

Diversity Combining for DS CDMA System in a Rayleigh Fading Channel with Three Spreading Codes

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Abstract

Fading problem is a major impairment of the wireless communication channel. In this paper we considers different diversity techniques to mitigate the fading problem in wireless channel for DS CDMA (Direct sequence Code Division Multiple Access) system.

Diversity is an effective method for increasing the received signal-to-noise ratio of a wireless communication system in a flat Rayleigh fading channel. Diversity branches can be established through frequency, time, antenna, or any combination of these diversity mechanisms.

The branch outputs can be processed using schemes such as selection combining, equal gain combining, or maximal ratio combining. The diversity combining technique used in this paper improved the performance of the DS CDMA system. For this system, three spreading code sequences are used to spread the spectrum of the signal namely, an M-sequence, a Gold sequence, and an Orthogonal Gold sequence. The BER performance in a two path flat Rayleigh fading environment for DS CDMA system with diversity combining is evaluated using MATLAB 7 computer simulation software.

الخلاصة

مشكلة الخفوت (Fading) من المشاكل الرئيسية التي تؤدي إلى إضعاف الإشارة في قنوات الاتصال اللاسلكي (Wireless Communication). في هذا البحث تمت دراسة مختلف تقنيات التنويع (Diversity) التي تقلل من مشكلة الخفوت في قنوات الإرسال اللاسلكي لنظام DS CDMA (Direct Sequence Code Division Multiple Access).

التنويع (Diversity) هي طريقة مؤثرة لزيادة نسبة الإشارة إلى الضوضاء في القنوات المتعددة في قنوات الاتصال اللاسلكي لقناة خفوت (Rayleigh). التنويع (Diversity) ممكن تكوينها في (Frequency, Time, Antenna) أو أي اتحاد بين هذه التقنيات.

مخارج التنويع (Diversity) من الممكن معالجتها باستخدام أنظمة مثل (diversity combining) وهي (Selection, Equal Gain, or Maximal Ratio Combining). لقد تم تحسين الأداء لنظام (DS CDMA) باستخدام تقنية (Diversity Combining).

في هذا النظام تم استخدام ثلاث أنواع من أنواع الشفرات لغرض عمل انتشار للطيف (Spread Spectrum) وهي (M-Sequence, a Gold Sequence, and an Orthogonal Gold Sequence). لقد تم

حساب نسبة احتمالية خطأ البت (BER) لنظام (DS CDMA) باستخدام تقنية (Diversity Combining) عندما تمر الإشارة بمسارين للخفوت. لقد تمت عملية المحاكاة باستخدام الحاسبة عن طريق (MATLAB7 Computer Software).

1. Fading in Communication Channels

Fading is the term used to describe the rapid fluctuations in the amplitude of the received radio signal over a short period of time. Fading is a common phenomenon in Mobile Communication Channels, where it is caused due to the interference between two or more versions of the transmitted signals which arrive at the receiver at slightly different times. The resultant received signal can vary widely in amplitude and phase, depending on various factors such as the intensity, relative propagation time of the waves, bandwidth of the transmitted signal etc... [1,2].

1.1 Mathematical Model

Consider a transmitted signal $s(t) = A\cos(2\pi f_c t)$ through a fading channel. The received signal can be expressed as (ignoring the effects of noise):

$$y(t) = A \sum_{i=1}^N a_i \cos(2\pi f_c t + \theta_i) \dots\dots\dots (1)$$

where,

- a_i and θ_i : is the attenuation and phase-shift fluctuating of the i^{th} multipath component.
- N: is the number of delayed paths.

It must be noted that a_i and θ_i are random variables. The above expression can be re-written as:

$$y(t) = A \left\{ \left(\sum_{i=1}^N a_i \cos(\theta_i) \right) \cos(2\pi f_c t) - \left(\sum_{i=1}^N a_i \sin(\theta_i) \right) \sin(2\pi f_c t) \right\} \dots\dots\dots (2)$$

We introduced two random processes $X_1(t)$ and $X_2(t)$, such that the above equation becomes:

$$y(t) = A \{ X_1(t) \cos(2\pi f_c t) - X_2(t) \sin(2\pi f_c t) \} \dots\dots\dots (3)$$

If the value of N is large (i.e., a large number of scattered waves are present), invoking the Central-Limit Theorem, we get approximate $X_1(t)$ and $X_2(t)$ to be Gaussian random variables with zero mean and variance σ^2 . The expression (3) can be rewritten as:

$$y(t) = AR(t) \cos(2\pi f_c t + \theta(t)) \dots\dots\dots (4)$$

where, the amplitude of the received waveform R(t) is given by:

$$R(t) = \sqrt{X_1(t)^2 + X_2(t)^2} \dots\dots\dots (5)$$

Since the processes $X_1(t)$ and $X_2(t)$ are Gaussian, it can be shown that R(t) has a Rayleigh Distribution with a probability density function (pdf) [2] given by:

$$f_R(r) = \frac{r}{2\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \quad r > 0 \dots\dots\dots (6)$$

The phase of the received waveform $\theta(t)$ is given by:

$$\theta(t) = \tan^{-1} \left(\frac{X_2(t)}{X_1(t)} \right) \dots\dots\dots (7)$$

Since the processes $X_1(t)$ and $X_2(t)$ are Gaussian, it can be shown that $\theta(t)$ has a Uniform Distribution with a probability density function (pdf) given by:

$$f_\theta(\theta) = \frac{1}{2\pi} \quad -\pi \leq \theta \leq \pi \dots\dots\dots (8)$$

The distortion in the phase can be easily overcome if differential modulation is employed. It is the amplitude distortion $R(t)$ that severely degrades performance of digital communication systems over fading channels. It is usually reasonable to assume that the fading stays essentially constant for at least one signaling interval ^[1,2].

2. Code Division Multiple Access (CDMA)

CDMA is the code division multiple access technique in wireless communications that allows a number of users to simultaneously access a channel by modulating and spreading the information signals with code sequences. CDMA is currently the most used technology in wireless communications and is also targeted for the third generation of wireless standards for its better spectral efficiency, better performance and easier base station placement compared to others. In CDMA each user is assigned a unique code sequence it uses to encode its information-bearing signal. The receiver, knowing the code sequences of the user, decodes a received signal after reception and recovers the original data. This is possible since the cross correlations between the code of the desired user and the codes of the other users are small. Since the bandwidth of the code signal is chosen to be much larger than the bandwidth of the information-bearing signal, the encoding process enlarges (spreads) the spectrum of the signal. The resulting signal is also called a spread-spectrum signal, and CDMA is often denoted as spread-spectrum multiple access (SSMA). The spectral spreading of the transmitted signal gives to CDMA its multiple access capability. A spread-spectrum modulation technique must be fulfill two criteria:

- ✚ The transmission bandwidth must be much larger than the information bandwidth.

- ✚ The resulting radio-frequency bandwidth is determined by the ratio of transmitted bandwidth BW_{ss} (chip rate R_c) to information bandwidth BW_{info} (data symbol rate R_s) and is called the *processing gain*, G_p , of the spread-spectrum system ^[3,4,5].

$$G_p = \frac{BW_{ss}}{BW_{info}} = \frac{R_c}{R_s} = \frac{T_b}{T_c} = N_c \dots\dots\dots (9)$$

where:

T_b is called the bit duration.

T_c is the chip duration.

N_c is the number of chips per information bit.

The receiver correlates the received signal with a synchronously generated replica of the spreading code to recover the original information-bearing signal. This implies that the receiver must know the code used to modulate the data. Because of the coding and the resulting enlarged bandwidth, SS (Spread Spectrum) signals have a number of properties that differ from the properties of narrowband signals. The most interesting ones, from the communication systems point of view, are discussed below.

2.1 Multiple Access Capability

If multiple users transmit a spread-spectrum signal at the same time, the receiver will still be able to distinguish between the users provided each user has a unique code that has a sufficiently low cross-correlation with the other codes. Correlating the received signal with a code signal from a certain user will then only disperse the signal of this user, while the other spread-spectrum signals will remain spread over a large bandwidth. Thus, within the information bandwidth the power of the desired user will be larger than the interfering power provided there are not too many interferers, and the desired signal can be extracted ^[3,4,6,7].

2.2 Protection against Multipath Interference

Due to reflections (and refractions) a signal will be received from a number of different paths of the same transmitted signal but with different amplitudes, phases, delays, and arrival angles. Adding these signals at the receiver will be constructive at some of the frequencies and destructive at others. In the time domain, this results in a dispersed signal. Spread-spectrum modulation can combat this multipath interference; however, the way in which this is achieved depends very much on the type of modulation used ^[1,3,5,7].

2.3 Privacy

The transmitted signal can only be dispersed and the data recovered if the code is known to the receiver ^[3].

2.4 Interference Rejection

Cross-correlating the code signal with a narrowband signal will spread the power of the narrowband signal thereby reducing the interfering power in the information bandwidth. When the spread-spectrum signal receives a narrowband interference signal. The SS (Spread Spectrum) signal at the receiver is “dispread” while the interference signal is spread, making it appear as background noise compared to the dispread signal^[3,6,7].

2.5 Anti-Jamming Capability

This is more or less the same as interference rejection except the interference is now willfully inflicted on the system. It is this property, together with the next one, that makes spread-spectrum modulation attractive for military applications^[3,6,7].

2.6 Low Probability of Interception (LPI)

Because of its low power density, the spread-spectrum signal is difficult to be detected and intercepted by a hostile listener^[3].

3. Concept behind CDMA Transmission Scheme

CDMA protocols can be classified in two different ways: by the concept behind the protocols or by the modulation method used. The first classification gives us two groups of protocols, namely, averaging systems and avoidance systems. Averaging systems reduce interference by averaging the interference over a long time interval. Avoidance systems reduce interference by avoiding it for a large part of the time.

Classifying the CDMA protocols by the modulation method gives us five groups of protocols: (1) direct sequence (DS) or pseudo noise, (2) frequency hopping, (3) time hopping, (4) chirp SS (Spread Spectrum), and (5) hybrid. Of these, the first (DS) is an averaging SS protocol, and hybrid protocols can be averaging protocols depending on whether DS is used as part of the hybrid method. All the other protocols are avoidance protocols^[1,3,6,7].

Section 4 discusses the CDMA protocols in terms of the direct sequence modulation technique.

4. Direct Sequence Code Division Multiple Access (DS-CDMA)

In DS CDMA the modulated information bearing signal (the data signal) is directly modulated by a digital, discrete-time, discrete-valued code signal. The data modulation is often omitted and the data signal is directly multiplied by the code signal and the resulting signal modulates the wideband carrier. It is from this direct multiplication that the direct sequence CDMA gets its name. The configuration of the synchronous DS-CDMA is shown in **Fig.(1)**^[3,4,5].

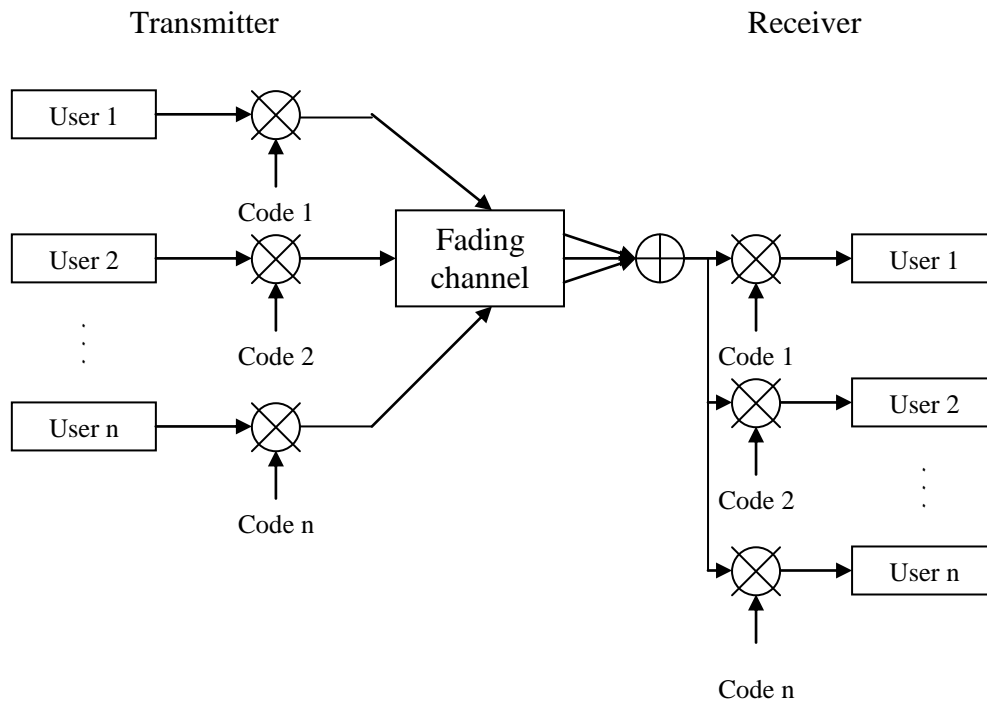


Figure (1) Synchronous DS CDMA system

For the code modulation, various modulation techniques can be used, such as PSK (Phase shift keying), DPSK (Differential phase shift keying), QPSK (quaternary phase shift keying) and MSK (Minimum shift keying). For QPSK modulation. The phase transition sometimes passes the origin, meaning that the phase's changes 180° , and the spectrum will be spread in comparison with that of other phase transitions. One way to reduce the number of origin crossing is to use OQPSK (Offset Quadrature Phase Shift Keying). The OQPSK modulation is the same as QPSK but the signal of the Quadrature Phase signal is half symbol delayed from that of the in phase signal. The OQPSK proposed in this paper used as a code modulation to reduce the big phase changes between in phase channel and Quadrature phase channel.

The binary data signal modulates the RF (Radio Frequency) carrier. The modulated carrier is then modulated by the code signal. This code signal consists of a number of code bits called "chips" that can be either +1 or -1. To obtain the desired spreading of the signal, the chip rate of the code signal must be much higher than the chip rate of the information signal. The chip rate $R_c (= 1/T_c)$ is a multiple integer of the symbol rate $R_s (= 1/T_s)$ ^[1,3,4,5]. The rate of the code signal is called the chip rate; one chip denotes one symbol when referring to spreading code signals. To perform the despreading operation, the receiver must not only know the code sequence used to spread the signal, but also synchronize the codes of the received signal and the locally generated code. This synchronization must be accomplished at the beginning of the reception and maintained until the whole signal has been received. Correlation of the received spread spectrum signal with the PN sequence of user N only disperse the signal of user N. The other users produce noise for user N ^[4,6]. The code

synchronization/tracking block performs this operation. After despreading a data modulated signal results, and after demodulation the original data can be recovered.

5. Generation of a Spreading Code

In the previously described CDMA systems, the choice of the type of code sequence is important with respect to the resistance against both multipath interference and multiuser interference. To overcome the interference, several requirements must be satisfied^[4,6]:

1. Each code sequence generated from a set of code-generation functions must be periodic with a constant length.
2. Each code sequence generated from a set of code-generation functions must be easily distinguished from its time-shifted code.
3. Each code sequence generated from a set of code-generation functions must be easily distinguished from other code sequences.

The selection of a good code is important, because type and length of the code sets bounds on the system capability. There for, three code sequences are discussed below.

5.1 PN Code Generator

It generates a PN (pseudo-random noise) code sequence that is used to spread the encoded and modulated source data. The PN sequences used in paper are m sequences, Gold sequences and Orthogonal Gold sequences^[1,8,9].

5.1.1 M-Sequences

The maximum-length shift register sequences, also known, as the M-sequences are the widely used PN code sequences. It has a length $L = 2^m - 1$ and is generated by m stage shift register with linear feedback. The sequence is periodic with period L and has a sequence of 2^{m-1} ones and $2^{m-1} - 1$ zeros. The binary sequence of {0, 1} is mapped into corresponding sequence of {-1, 1}. M-sequences have good auto correlation properties. But for CDMA systems with multiple users, good cross correlation properties are required which is quite poor for m-sequences^[1,8,9].

5.1.2 Gold Sequences

Gold codes have good cross correlation properties which are constructed by summing "*preferred pairs*" of M-sequences, or maximal length sequences. For large and odd values of M-sequences, the cross correlation values are better. Gold sequences are constructed using these M-sequence, by exclusive OR of two M-sequence. The number of Gold sequences generated by a generator circuit is 2^{m+1} .^[4,8,9]

5.1.3 Orthogonal Gold Sequences

The Gold sequence has many different codes compared to those of the M- sequence. However, there are several problems associated with the Gold sequence^[9]:

1. The proportion of 0 to 1 is not always balanced.

2. The cross correlation value of the Gold sequence is not 0 in a synchronized environment.
3. The code length is an odd number. As a result, a special clock is needed to generate the Gold sequence.

To solve the above problems, one chip is added to the Gold sequence to balance the proportion of 0 to 1. The cross correlation value of the orthogonal Gold sequence is 0 at the synchronous point. At other points, the characteristics of the sequence are similar to those of the Gold sequence.

The three previous PN sequences are used in CDMA systems (M sequences, Gold sequences and Orthogonal Gold sequences) spread the spectrum of the information signal. Hence, the large channel bandwidth R_c (chip rate) instead of R_s (symbol rate) increase the received noise power with G_p (processing gain) [4].

$$N_{inf} = N_o \cdot BW_{inf} \dots\dots\dots (10)$$

$$N_{ss} = N_o \cdot BW_{ss} = N_{inf} \cdot G_p \dots\dots\dots (11)$$

Therefore, the increase in received noise power degrades the BER (Bit Error Rate) when increasing number of users.

6. Diversity

Diversity techniques can be used to improve system performance in fading channels. Instead of transmitting and receiving the desired signal through one channel, we obtain L copies of the desired signal through M different channels. The idea is that while some copies may undergo deep fades, others may not. We might still be able to obtain enough energy to make the correct decision on the transmitted symbol. There are several different kinds of diversity which are commonly employed in wireless communication systems [1,2,11]:

1. Frequency diversity:

Transmission of same signal at different frequencies (frequency separation should be larger than the coherence bandwidth of the channel) [10].

2. Time diversity:

Transmission of same signal sequence at different times (time separation should be larger than the coherence time of the channel) [10].

3. Space diversity:

Several receiving antennas spaced sufficiently far apart (spatial separation should be sufficiently large to reduce correlation between diversity branches, The minimum antenna separation required is approximately one half wavelength. 0.38λ to be exact) [10,11].

4. Polarization diversity:

Only two diversity branches are available. Not widely used [11].

6.1 Diversity Combining Methods

The idea of diversity is to combine several copies of the transmitted signal, which undergo independent fading, to increase the overall received power. Different types of diversity call for different combining methods. Here, we review several common diversity combining methods.

For a slowly flat fading channel, the equivalent lowpass of the received signal of branch i can be written as ^[10].

$$r_i(t) = A_i e^{j\theta_i} s(t) + z_i(t) \quad i = 0, 2, \dots, M - 1 \dots \dots \dots (12)$$

Where:

$s(t)$: is the equivalent lowpass of the transmitted signal,

$A_i e^{j\theta_i}$: is the fading attenuation of branch i ,

$Z_i(t)$: is the AWGN. Out of M branches.

M replicas of the transmitted signal are obtained:

$$r = \left[r_0(t) \quad r_1(t) \quad \dots \quad r_{M-1}(t) \right] \dots \dots \dots (13)$$

6.1.1 Selection Diversity

Selection diversity, shown in **Fig.(2)**, for two branch diversity system in Rayleigh fading channel is the simplest of these methods. From a collection of antennas, the branch that receives the signal with the largest signal-to-noise ratio at any time is selected and connected to the demodulator. As one would expect, the larger the number of available branches the higher the probability of having a larger signal-to-noise ratio (SNR) at the output ^[2,10,12].

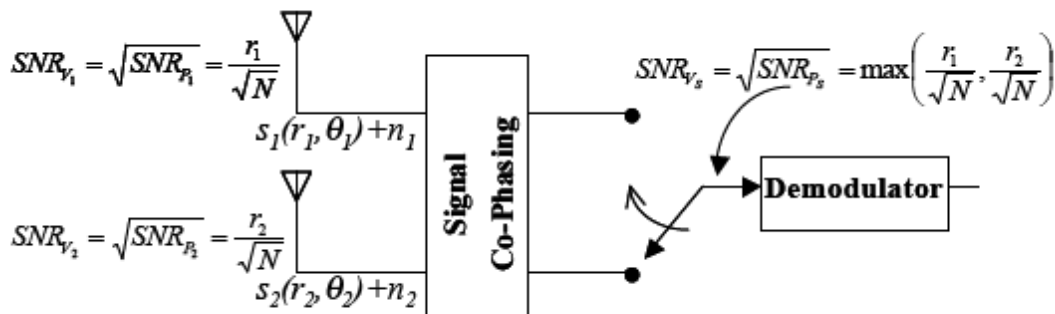


Figure (2) Block diagram of a two-branch selection diversity system for equal noise powers in both branches

The inputs to the branches in **Fig.(2)** are the Rayleigh signals s_1 and s_2 . The signals s_1 and s_2 are received with amplitudes r_1 and r_2 and with phase's θ_1 and θ_2 respectively. The analysis that follows will primarily focus on the magnitude of the received envelopes (r_1, r_2)

since the value of these variables determines the strength of the received signals. s_1 and s_2 are assumed to be time synchronized and contain the same transmitted information but are received at the receiver with different strengths and phases due to the propagation effects of the channel. Both branches are corrupted by additive noise sources n_1 and n_2 respectively. n_1 and n_2 are identically distributed white Gaussian noise sources uncorrelated with each other.

The noise sources arriving from the surroundings combine at each antenna differently and together with the receiver noise, which is unique for each receiver, ensures that signals n_1 and n_2 are very much uncorrelated.

At a given instant (t_0) and receiver location, the receiver receives a signal with amplitude $r_1(t_0)$ and $r_2(t_0)$ at both branches. The signal-to-noise ratio at the input of each diversity branch is the ratio of instantaneous signal power to noise power, or $SNR_{P1,2}(t_0)$. The subscripts 1 and 2 refer to the channel, or the branch, 1 and 2 of the diversity system. At time t_0 , the SNR_P received by each antenna element is therefore given by [11,12]:

$$SNR_{P_{1,2}}(t_0) = \frac{\text{Power}_{\text{Signal}}(t_0)}{\text{Power}_{\text{Noise}}(t_0)} = \frac{r_{1,2}(t_0)^2}{E[n_{1,2}^2]} = \frac{r_{1,2}(t_0)^2}{N} \dots\dots\dots (14)$$

The receiver monitors the signal-to-noise ratio of both channels and connects the branch with the largest SNR at any instant in time to the demodulator. The voltage and power signal-to-noise ratio (SNR_{VS} and SNR_{PS}) after selection combining is simply the maximum of both branches or equivalently [2,10,11,12].

$$SNR_{P_s} = \max(SNR_{P_1}, SNR_{P_2}) = \max\left(\frac{r_1^2}{N}, \frac{r_2^2}{N}\right) = \frac{1}{N} \max(r_1^2, r_2^2) \dots\dots\dots (15)$$

$$SNR_{V_s} = \sqrt{SNR_{P_s}} = \max\left(\frac{r_1}{\sqrt{N}}, \frac{r_2}{\sqrt{N}}\right) = \frac{1}{\sqrt{N}} \max(r_1, r_2) \dots\dots\dots (16)$$

6.1.2 Maximal Ratio Combining

Maximal ratio combining takes better advantage of all the diversity branches in the system. **Figure (3)** shows this configuration for a two-branch diversity system. Both branches are weighted by their respective instantaneous voltage-to-noise ratios. The branches are then co-phased prior to summing in order to insure that all branches are added in phase for maximum diversity gain.

The summed signals are then used as the received signal and connected to the demodulator. Maximal ratio combining will always perform better than either selection diversity or equal gain combining because it is an optimum combiner [2,10,11,12].

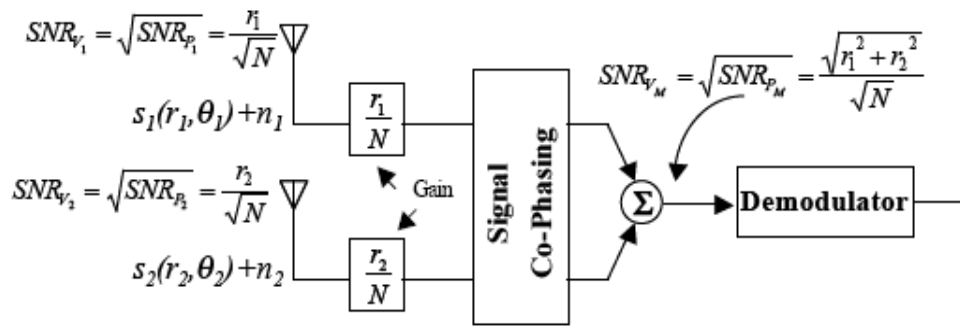


Figure (3) Block diagram of a two-branch maximal ratio combiner for equal noise powers in both branches

The inputs to the maximal ratio combiner Fig.(3) are both Rayleigh distributed signals (with envelopes r_1 and r_2) with additive independent noise voltage sources n_1 and n_2 . Where n_1 and n_2 are zero mean white Gaussian random variables with a variance of N ; The output signal to noise ratio, $SNR_{P,M}$, at t_0 after maximal ratio combining is given by the ratio of signal to noise power^[12].

$$SNR_{P_M}(t_0) = \frac{\text{Power}_{\text{Signal}}}{\text{Power}_{\text{Noise}}} = \frac{P_{S,M}(t_0)}{P_{N,M}(t_0)} = \frac{V_{S,M}(t_0)^2}{E[V_{N,M}(t_0)^2]} \dots\dots\dots (17)$$

$$= \frac{r_1(t_0)^2 + r_2(t_0)^2}{N} = \frac{1}{N}(r_1(t_0)^2 + r_2(t_0)^2)$$

6.1.3 Equal Gain Combining

Equal gain combining (EGC) can be viewed as a special case of maximal ratio combining as shown in Fig.(4). In this scheme the gains of the branches are all set to a predetermined value and are not changed. As with the previous case, both branch signals are multiplied by the same branch gain (G) and the resulting signals are co-phased and summed. The resultant output signal is connected to the demodulator^[2,10,12].

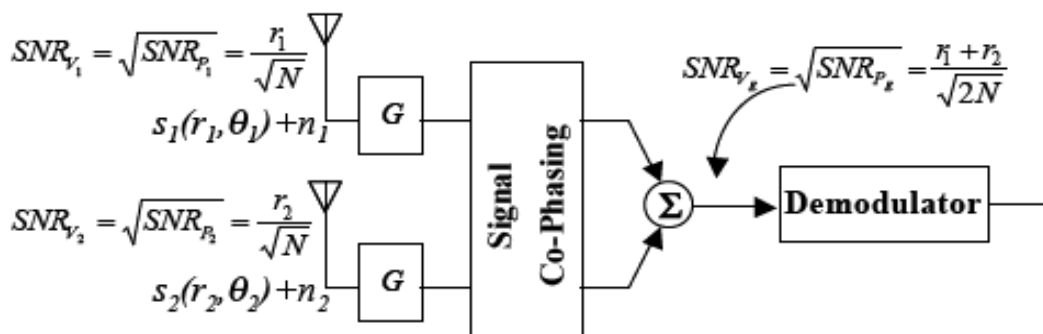


Figure (4) Block diagram of a two-branch equal gain combiner for equal noise powers in both branches

As before, the signals arriving at both branches from the transmitter have envelopes given by r_1 and r_2 and have a distribution described by a Rayleigh probability density function. Both received signals are corrupted by white Gaussian noise sources n_1 and n_2 . Fig.(4) describes the equal gain combining technique in which all branches are pre-multiplied by G (branch gain) and then co-phased, such that the amplitude of the output signal is the direct addition of branch envelopes. The instantaneous signal power, $P_{S,E}(t_0)$, is given by the envelope squared or [12]:

$$P_{S,E}(t_0) = V_{S,E}(t_0)^2 = G^2(r_1(t_0) + r_2(t_0))^2 \dots\dots\dots (18)$$

The instantaneous power signal-to-noise ratio is the ratio of signal to noise power and at t_0 evaluates to

$$\begin{aligned} SNR_{P_E}(t_0) &= \frac{\text{Power}_{\text{Signal}}}{\text{Power}_{\text{Noise}}} = \frac{P_{S,E}(t_0)}{P_{N,E}(t_0)} = \frac{V_{S,E}(t_0)^2}{E[V_{N,E}(t)^2]} \dots\dots\dots (19) \\ &= \frac{G^2(r_1(t_0) + r_2(t_0))^2}{2G^2N} = \frac{1}{2N}(r_1(t_0) + r_2(t_0))^2 \end{aligned}$$

Since the value of G (branch gain) does not affect the output signal-to-noise ratio, this value is usually set to unity in practical applications.

7. Performance by Computer Simulation

This section calculates BER of a DS CDMA system with three spreading code with and without diversity combining by using MATLAB 7 computer simulation software. The following parameters are used in program.

- $R_s = \text{symbol rate} = 256 \text{ Ksymbols/sec.}$
- $m = \text{Number of modulation level} = 2 \text{ for OQPSK}$
- $b_r = \text{bit rate} = m.R_s = 512 \text{ kbits/sec}$
- $T_b = \text{bit duration} = 1/b_r$
- $\text{Number of user in DS CDMA system} = 10$
- $R_c = \text{chip rate} = G_p.R_s$
- $T_c = \text{chip duration} = 1/R_c$

The shift register for generating M sequence polynomial is $g(x)=X^5+X^2+1$

And for Gold sequence, the shift registers for generating a preferred pair of M sequences, corresponding to the polynomials

- $g(x)=X^5+X^2+1$
- $g(x)=X^5+X^4+X^3+X^2+1$

There are generating 33 different sequences, corresponding to the 33 relative phases of the two M sequence.

We assume a flat Rayleigh fading channel, where there are two paths in the multipath delay profile and it is assumed that the delayed wave have a mean power of 20 dB smaller than that of the direct wave and the delay path equal to symbol duration.

The configuration of the synchronous DS CDMA shown in **Fig.(1)**. In this Figure, assume 10 users employ their own sequences to spread the information data. At each user's terminal, the information data are modulated by the OQPSK modulation. Then, the bits of the modulation data are spread by a code sequence, such as an (M-sequence, Gold sequence or Orthogonal Gold sequence). The spread data of all 10 users are transmitted to the base station at the same time. The base station detects the information data of each user by correlating the received signal with a code sequence allocated to each user.

The computer simulation results on the BER performance for 10 users DS CDMA system using three spreading code (M-sequence, Gold sequence or Orthogonal Gold sequence) without diversity combining compared with the theoretical value are shown in **Fig.(5)**. We assume the processing gain $G_{DS} = 31$ for (M sequence & Gold code) and $G_{DS} = 32$ for orthogonal Gold code.

The bit error rate (BER) is calculated by XOR'ing the information signal at the transmitter with the finally received signal and then dividing it with the number of Transmitted bits. The BER is then plotted against the SNR (E_b/N_0) values.

It can clearly seen that the Orthogonal Gold code provides the best performance .i.e. when the user codes are Orthogonal, there is no interference between the users after despreading and the privacy of the communication of each user is protected. Hence, the target user signal can be successfully recovered from the channel noise and the multi-user interference. While (M-sequence and Gold code) are not perfectly Orthogonal, hence the cross correlation between user codes introduces performance degradation (increase noise power after despreading), which limits the maximum number of simultaneous users and the BER performance degrades.

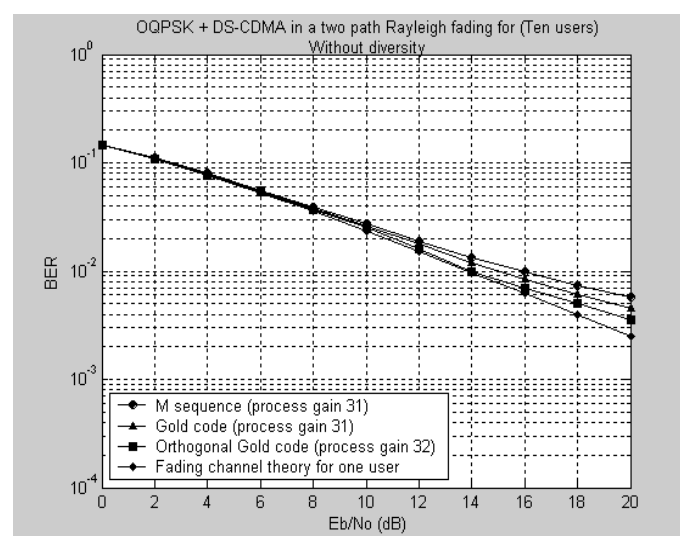


Figure (5) Performance of 10 users DS CDMA in a two path Rayleigh fading channel with three spreading code (M-sequence, Gold sequence and Orthogonal Gold sequence) without diversity combining

The results of two branches diversity combining of 10 users DS CDMA system with M-sequence (process gain $G_{DS} = 31$) with diversity combining compared with the DS CDMA system without diversity combining in a flat Rayleigh fading channel with the same previous channel requirement are shown in **Fig.(6)**.

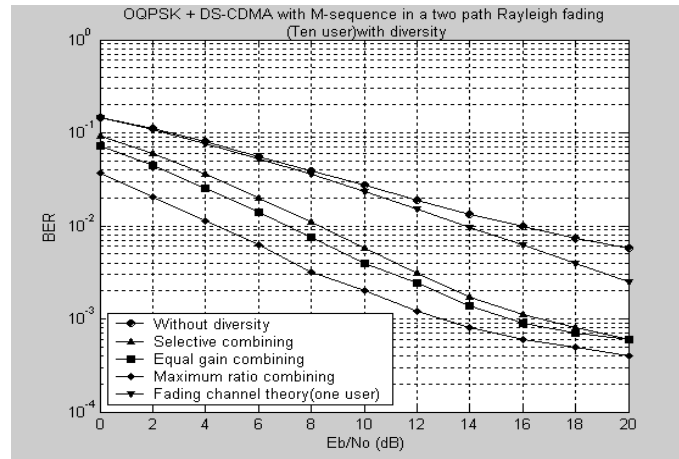


Figure (6) Performance of 10 users DS CDMA used M-sequence in a two path Rayleigh fading channel with diversity combining

The performance of the system improvement in the BER is maximum for Maximal Ratio combining (MRC). i.e. MRC has the best performance; Equal Gain combining (EGC) has a slightly lower performance while Selective Combining (SC) is clearly the worst and (EGC) performance very close to the (SC). We notice that the BER decreases when we increase the SNR, which is normal because the signal becomes stronger than the noise and multipath fading. While, after 20 dB the performance dose not improved.

Figure (7) show the results of two branches diversity combining for 10 users DS CDMA system with Gold sequence (process gain $G_{DS} = 31$) with diversity combining compared with the DS CDMA system without diversity combining in a flat Rayleigh fading channel with the same previous channel requirement.

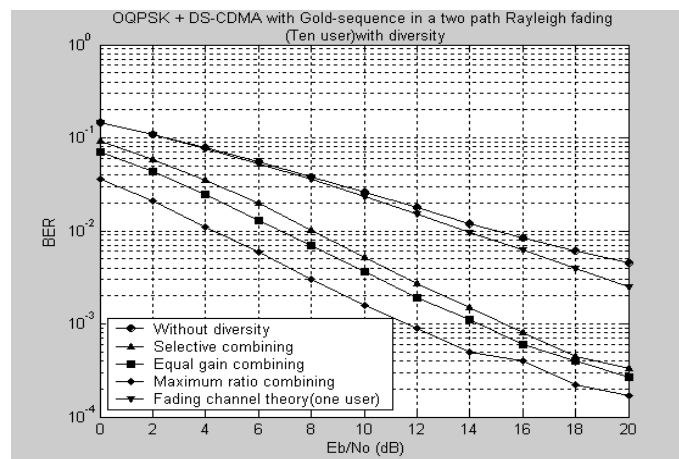


Figure (7) Performance of 10 users DS CDMA used Gold code in a two path Rayleigh fading channel with diversity combining

MRC has the best performance; EGC has a slightly lower performance while Selective Combining SC is clearly the worst and (EGC) performance very close to the (SC). We notice that the system performance improved when we increase the SNR. The DS CDMA used Gold code has best performance compared with the DS CDMA system used M sequence as a modulation code with diversity combining.

Figure (8) show the results of two branches diversity combining for 10 users DS CDMA system with Orthogonal Gold sequence (process gain $G_{DS} = 32$) with diversity combining compared with the DS CDMA system without diversity combining in a flat Rayleigh fading channel with the same previous channel requirement.

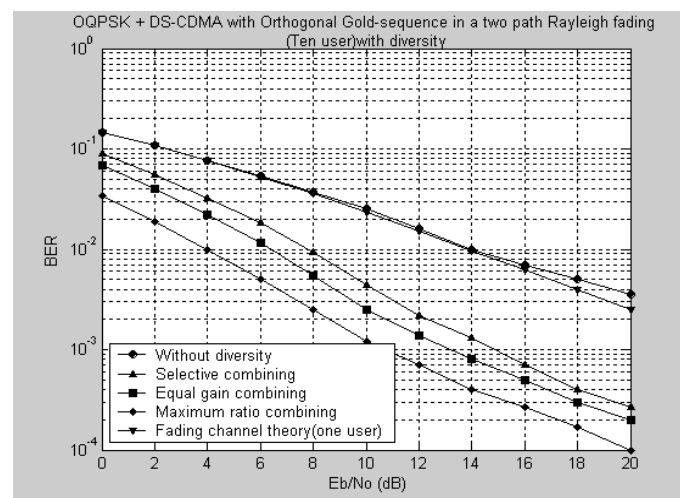


Figure (8) Performance of 10 users DS CDMA used Orthogonal Gold code in a two path Rayleigh fading channel with diversity combining

MRC has the best performance; EGC has a slightly lower performance while Selective Combining SC is clearly the worst and (EGC) performance very close to the (SC). We notice that the system performance improved when we increase the SNR. The Orthogonal Gold code is the best performance among two codes used in a DS CDMA system as a modulation code with diversity combining.

8. Conclusion

The diversity is used to provide the receiver with several replicas of the same signal. Diversity techniques are used to improve the performance of the radio channel without any increase in the transmitted power. As higher as the received signal replicas are decorrelated, as much as the diversity gain. The performance of these combining schemes will be evaluated for Rayleigh fading channels.

Among different combining techniques MRC with Orthogonal Gold code in DS CDMA has the best performance and the highest complexity, EGC performance better than SC. While SC has the lowest performance and the least complexity.

9. References

1. John, G. Proakis, "*Digital Communications*", McGraw-Hill, New York, NY, 1995.
2. V. C., Ramasami, "*BER Performance over Fading Channels and Diversity Combining*", EECS 862 Project, 2004.
3. Ramjee Prasad, "*An Overview of CDMA Evolution Toward Wideband CDMA*", IEEE Comm. Surveys, Vol. 1, No. 1, Fourth Quarter, 1998.
4. Ir., J. Meel, "*Spread Spectrum (SS)*", Sirius Comm.-Rotselaar-Belgium, 1999.
5. Frank H. P., Fitzek, "*Code Division Multiple Access*", Lecture 2 in CDMA from Ph.D. thesis, 04 February 2003.
6. Ojanpera, and R., Prasad, "*Wideband CDMA for Third Generation Mobile Communications*", Artech House, Oct. 1998.
7. Garg, V. K., K. Smolik, and J. E., Wilkes, "*Applications of CDMA in Wireless/Personal Communications*", Prentice-Hall, 1997.
8. Soma Ghosh, "*Performance Analysis of Direct Spread Spectrum (CDMA) System*", Wireless Comm., SC715 Project, Boston University, 2004.
9. Kimmo Kettunen, "*Code Selection for CDMA Systems*", Licentiate Course on Signal Processing in Communications, FALL-1997.
10. Hafeth Hourani, "*An Overview of Diversity Techniques in Wireless Communication Systems*", Helsinki University of Technology, Postgraduate Course in Radio Communications (2004/2005).
11. Andrea Goldsmith, "*Wireless Communications*", First Eddition, Stanford University, 2004.
12. Kai Dietze, "*Analysis of a Two-Branch Maximal Ratio and Selection Diversity System with Unequal Branch Powers and Correlated Inputs for a Rayleigh Fading Channel*", Thesis Submitted to the Faculty of the Virginia Polytechnic Institute and State University. March 30, 2001.