCPCH (shaded regions) are always on Ts0 using channelization codes $c_{Q=16}^{(k=1)}$ and $c_{Q=16}^{(k=2)}$.

Receiver Characteristics

Of all the technical specifications illustrated and explained in the standard, there is no reference as to how the TD-SCDMA receiver is physically designed. There are of course detailed descriptions as to the minimum reception requirements, but there are no instructions on how to implement them.

As shown previously in Figure 2.4, the transmitter consists of an IQ modulator and two root-raised cosine pulse-shaping filters. To design an appropriate receiver, the transmitter was reverse engineered and implemented in reverse order. To begin, since the transmitter utilizes an IQ modulator, an identical IQ demodulator was placed at the receiver. This type of demodulation creates a baseband reproduction of the original signal and another at twice the carrier frequency (ω_C). To remove the high-frequency component, matching finite impulse response (FIR) low pass filters are required. By looking at the frequency response of the raised cosine filter in Figure 2.5, we see that this is a low pass filter with exactly the desired bandwidth and cut-off frequency. Using root- raised cosine filters matched to the ones in the transmitter; we can accomplish both low pass filtering and satisfy the Nyquist's criterion for reducing ISI.

The next step is to sample the time domain output of the FIR filters at the chip rate and pass the resulting digital waveform through a CDMA receiver. If the synchronized received signal has the same scrambling and OVSF code as the one used being used by the receiver, the original QPSK or 8PSK complex data sequence will be extracted. If the received signal is out of synchronization or is scrambled and spread using different codes, the receiver will not recreate the original data.

To fully reproduce the original information data as sent by the base station or user, the receiver must demodulate the complex data sequence and un-encode the resulting digital data. Depending on the number of users on a physical channel and the requested data rates, this process could involve interleaving, puncturing, and turbo or convolution decoding. Figure 2.14 illustrates the complete theoretical receiver as designed by the author.

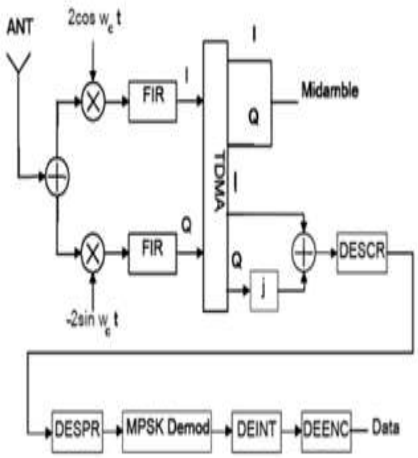


Figure 2.14. Possible TD-SCDMA receiver for DPCH. After the I/Q summation, the signal is descrambled (DESCR), despread (DESPR), demodulated, de-interleaved (DEINT), and de-encoded (DEENC). After Ref. [13].

PERFORMANCE ANALYSIS OF TD-SCDMA

TD-SCDMA Signals in the Presence of AWGN:

To evaluate the performance of TD-SCDMA under adverse conditions we will begin with the most basic of noise channels, the additive white Gaussian noise (AWGN) channel. AWGN is defined as a zero-mean Gaussian random process whose power spectral density (PSD) is flat or *white* over all frequencies. The source of AWGN is thermal noise, which “is caused by the thermal motion of electrons in all dissipative components” [9].Since the systems that are adversely affected by AWGN rely upon electrical conduction to operate; there are few ways to minimize the effect of AWGN.

To begin the evaluation, we will need a mathematical equation to represent the received signal at the input to the receiver. Assuming perfect synchronization and using (2.4) with Figure 2.4, we can interpolate that the total received signal $s(t)$ is

$$s(t)=\sqrt{2}A_c\left[R_e\left\{d^{(k,i)}(t)\right\}\cos(w_c t)-\operatorname{Im}\left\{d^{(k,i)}(t)\right\}\sin(w_c t)\right]+n(t) \qquad (3.1)$$

Where

$d^{(k,i)}$ Is the spreading and scrambling data

C (t) is the complex spreading and scrambling code and

$Cr_0(t)$ is the root-raised cosine filter impulse response

If we assume a receiver design as shown in Figure 2.14, we see that the signal is passed through an IQ demodulator, low-pass filtered with matching root-raised cosine filters, and recombined into a complex expression. We will also assume the filter removes components at twice the carrier frequency, and therefore before de-spreading we have a

$$r(n)=r_I(n)+j.r_Q(n) \qquad (3.3)$$

where,

$$r_I(n)=\sqrt{2}A_c\operatorname{Re}\left[d_n^{(k,i)}c(t)\right]+\left\{\left[2n(t)\cos(w_c t)\right]\otimes Cr(t)\right\}\big|_{t=nT_c} \qquad (3.4)$$

and

$$r_Q(n)=\sqrt{2}A_c\operatorname{Im}\left[d_n^{(k,i)}c(t)\right]-\left\{\left[2n(t)\sin(w_c t)\right]\otimes Cr(t)\right\}\big|_{t=nT_c} \qquad (3.5)$$

In both equations, T_C is the chip period and the symbol $\otimes$ represents a convolution of the noise with the root-

raised cosine filter impulse response. A point of interest is that we are no longer strictly in the continuous time domain. This is a result of the RRC filter, which
samples and holds the output every T_c seconds in order to reduce ISI.

The next section of the receiver takes the sampled signal and reverses the spreading and scrambling procedures that were done in the transmitter. Because TD- SCDMA uses a complex scrambling sequence, the receiver uses a complex conjugate of the spreading and scrambling codes to return the information data. If the receiver had used an exact replica of the transmitter's spreading and scrambling codes, some de-scrambled chips would undergo a 180° phase shift. For example, if the information data symbol was $1-j$ and the scrambling code was j we would transmit $j\bullet(1-j)=(1+j)$.At the receiver, we used the same scrambling code j we would recover $j\bullet(1+j)=-1+j$.Which is the inverse of what we sent. By taking the complex conjugate of the transmitter code, we would recover $-j\bullet(1+j)=(1-j)$,which is an exact replica of the original signal

Using the above, we find that the received signal at the output of the de-scrambling and de-spreading stage is

$$x(t)=\sqrt{2}A_c c^*(t_c)\left\{d_n^{(k,i)}c(t)\right\}+$$
$$c^*(t_c)\left\{\left[2n(t)\cos(w_c t)-j2n(t)\sin(w_c t)\right]\otimes Cr(t)\right\}|_{nT_c} \qquad (3.6)$$
Where

$c^*(t)$ is the complex conjugate of the original spreading and scrambling sequence.
We can further simplify the first term by using (3.2) to reduce it to $\sqrt{2}A_c d_n^{(k,i)}$ since

$$n'(nT_c)=c^*(nT_c)\left\{\left[2n(t)\cos(w_c t)-j2n(t)\sin(w_c t)\right]\otimes Cr(t)\right\}|_{nT_c} \quad (3.8)$$
$$S_{n_{I,Q}}(f)=N_0\,|Cr(f)|^2 \qquad (3.9)$$

$$S_n(f)=\begin{cases} N_0 & 0\le|f|\le\frac{(1-\alpha)}{2T_c}\\ \frac{N_0}{4}\left[1+\cos\left[\frac{\pi(|f|\cdot 2T_c-1+\alpha)}{2\alpha}\right]\right]^2 & \frac{(1-\alpha)}{2T_c}\le|f|\le\frac{(1+\alpha)}{2T_c}\\ 0 & |f|\le\frac{(1+\alpha)}{2T_c}\end{cases} \qquad (3.10)$$

$$X_s(f)=P(f)\sum_{n=-\infty}^{\infty}X(f-nf_s) \qquad (3.11)$$
$$S_{C^*}=T_C\sin c^2(fT_c) \qquad (3.12)$$

$$R_c(\tau)=\begin{cases}1-\frac{|\tau|}{T_c} & |\tau|\le T_c\\ 0 & otherwise\end{cases} \qquad (3.14)$$

$$S_{n'}(f)=T_c\sin c^2(fT_c)\otimes 2T_c\sin c^2(fT_c)N_0R_c \qquad (3.13)$$
and thus the multiplication of the two is

$$R_n(\tau)=\begin{cases}2N_0R_c\left(1-\frac{|\tau|}{T_c}\right)^2 & |\tau|\le T_c\\ 0 & otherwise\end{cases} \qquad (3.15)$$

Taking the Fourier transform to convert back into the power spectral density domain, we

$$S_n = 2N_0 R_c \left\{ \frac{T_c}{2}\operatorname{sinc}^2\left(f\frac{T_c}{2}\right) - \left(\frac{1}{T_c}\right)^2 \left(\frac{1}{2\pi}\right)^2 \frac{\partial^2}{\partial f^2}\left[T_c \operatorname{sinc}(fT_c)\right] \right\}. \qquad (3.16)$$

The final stage of receiver before converting the QPSK or 8PSK symbols back into binary ones and zeros is either an integrator or summer. The integrator or summer combines consecutive chips over one bit interval to reconstruct the information data. In this analysis we will choose an integrator and use the theorem that $S_{out}(f) = S_{in}(f)\left|H(f)\right|^2$, where $H(f) = \operatorname{sinc}(fT_b)$ is the transfer function of the integrator. This means that the noise PSD at the output of the receiver is

$$S_{n_{out}} = 2N_0 R_c \left\{ \frac{T_c}{2}\operatorname{sinc}^2\left(\frac{fT_c}{2}\right) - \left(\frac{1}{T_c}\right)^2 \left(\frac{1}{2\Pi}\right)^2 \frac{\partial^2}{\partial f^2}\left[T_c \operatorname{sinc}(fT_c)\right] \right\} \left\{\operatorname{sinc}^2(fT_b)\right\} \quad (3.17)$$

Since we are really only interested in the noise power at the output of the receiver we need to compute

$$\sigma^2 = \int_{-\infty}^{\infty} S_{n_{out}}(f)\,df \qquad (3.18)$$

Now that we know the noise power of our signal we will compute the phase of our complex valued signal and use a threshold detector to determine the corresponding MPSK symbol. If the computed phase lies between two threshold lines, estimation is made as to what the original MPSK symbol was. In the simulations we take the difference between this estimate and the actual transmitted symbol to determine the actual probability of symbol error. From [15] we conclude that the probability of a symbol error for $M \geq 8$ can be approximated by

$$P_M \approx 2Q\left(\sqrt{2\log_2(M)\frac{E_b}{N_0}\sin\left(\frac{\Pi}{M}\right)}\right) \qquad (3.19)$$

Because this equation is not good approximation for M=2 or M=4, for QPSK we will use the exact expression

$$P_4 = 2Q\left(\sqrt{\frac{2E_b}{N_0}}\right)\left[1 - \frac{1}{2}Q\left(\sqrt{\frac{2E_b}{N_0}}\right)\right] \qquad (3.20)$$

Where E_b / N_0 are the signal to noise ratio at the input to the receiver.

In the computer simulation, we will leave the signals at baseband to analyze a TD-SCDMA signal being transmitted and received. This procedure is identical to analyzing the system at pass band as long as we take into account the effect that heterodyning and filtering has on the signal and noise terms. When we run the simulation for the probability of symbol error for this receiver in the presence of AWGN, we obtain results as shown in Figure 3.1

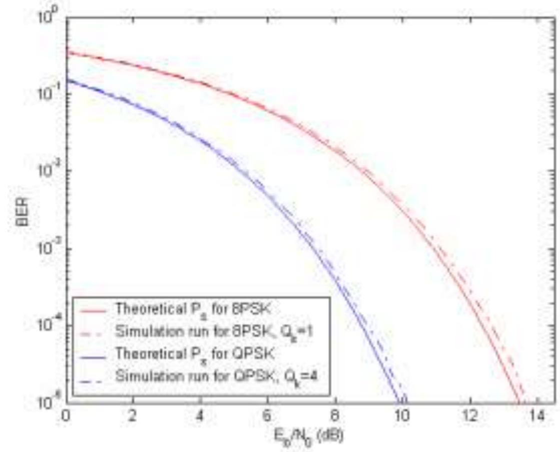


Figure 3.1: Probability of symbol error versus E_b/N_0 for TD-SCDMA using QPSK and 8PSK in AWGN.

But the performance of our system in the presence of fading is even more so. In the previous section we discussed errors introduced by thermal noise in the electronic components themselves. In this section we will discuss the effects of transmitting and receiving a signal over a fading channel.

A Rayleigh fading channel occurs when we consider that there are no stationary objects between the transmitter and receiver. This is an unlikely scenario, but the analysis is much simpler than assuming multiple non-moving objects. If we assume all our variables as being in motion we can model our environment as a zero-mean, complex valued Gaussian process whose envelope is Rayleigh distributed [15]. This means that the amplitude of our received signal at any given point in time has a Rayleigh probability distribution defined as,

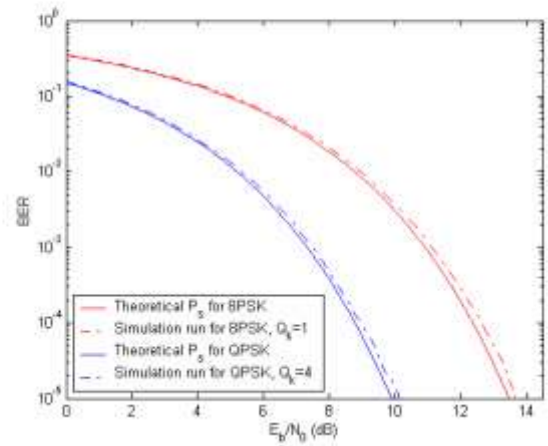


Figure 3.2An analysis of the performance of TD-SCDMA in the presence of AWGN is important, In AWGN with Rayleigh Fading

$f_R(r) = \frac{r}{\sigma^2} e^{-r^2/2\sigma^2} \qquad r \geq 0 \ \sigma \succ 0$ (3.21) The mean of this distribution is $\overline{R} = \sigma\sqrt{\frac{\Pi}{2}}$ and the variance is $\sigma_R'^2 = \left(1 - \frac{\Pi}{4}\right) 2\sigma^2$ .We can also define the average power of the signal

$r^{\bar{2}} = \sigma_R^2 - \left(\overline{R}\right)^2 = 2\sigma^2\left(1 - \frac{\Pi}{4}\right) - \sigma^2\frac{\Pi}{4} = 2\sigma^2$ (3.22) The performance of MPSK over frequency-no selective, slow fading Rayleigh channels is well is documented in [15]. To begin our analysis, we will use the basic equation for the probability of symbol error with Rayleigh fading

$$P_s = \int_0^{\infty} P_s(\gamma_s) f_{\Gamma_s}(\gamma_s) \delta\gamma_s \qquad (3.23)$$

Using (3.19) in (3.23) we can evaluate this equation to obtain

$$P_s = \int_0^{\infty} 2Q\left(\sqrt{2\gamma_s}\, \sin c \frac{\Pi}{M}\right) \frac{1}{\overline{\gamma}_s} \exp\left(\frac{-\gamma_s}{\overline{\gamma}_s}\right) \delta\gamma_s \quad = 1 - \sqrt{\frac{\overline{\gamma_s \sin^2\left(\frac{\Pi}{M}\right)}}{1+\overline{\gamma}_s \sin^2\left(\frac{\Pi}{M}\right)}} \qquad (3.24)$$

When we add Rayleigh fading to our computer simulation for AWGN we obtain results shown in Figure 3.2. As was the case with only AWGN, the author was not able to accurately set $\bar{E}_b/N_0$ due to the nature of the RRC filter. This explains why the plots for the Rayleigh fading do not exactly match the theoretical solution. Otherwise, the performance of TD-SCDMA in Rayleigh fading is the same as a generic direct sequence spread spectrum signal.

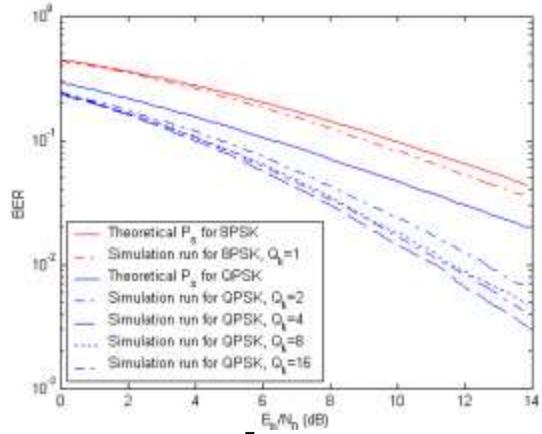


Figure 3.2. Probability of symbol error versus $\bar{E}_b/N_0$ for TD-SCDMA using QPSK and 8PSK in the presence of frequency-no selective, slow Rayleigh fading

If we look at the performance of the system without the root-raised cosine filtering we can better match up $\bar{E}_b/N_0$. This yields results that are closer to the theoretical values, and in all aspects we can be consider them to be closer to the actual values than Figure 3.2. The simulation results without the root-raised cosine filter are illustrated in Figure 3.3

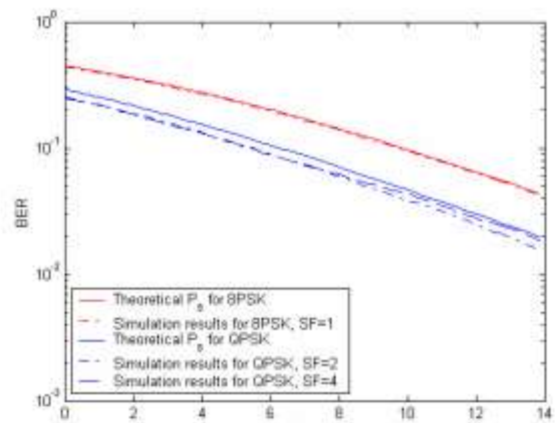


Figure 3.3. Probability of symbol error versus $\bar{E}_b/N_0$ for TD-SCDMA without root-raised cosine filtering using QPSK and 8PSK in the presence of frequency-non selective, slow Rayleigh fading.

CONCLUSION

Currently, TD-SCDMA has been incorporated into the 3G cellular standard of UMTS/UTRA as the TDD low chip rate option. This 3G standard, which includes WCDMA, is based on the GSM core network that is prevalent throughout much of the world. TD-SCDMA had previously been submitted as a separate candidate, but since the goal of IMT-2000 was to harmonize the world with a global cellular standard, several candidates, including TD-SCDMA, were incorporated into others. Nevertheless, there is no stipulation that TD-SCDMA cannot be employed as a separate system since the ITU has no legal authority to enforce their ideals of global standardization. For example, China, where TD-SCDMA was originally developed, is a prime candidate for supporting and utilizing their home-grown technology. Even so, it is more than likely that service providers of 2G and 2.5G cellular service will chose an upgrade path to 3G which allows backward compatibility with their current systems.

The main advantage of using TD-SCDMA is that the system employs TDD to have both the uplink and downlink capabilities on the same frequency band. This is a departure from WCDMA and CDMA2000, which employ FDD and a paired spectrum for forward and reverse links. Using an unpaired spectrum allows TD-SCDMA to be more versatile than those systems that do not employ this technology. As a comparison, three TD-SCDMA physical channels can fit within one WCDMA paired spectrum or two CDMA2000 paired spectrums. Although this can be advantageous at times, TD-SCDMA generally has a lower user/cell ratio than the other two given the same bandwidth.

The second main feature of TD-SCDMA is that this technology utilizes code division multiple access, as the name implies. This means that in addition to using one physical channel for both uplink and downlink transmissions, multiple users can share the same physical channel with only minimal interference between their signals. Therefore, like IS-95, TD-SCDMA is an interference-limited system where the more users on a given physical channel the greater the multi-user interference.

When analyzed, the performance of TD-SCDMA under adverse conditions is very similar to other CDMA systems. A slight difference lies in the fact that TD-SCDMA employs matching root-raised cosine filters at both the transmitter and receiver to reduce ISI. The exact details of how this filter performed were not well documented and the author had to derive them from start to finish, which was made more difficult due to the fact that TD-SCDMA employs complex valued spreading codes. Interestingly, having this type of filter at the receiver, even though the filter is low-pass in nature, has minimal effect on AWGN aside from a scaling factor. This phenomenon was computed analytically and verified via simulation. Implementation of this property made further analysis much easier and allowed the author to use existing analytical equations to verify the simulations.

Because AWGN is not an interesting or challenging adverse condition, Rayleigh fading was also considered and additional simulation results were produced. Again, the results were similar to existing theoretical equations since TD-SCDMA is akin to most direct sequence spread spectrum systems. Although the plots obtained when employing the RRC seem to show a relationship between the spreading factor used and the BER, this could not be shown analytically. Rerunning the simulation without the RRC produced the expected results and implies that the author has an error in establishing the proper average signal-to-noise ratio.

The next step was to examine attempts to disrupt the simulated TD-SCDMA transmission. Two types of interfering methods were employed, tone jamming and barrage-jamming. Because the performance of TD-SCDMA is similar to other CDMA systems, the results of jamming the transmission were very close. Only the tone- jamming scenario produced significantly different results, but this was due to the fact that TD-SCDMA employs very small spreading factors and the only theoretical equations that exist are for large spreading factors. We found that for small spreading factors the tone- jamming signal has an affect similar to a standard non-CDMA QPSK signal with tone jamming. By adding a constant related to the spreading factor, the author was able to match an analytical equation to the numerical simulations. This could not be verified for all spreading factors, but enough compared relatively well that these theoretical equations have some merit. The last stage was to theorize how an individual or organization could intercept and exploit a TD-SCDMA transmission. Because all 3G standards are published and well documented, the radio protocol processes can be adapted to allow for covert interception of TD-SCDMA transmissions. The key to the process is synchronization, and without this fundamental aspect no interception can take place. Once this synchronization is achieved, with both the base station and the intended target, then more detailed procedures can be developed to intercept and interpret the signals.

All things considered, despite TD-SCDMA's advantage by using TDD and having a smaller bandwidth, the author does not foresee this technology gaining a large share of the 3G market unless China goes with their home-grown system. WCDMA and CDMA2000, the two main competitors, already have a solid core network and marketing base in various parts of the world. This means that TD-SCDMA, which uses principles employed by both WCDMA and CDMA2000, will have a hard time attracting customers. This can be seen in the fact that TD-SCDMA was incorporated in UTRA as a low chip rate *option* whereas WCDMA is more prominent in that standard. Without a key feature that will improve the performance of a system above and beyond WCDMA or CDMA2000, the author doubts any other system will gain much popularity.

RESULTS

GENERATION OF TD_SCDMA SIGNALS

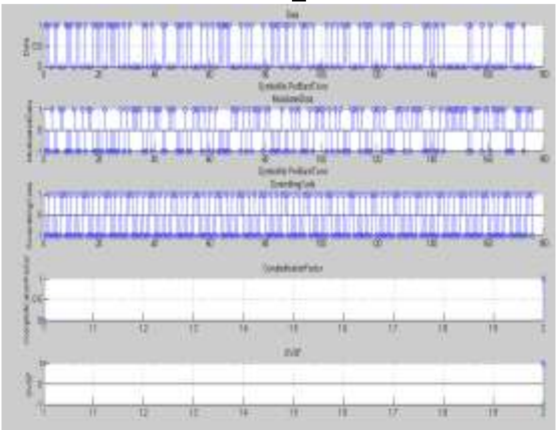


Figure 1

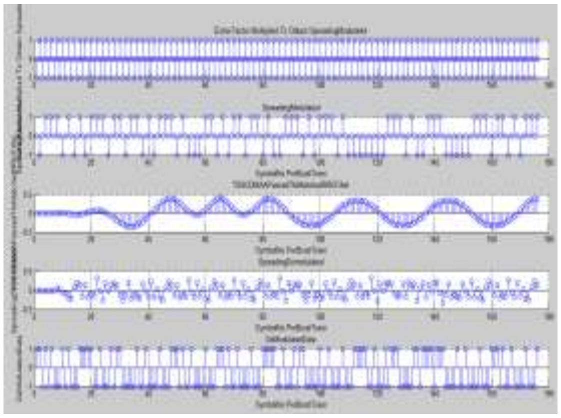


Figure 2

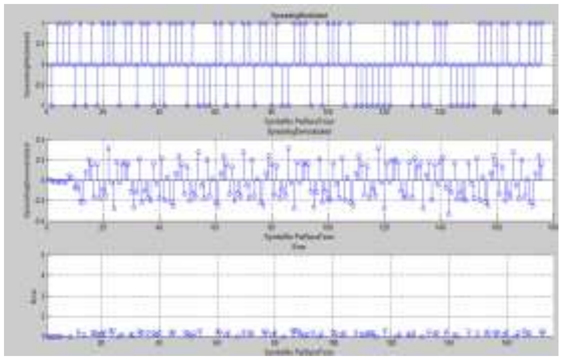
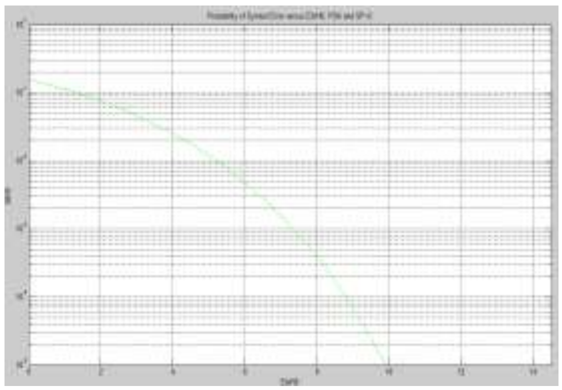


Figure 3



Final Main output

PERFORMANCE ANALYSIS OF TD_SCDMA IN AWGN CHANNEL

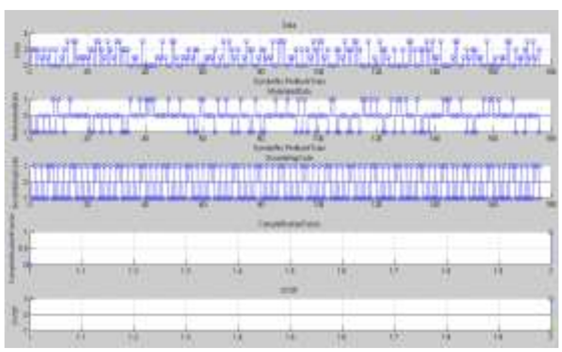


Figure 1

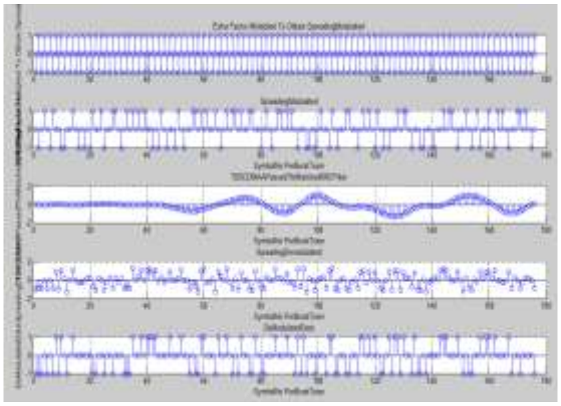


Figure 2

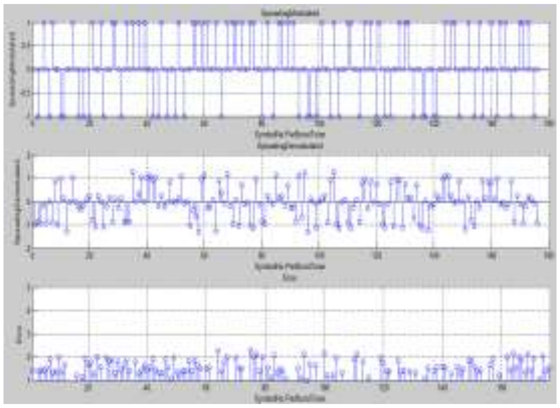
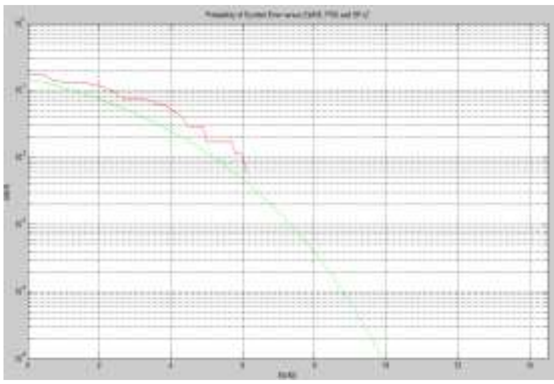


Figure 3



Final Output

PERFORMANCE ANALYSIS OF TD_SCDMA IN RAYLEIGH CHANNEL

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Impact Factor: 2.745 (SIJF)

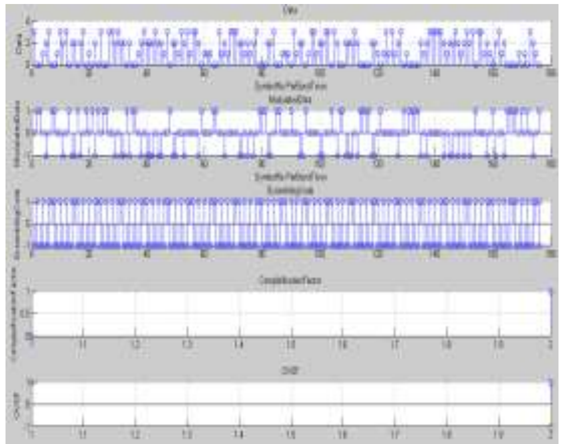


Figure 1

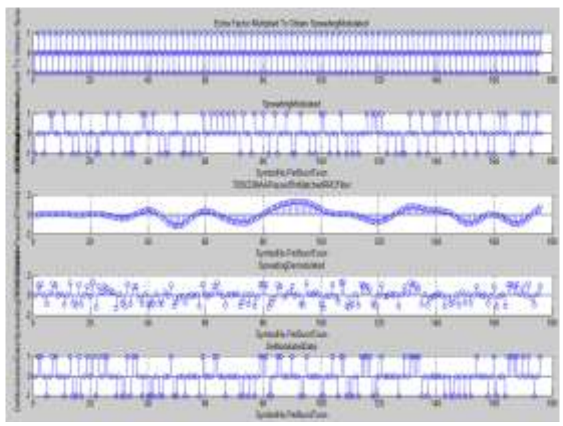


Figure 2

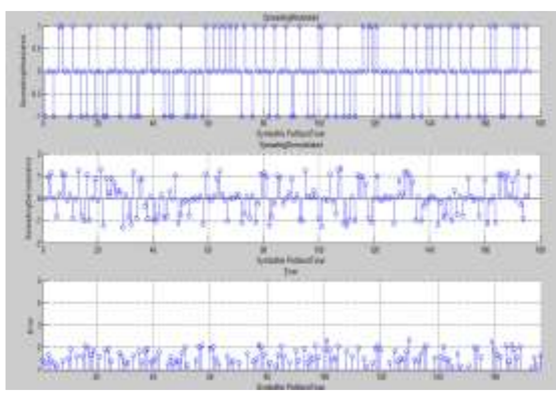
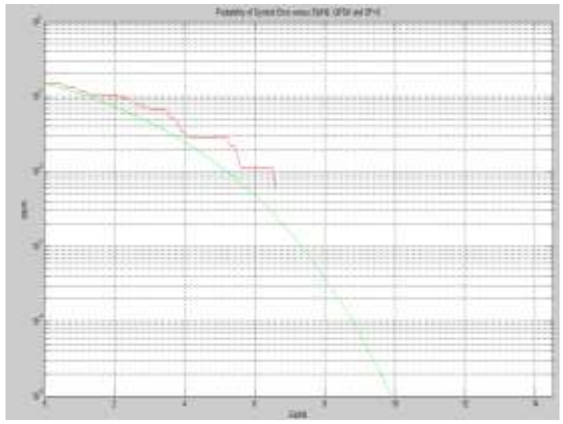


Figure 3



Final Output

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