CDMA TECHNOLOGY

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of technology in 'Electronics and Communication'

BY

Ajay Kumar Tandi
10509004
Manoj Kumar Beuria
10509005

SUPERVISOR

Professor Poonam Singh

Department of Electronics and Communication Engineering
National Institute of Technology
Rourkela
Orissa

ACKNOWLEDGMENT

We place on record and warmly acknowledge the continuous encouragement, invaluable supervision, timely suggestions and inspired guidance offered by our guide **prof. Poonam Singh**, Department of Electronics and Instrumentation Engineering, National Institute of Technology, Rourkela, in the bringing this report to a successful completion.

We are grateful to **Prof.S.K. Patra**, Head of the Department of Electronics and Communication Engineering for permitting us to make use of the facilities available in the department to carry out the project successfully. Last but not the least we express our sincere thanks to all our friends who have patiently extended all sorts of help for accomplishing this undertaking.

Finally we extend our gratefulness to one and all who are directly or indirectly involved in the successful completion of this project work.

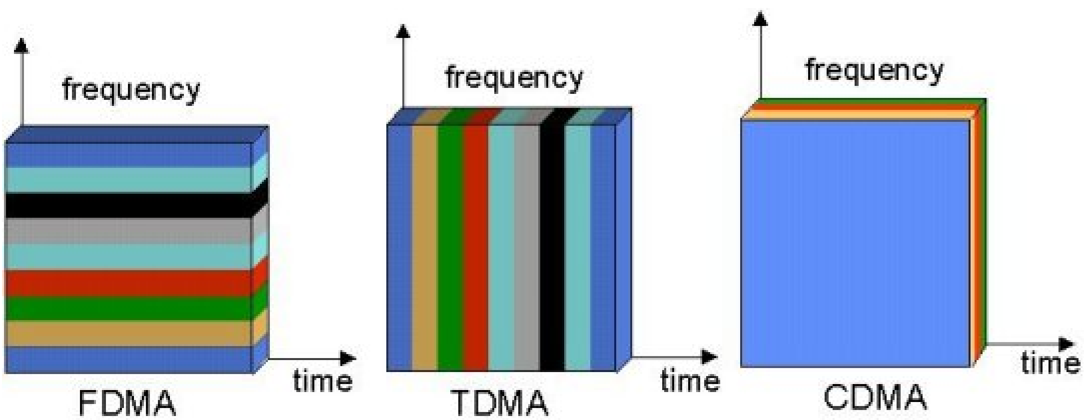
AJAYKUMARTANDI(10509004)

MANOJKUMARBEURIA (10509005)

THEORY

ACCESS SCHEMES

For radio systems there are two resources, frequency and time. Division by frequency, so that each pair of communicators is allocated part of the spectrum for all of the time, results in Frequency Division Multiple Access (FDMA). Division by time, so that each pair of communicators is allocated all (or at least a large part) of the spectrum for part of the time results in Time Division Multiple Access (TDMA). In Code Division Multiple Access (CDMA), every communicator will be allocated the entire spectrum all of the time. CDMA uses codes to identify connections.



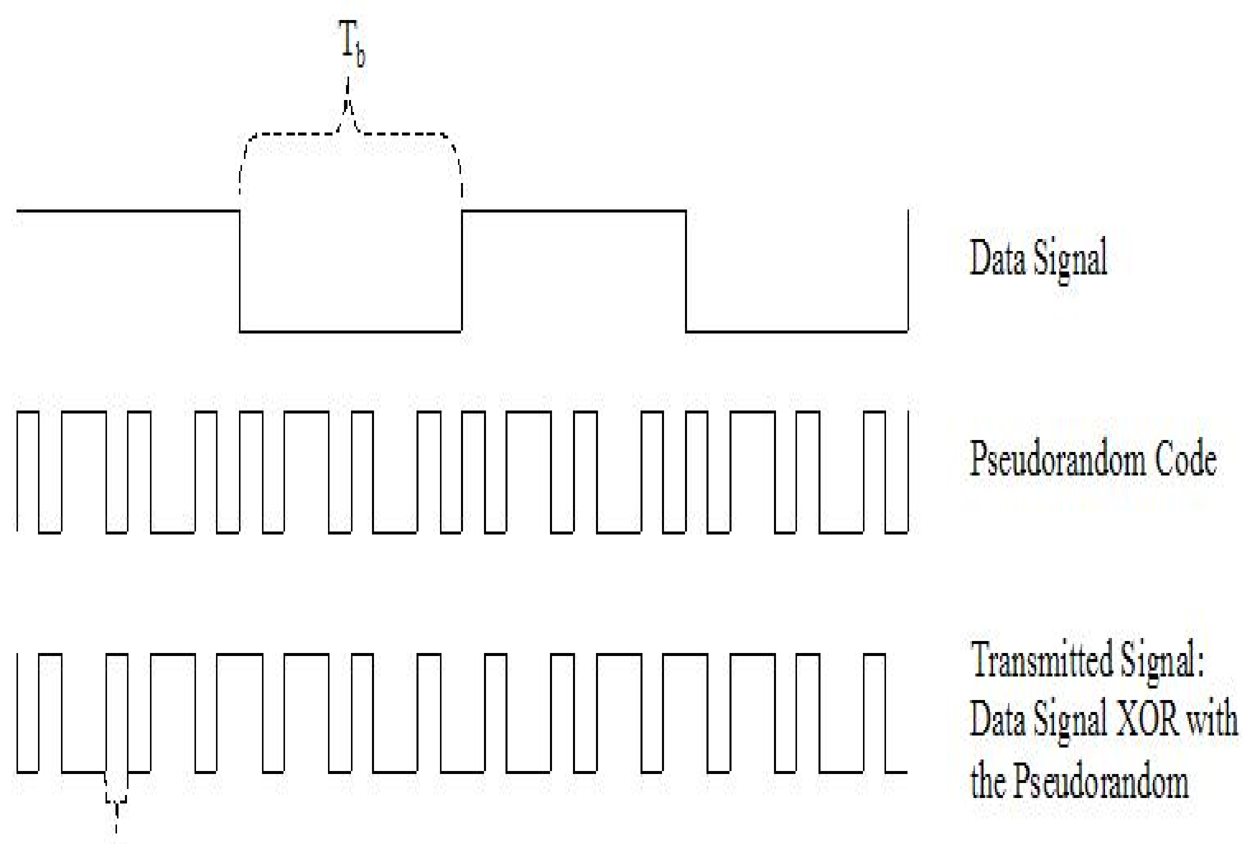
Code division multiple access (**CDMA**) is a channel access method utilized by various radio communication technologies. It should not be confused with the mobile phone standards called cdmaOne and CDMA2000 (which are often referred to as simply "CDMA"), that use CDMA as their underlying channel access methods.

One of the basic concepts in data communication is the idea of allowing several transmitters to send information simultaneously over a single communication channel. This allows several users to share a bandwidth of frequencies. This concept is called multiplexing. CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code) to allow multiple users to be multiplexed over the same physical channel. By contrast, time division multiple access (**TDMA**) divides access by time, while frequency-division multiple access (**FDMA**) divides it by frequency. CDMA is a form of "spread-spectrum" signaling, since the modulated coded signal has a much higher data bandwidth than the data being communicated.

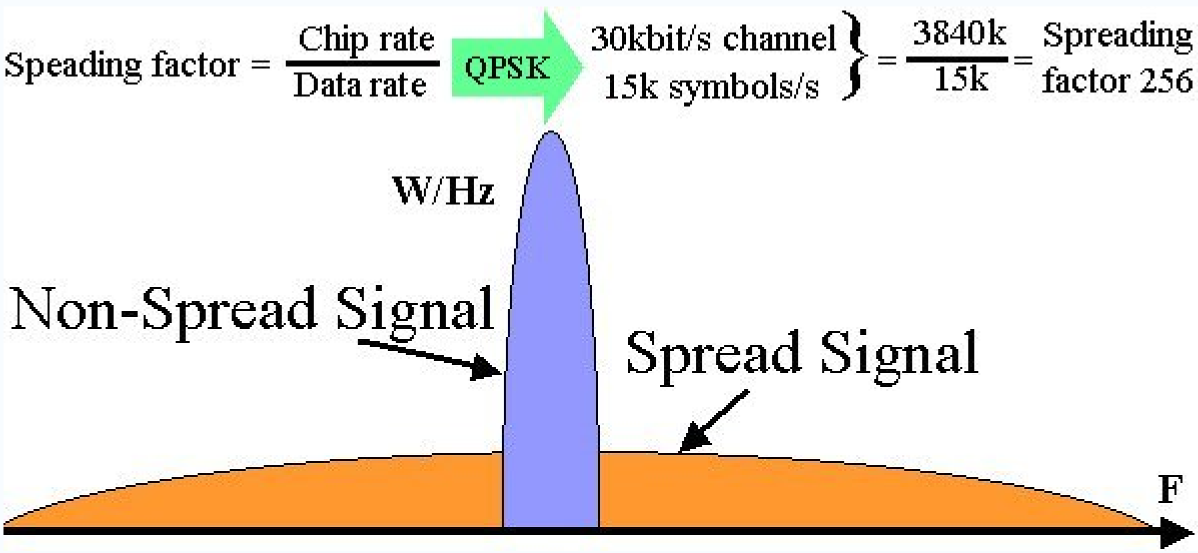
An analogy to the problem of multiple access is a room (channel) in which people wish to communicate with each other. To avoid confusion, people could take turns speaking (time division), speak at different pitches (frequency division), or speak in different languages (code division). CDMA is analogous to the last example where people speaking the same language can understand each other, but not other people. Similarly, in radio CDMA, each group of users is given a shared code. Many codes occupy the same channel, but only users associated with a particular code can understand each other.

Technical details

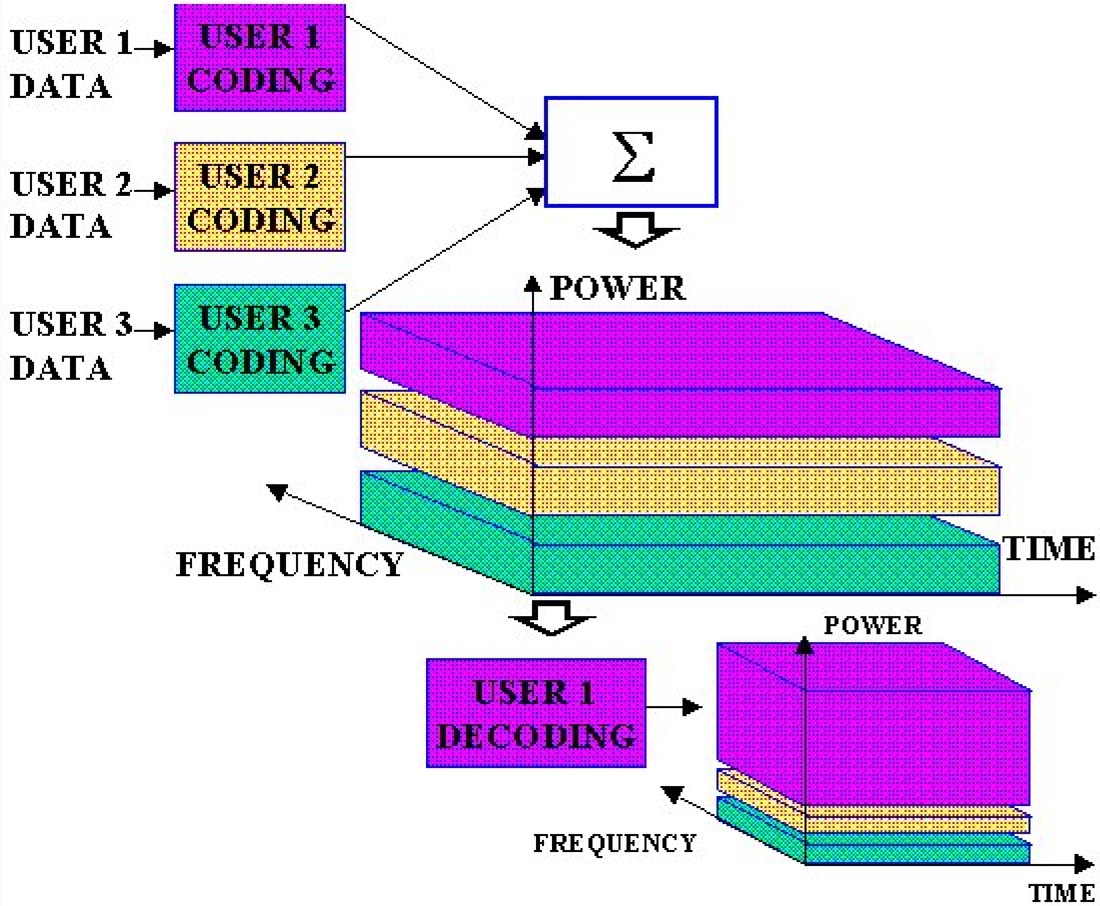
CDMA is a spread spectrum multiple access technique. In CDMA a locally generated code runs at a much higher rate than the data to be transmitted. Data for transmission is simply logically XOR (exclusive OR) added with the faster code. The figure shows how spread spectrum signal is generated. The data signal with pulse duration of T_b is XOR added with the code signal with pulse duration of T_c. (Note: bandwidth is proportional to $1 / T$ where T = bit time) Therefore, the bandwidth of the data signal is $1 / T_b$ and the bandwidth of the spread spectrum signal is $1 / T_c$. Since T_c is much smaller than T_b, the bandwidth of the spread spectrum signal is much larger than the bandwidth of the original signal.



CDMA uses Direct Sequence spreading, where spreading process is done by directly combining the baseband information to high chip rate binary code. The Spreading Factor is the ratio of the chips (UMTS = 3.84Mchips/s) to baseband information rate. Spreading factors vary from 4 to 512 in FDD UMTS. Spreading process gain can in expressed in dBs (Spreading factor 128 = 21dB gain).



Each user in a CDMA system uses a different code to modulate their signal. Choosing the codes used to modulate the signal is very important in the performance of CDMA systems. The best performance will occur when there is good separation between the signal of a desired user and the signals of other users. The separation of the signals is made by correlating the received signal with the locally generated code of the desired user. If the signal matches the desired user's code then the correlation function will be high and the system can extract that signal. If the desired user's code has nothing in common with the signal the correlation should be as close to zero as possible (thus eliminating the signal); this is referred to as cross correlation. If the code is correlated with the signal at any time offset other than zero, the correlation should be as close to zero as possible. This is referred to as auto-correlation and is used to reject multi-path interference. [2]



In general, CDMA belongs to two basic categories: synchronous (orthogonal codes) and asynchronous (pseudorandom codes Code Division Multiplexing (Synchronous CDMA)

Synchronous CDMA

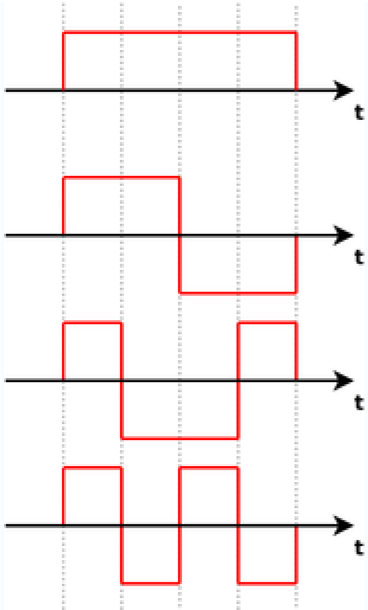
Synchronous CDMA exploits mathematical properties of orthogonality between vectors representing the data strings. For example, binary string "1011" is represented by the vector (1, 0, 1, 1). Vectors can be multiplied by taking their dot product, by summing the products of their respective components. If the dot product is zero, the two vectors are said to be *orthogonal* to each other. (Note: If u=(a,b) and v=(c,d), the dot product u.v = a*c + b*d) Some properties of the dot product help to understand how W-CDMA works. If vectors *a* and *b* are orthogonal, then

$$\mathbf{a}\cdot(\mathbf{a}+\mathbf{b}) = ||\mathbf{a}||^2 \quad \text{since} \quad \mathbf{a}\cdot\mathbf{a}+\mathbf{a}\cdot\mathbf{b} = ||a||^2 + 0,$$
$$\mathbf{a}\cdot(-\mathbf{a}+\mathbf{b}) = -||\mathbf{a}||^2 \quad \text{since} \quad -\mathbf{a}\cdot\mathbf{a}+\mathbf{a}\cdot\mathbf{b} = -||a||^2 + 0,$$
$$\mathbf{b}\cdot(\mathbf{a}+\mathbf{b}) = ||\mathbf{b}||^2 \quad \text{since} \quad \mathbf{b}\cdot\mathbf{a}+\mathbf{b}\cdot\mathbf{b} = 0 + ||b||^2,$$
$$\mathbf{b}\cdot(\mathbf{a}-\mathbf{b}) = -||\mathbf{b}||^2 \quad \text{since} \quad \mathbf{b}\cdot\mathbf{a}-\mathbf{b}\cdot\mathbf{b} = 0 - ||b||^2.$$

Each user in synchronous CDMA uses an orthogonal codes to modulate their signal. An example of four mutually orthogonal digital signals is shown in the figure. Orthogonal codes have a cross-correlation equal to zero; in other words, they do not interfere with each other. In the case of IS-95 64 bit Walsh codes are used to encode the signal to separate different users. Since each of the 64 Walsh codes are orthogonal to one another, the signals are channelized into 64 orthogonal signals. The following example demonstrates how each users signal can be encoded and decoded.

Example

Start with a set of vectors that are mutually orthogonal. (Although mutual orthogonality is the only condition, these vectors are usually constructed for ease of decoding, for example columns or rows from Walsh matrices.) An example of orthogonal functions is shown in the picture on the left. These vectors will be assigned to individual users and are called the "code", "chipping code" or "chip code". In the interest of brevity, the rest of this example uses codes (v) with only 2 digits.



An example of four mutually orthogonal digital signals.

Each user is associated with a different code, say **v**. If the data to be transmitted is a digital zero, then the actual bits transmitted will be **–v**, and if the data to be transmitted is a digital one, then the actual bits transmitted will be **v**. For example, if **v**=(1,–1), and the data that the user wishes to transmit is (1, 0, 1, 1) this would correspond to (**v**, **–v**, **v**, **v**) which is then constructed in binary as ((1,–1),(–1,1),(1,–1),(1,–1)). For the purposes of this article, we call this constructed vector the *transmitted vector*.

Each sender has a different, unique vector **v** chosen from that set, but the construction method of the transmitted vector is identical.

Now, due to physical properties of interference, if two signals at a point are in phase, they add to give twice the amplitude of each signal, but if they are out of phase, they "subtract" and give a signal that is the difference of the amplitudes. Digitally, this behaviour can be modelled by the addition of the transmission vectors, component by component.

If sender0 has code (1,–1) and data (1,0,1,1), and sender1 has code (1,1) and data (0,0,1,1), and both senders transmit simultaneously, then this table describes the coding steps:

Step	Encode sender0	Encode sender1
0	vector0=(1,–1), data0=(1,0,1,1)=(1,–1,1,1)	vector1=(1,1), data1=(0,0,1,1)=(–1,–1,1,1)
1	encode0=vector0.data0	encode1=vector1.data1
2	encode0=(1,–1).(1,–1,1,1)	encode1=(1,1).(–1,–1,1,1)
3	encode0=((1,–1),(–1,1),(1,–1),(1,–1))	encode1=((–1,–1),(–1,–1),(1,1),(1,1))
4	signal0=(1,–1,–1,1,1,–1,1,–1)	signal1=(–1,–1,–1,–1,1,1,1,1)

Because signal0 and signal1 are transmitted at the same time into the air, they add to produce the raw signal:
(1,–1,–1,1,1,–1,1,–1) + (–1,–1,–1,–1,1,1,1,1) = (0,–2,–2,0,2,0,2,0)

This raw signal is called an interference pattern. The receiver then extracts an intelligible signal for any known sender by combining the sender's code with the interference pattern, the receiver combines it with the codes of the senders. The following table explains how this works and shows that the signals do not interfer with one another:

Step	Decode sender0	Decode sender1
0	vector0=(1,–1), pattern=(0,–2,–2,0,2,0,2,0)	vector1=(1,1), pattern=(0,–2,–2,0,2,0,2,0)
1	decode0=pattern.vector0	decode1=pattern.vector1
2	decode0=((0,–2),(–2,0),(2,0),(2,0)).(1,–1)	decode1=((0,–2),(–2,0),(2,0),(2,0)).(1,1)
3	decode0=((0+2),(–2+0),(2+0),(2+0))	decode1=((0–2),(–2+0),(2+0),(2+0))
4	data0=(2,–2,2,2)=(1,0,1,1)	data1=(–2,–2,2,2)=(0,0,1,1)

Further, after decoding, all values greater than 0 are interpreted as 1 while all values less than zero are interpreted as 0. For example, after decoding, data0 is (2,–2,2,2), but the receiver interprets this as (1,0,1,1).

We can also consider what would happen if a receiver tries to decode a signal when the user has not sent any information. Assume signal0=(1,-1,-1,1,1,-1,1,-1) is transmitted alone. The following table shows the decode at the receiver:

Step	Decode sender0	Decode sender1
0	vector0=(1,–1), pattern=(1,-1,-1,1,1,-1,1,-1)	vector1=(1,1), pattern=(1,-1,-1,1,1,-1,1,-1)
1	decode0=pattern.vector0	decode1=pattern.vector1
2	decode0=((1,–1),(–1,1),(1,-1),(1,-1)).(1,–1)	decode1=((1,–1),(–1,1),(1,-1),(1,-1)).(1,1)
3	decode0=((1+1),(–1-1),(1+1),(1+1))	decode1=((1–1),(–1+1),(1-1),(1-1))
4	data0=(2,–2,2,2)=(1,0,1,1)	data1=(0,0,0,0)

When the receiver attempts to decode the signal using sender1's code, the data is all zeros, therefore the cross correlation is equal to zero and it is clear that sender1 did not transmit any data.

Asynchronous CDMA

The previous example of orthogonal Walsh sequences describes how 2 users can be multiplexed together in a synchronous system, a technique that is commonly referred to as Code Division Multiplexing (CDM). The set of 4 Walsh sequences shown in the figure will afford up to 4 users, and in general, an NxN Walsh matrix can be used to multiplex N users. Multiplexing requires all of the users to be coordinated so that each transmits their assigned sequence **v** (or the complement, **-v**) starting at exactly the same time. Thus, this technique finds use in base-to-mobile links, where all of the transmissions originate from the same transmitter and can be perfectly coordinated.

On the other hand, the mobile-to-base links cannot be precisely coordinated, particularly due to the mobility of the handsets, and require a somewhat different approach. Since it is not mathematically possible to create signature sequences that are orthogonal for arbitrarily random starting points, unique "pseudo-random" or "pseudo-noise" (PN) sequences are used in *Asynchronous* CDMA systems. A PN code is a binary sequence that appears random but can be reproduced in a deterministic manner by intended receivers. These PN codes are used to encode and decode a users signal in Asynchronous CDMA in the same manner as the orthogonal codes in synchrous CDMA (shown in the example above). These PN sequences are statistically uncorrelated, and the sum of a large number of PN sequences results in Multiple Access Interference (MAI) that is approximated by a Gaussian noise process (following the "central limit theorem" in statistics). If all of the users are received with the same power level, then the variance (e.g., the noise power) of the MAI increases in direct proportion to the number of users. In other words, unlike synchronous CDMA, the signals of other users will appear as noise to the signal of interest and interfere slightly with the desired signal in proportion to number of users.

All forms of CDMA use spread spectrum process gain to allow receivers to partially discriminate against unwanted signals. Signals encoded with the specified PN sequence (code) are received, while signals with different codes (or the same code but a different timing offset) appear as wideband noise reduced by the process gain.

Since each user generates MAI, controlling the signal strength is an important issue with CDMA transmitters. A CDM (Synchronous CDMA), TDMA or FDMA receiver can in theory completely reject arbitrarily strong signals using different codes, time slots or frequency channels due to the orthogonality of these systems. This is not true for Asynchronous CDMA; rejection of unwanted signals is only partial. If any or all of the unwanted signals are much stronger than the desired signal, they will overwhelm it. This leads to a general requirement in any Asynchronous CDMA system to approximately match the various signal power levels as seen at the receiver. In CDMA cellular, the base station uses a fast closed-loop power control scheme to tightly control each mobile's transmit power. See Near-far problem for further information on this problem.

Advantages of Asynchronous CDMA over other techniques

Asynchronous CDMA's main advantage over CDM (*Synchronous* CDMA), TDMA and FDMA is that it can use the spectrum more efficiently in mobile telephony applications. (*In theory, CDMA, TDMA and FDMA have exactly the same spectral efficiency but practically, each has its own challenges - power control in the case of CDMA, timing in the case of TDMA, and frequency generation/filtering in the case of FDMA.*) TDMA systems must carefully synchronize the transmission times of all the users to ensure that they are received in the correct timeslot and do not cause interference. Since this cannot be perfectly controlled in a mobile environment, each timeslot must have a guard-time, which reduces the probability that users will interfere, but decreases the spectral efficiency. Similarly, FDMA systems must use a guard-band between adjacent channels, due to the random doppler shift of the signal spectrum which occurs due to the user's mobility. The guard-bands will reduce the probability that adjacent channels will interfere, but decrease the utilization of the spectrum.

Most importantly, Asynchronous CDMA offers a key advantage in the flexible allocation of resources. There are a fixed number of orthogonal codes, timeslots or frequency bands that can be allocated for CDM, TDMA and FDMA systems, which remain underutilized due to the bursty nature of telephony and packetized data transmissions. There is no strict limit to the number of users that can be supported in an *Asynchronous* CDMA system, only a practical limit governed by the desired bit error probability, since the SIR (Signal to Interference Ratio) varies inversely with the number of users. In a bursty traffic environment like mobile telephony, the advantage afforded by Asynchronous CDMA is that the performance (bit error rate) is allowed

to fluctuate randomly, with an average value determined by the number of users times the percentage of utilization. Suppose there are 2N users that only talk half of the time, then 2N users can be accommodated with the same *average* bit error probability as N users that talk all of the time. The key difference here is that the bit error probability for N users talking all of the time is constant, whereas it is a *random* quantity (with the same mean) for 2N users talking half of the time.

In other words, Asynchronous CDMA is ideally suited to a mobile network where large numbers of transmitters each generate a relatively small amount of traffic at irregular intervals. CDM (*Synchronous* CDMA), TDMA and FDMA systems cannot recover the underutilized resources inherent to bursty traffic due to the fixed number of orthogonal codes, time slots or frequency channels that can be assigned to individual transmitters. For instance, if there are N time slots in a TDMA system and 2N users that talk half of the time, then half of the time there will be more than N users needing to use more than N timeslots. Furthermore, it would require significant overhead to continually allocate and deallocate the orthogonal code, time-slot or frequency channel resources. By comparison, Asynchronous CDMA transmitters simply send when they have something to say, and go off the air when they don't, keeping the same PN signature sequence as long as they are connected to the system.

Spread Spectrum Characteristics of CDMA

Most modulation schemes try to minimize the bandwidth of this signal since bandwidth is a limited resource. However, spread spectrum techniques use a transmission bandwidth that is several orders of magnitude greater then the minimum required signal bandwidth. One of the initial reasons for doing this was military applications including guidance and communication systems. These systems were designed using spread spectrum because of its security and resistance to jamming. Asynchronous CDMA has some level of privacy built in because the signal is spread using a pseudorandom code; this code makes the spread spectrum signals appear random or have noise-like properties. A receiver cannot demodulate this transmission without knowledge of the pseudorandom sequence used to encode the data. CDMA is also resistant to jamming. A jamming signal only has a finite amount of power available to jam the signal. The jammer can either spread its energy over the entire bandwidth of the signal or jam only part of the entire signal. [3]

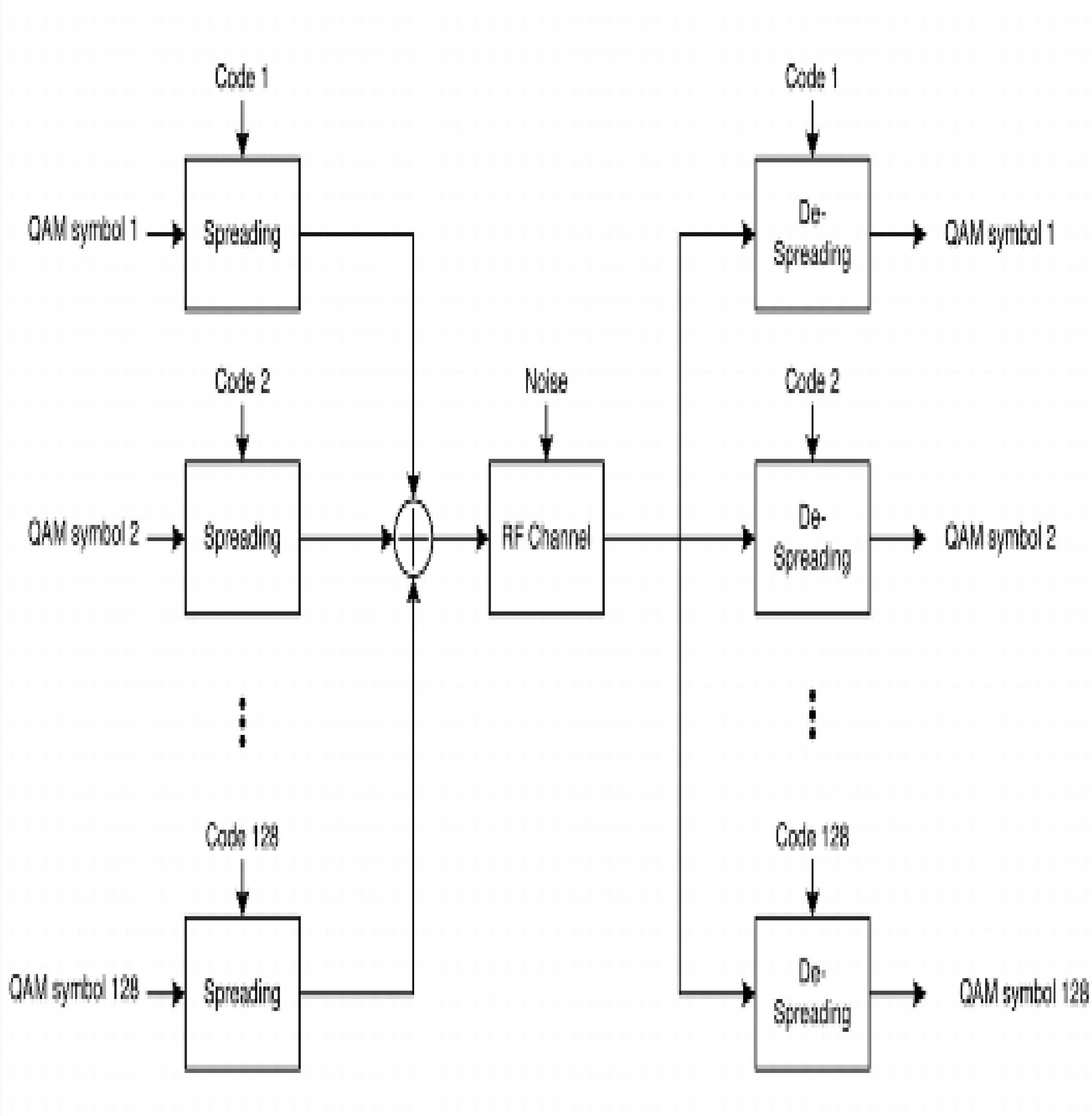
CDMA can also effectively reject narrowband interference. Since narrowband interference affects only a small portion of the spread spectrum signal, it can easily be removed through notch filtering without much loss of information. Convolution encoding and interleaving can be used to assist in recovering this lost data. CDMA signals are also resistant to multipath fading. Since the spread spectrum signal occupies a large bandwidth only a small portion of this will undergo fading due to multipath at any given time. Like the narrowband interference this will result in only a small loss of data and can be overcome.

Another reason CDMA is resistant to multipath interference is because the delayed versions of the transmitted pseudorandom codes will have poor correlation with the original pseudorandom code, and will thus appear as another user, which is ignored at the receiver. In other words, as long as the multipath channel induces at least one chip of delay, the multipath signals will arrive at the receiver such that they are shifted in time by at least one chip from the intended signal. The correlation properties of the pseudorandom codes are such that this slight delay causes the multipath to appear uncorrelated with the intended signal, and it is thus ignored.

Some CDMA devices use a rake receiver, which exploits multipath delay components to improve the performance of the system. A rake receiver combines the information from several correlators, each one tuned to a different path delay, producing a stronger version of the signal than a simple receiver with a single correlator tuned to the path delay of the strongest signal. [4]

Frequency reuse is the ability to reuse the same radio channel frequency at other cell sites within a cellular system. In the FDMA and TDMA systems frequency planning is an important consideration. The frequencies used in different cells need to be planned carefully in order to ensure that the signals from different cells do not interfere with each other. In a CDMA system the same frequency can be used in every cell because channelization is done using the pseudorandom codes. Reusing the same frequency in every cell eliminates the need for frequency planning in a CDMA system; however, planning of the different pseudorandom sequences must be done to ensure that the received signal from one cell does not correlate with the signal from a nearby cell. [5]

Since adjacent cells use the same frequencies, CDMA systems have the ability to perform soft handoffs. Soft handoffs allow the mobile telephone to communicate simultaneously with two or more cells. The best signal quality is selected until the handoff is complete. This is different than hard handoffs utilized in other cellular systems. In a hard handoff situation, as the mobile telephone approaches a handoff, signal strength may vary abruptly. In contrast, CDMA systems use the soft handoff, which is undetectable and provides a more reliable and higher quality signal. [5]

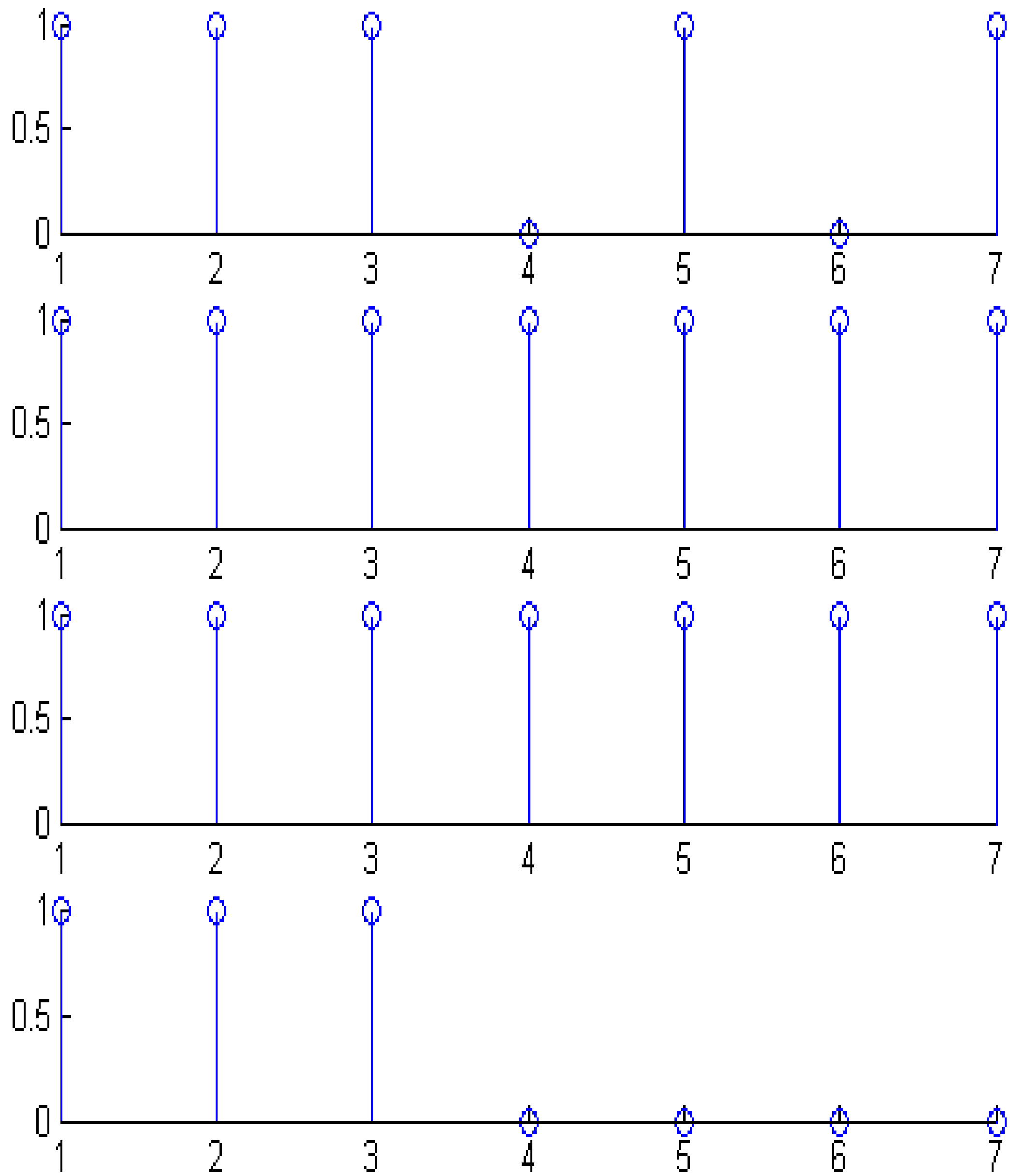


%MATLAB code for PN sequence generation

```
clc ;
clear all ;
close all;
N=input('enter the number of flip flops=');
   L=(2^N)-1;
   seq1=zeros(1,L);
   for i=1:N
      seq1(1,i)=1;
   end
   for i=N+1:L
   seq1(i)=~seq1(i-1).*seq1(i-1)+seq1(i-2).*~seq1(i-1);
   end
   subplot(4,1,1);
   stem(seq1);
   seq2=zeros(1,L);
for i=1:N
      seq2(1,i)=1;1
   end
```

```
for i=N+1:L
seq2(i)=~seq2(i).*seq2(i-1)+seq2(i-2).*~seq2(i-1);
end
 subplot(4,1,2);
stem(seq2);
seq3=zeros(1,L);
for i=1:N
    seq3(1,i)=1;
end
for i=N+1:L
seq3(i)=~seq3(i).*seq3(i-1)+seq3(i-1).*~seq3(i-1);
end
subplot(4,1,3);
stem(seq3);
seq4=zeros(1,L);
for i=1:N
    seq4(1,i)=1;
end
for i=N+1:L
seq4(i)=~seq4(i-2).*seq4(i-1)+seq4(i).*~seq4(i-1);
```

```
end

subplot(4,1,4);

stem(seq4);
```



%CDMA USING PN SEQUENCE CODE FOR 3 USERS%

```
clc ;

clear all ;

close all;

d = randn(1,3*100000) ;

c=1;

for o = 1:3

for j = 1:100000

if ( d(c)>=0)

D1(o,j)=1 ;

else

D1(o,j)=-1 ;

end

c = c+1 ;

end

end

for o = 1:3

j=1;

for k = 1:50000
```

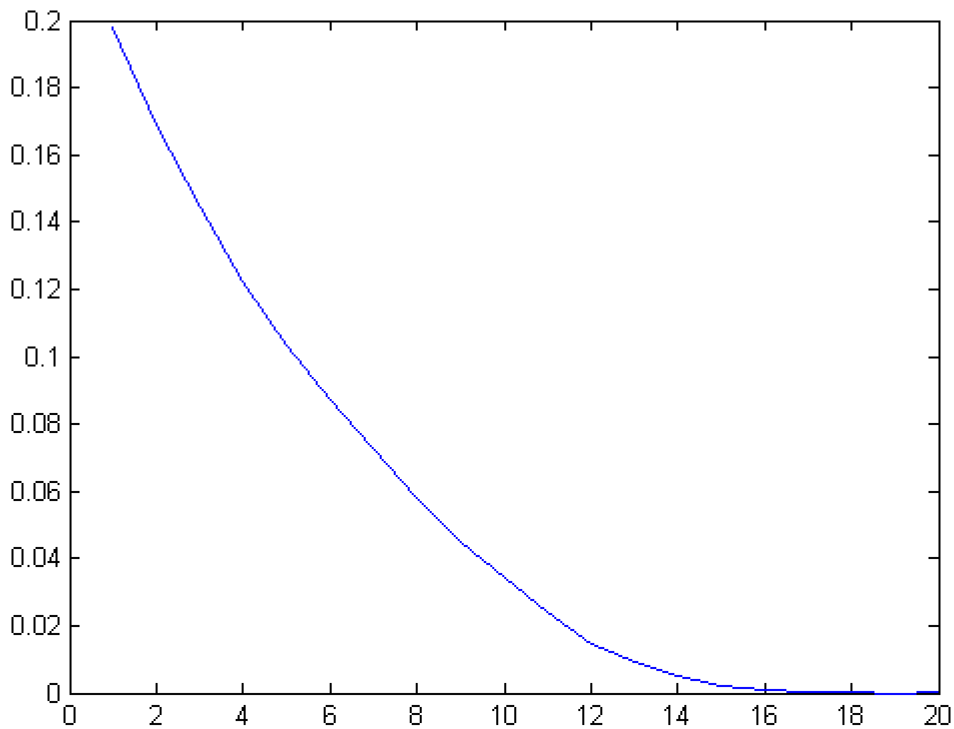
```
D(o,k)=D1(o,j)+(D1(o,j+1))*i;
j=j+2;
end
end
C=[-1 -1 -1 ;
   1 -1 -1 ;
   1 1 -1 ];
M = length(C);
M
Y = size(D);
Y
N = Y(1);
N
I = Y(2);
I
T = [];
G = zeros(I,M);
for n = 1:N
Z = zeros(I,M);
for o = 1:I
```

```
for m = 1:M

Z(o,m) = [D(n,o)*C(n,m)];

end

end

G = G + Z;

end

for o=1:I


G1(o,:)=ifft(G(o,:));

end

for snr=1:20

for o=1:I

G2(o,:)=awgn(G1(o,:),snr,0);

end

for o=1:I

G3(o,:)=fft(G2(o,:));

end

RECON = [];

for n = 1:N

TOT = zeros(1,I);
```

```
R = zeros(I,M);
for o = 1:I
for m = 1:M
R(o,m) = G3(o,m) * C (n,m);
TOT(o) = TOT(o) + R (o,m);
end
end
RECON = [RECON ; TOT / M];
end
RECON;
RECON1=zeros(M,I);
for v = 1:M
for j = 1:I
p= real(RECON(v,j));
if (p>=0)
RECON1(v,j)=1 ;
else
RECON1(v,j)=-1 ;
end
end
```

```
end
RECON2=zeros(M,I);
for o = 1:M
for j = 1:I
p= imag(RECON(o,j));
if (p>=0)
RECON2(o,j)=1 ;
else
RECON2(o,j)=-1 ;
end
end
end
RECON3=RECON1+(RECON2*i);
err = D-RECON3 ;
no_errs=0;
for o=1:M
for j=1:I
if(err(o,j)~=0)
no_errs=no_errs+1;
```

```
end

end

end

ber(snr)=no_errs/(I*M);

end

ber

 snr=1:20

 plot(snr,ber);
```



%MATLAB code for Walsh-Hadamard Code generation

```
clc;
close all;
clear all;
n=input('enter order of square hadamard matrix');
m=[]
for i=1:n
        m(1,i)=-1;
end
 for i=2:n
        for j=1:n/2
            m(i,j)=-1;
        end
    end
    for i=2:n
            for j=((n/2)+1):n
         m(i,j)=1;
        end
        end
```

```
 m
m2=[];
m2=[m m;
   m -m];
m2
```

%CDMA USING HADAMARD CODE FOR 4 USERS%

```
clc ;
clear all ;
close all;
d = randn(1,4*100000) ;
c=1;
for o = 1:4
for j = 1:100000
if ( d(c)>=0)
D1(o,j)=1 ;
else
D1(o,j)=-1 ;
```

```
end
c = c+1 ;
end
end
for o = 1:4
j=1;
for k = 1:50000
D(o,k)=D1(o,j)+(D1(o,j+1))*i;
j=j+2;
end
end
C=[-1 -1 -1 -1;
  -1 1 -1 1;
  -1 -1 1 1;
  -1 1 1 -1];
M = length(C);
M
Y = size(D);
Y
N = Y(1);
```

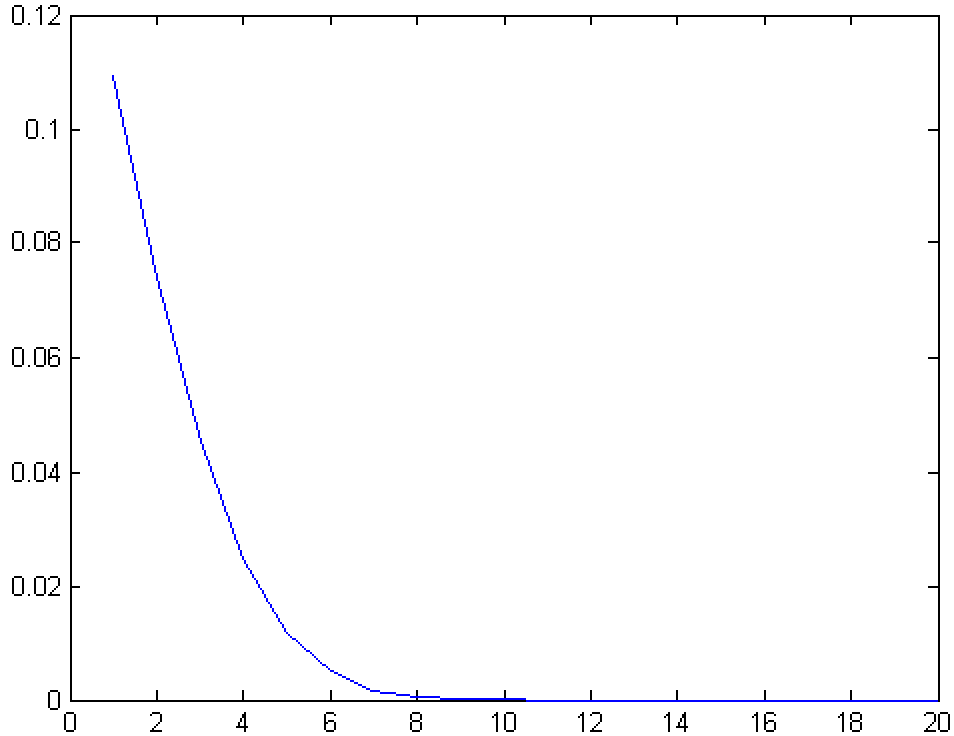
```
N

I = Y(2);

I

T = [];

G = zeros(I,M);

for n = 1:N

Z = zeros(I,M);

for o = 1:I

for m = 1:M

Z(o,m) = [D(n,o)*C(n,m)];

end

end

G = G + Z;

end

for o=1:I


G1(o,:)=ifft(G(o,:));

end

for snr=1:20

for o=1:I
```

```
G2(o,:)=awgn(G1(o,:),snr,0);
end
for o=1:I
G3(o,:)=fft(G2(o,:));
end
RECON = [];
for n = 1:N
TOT = zeros(1,I);
R = zeros(I,M);
for o = 1:I
for m = 1:M
R(o,m) = G3(o,m) * C (n,m);
TOT(o) = TOT(o) + R (o,m);
end
end
RECON = [RECON ; TOT / M];
end
RECON;
RECON1=zeros(M,I);
for v = 1:M
```

```
for j = 1:I

p= real(RECON(v,j));

if (p>=0)

RECON1(v,j)=1 ;

else

RECON1(v,j)=-1 ;

end

end

end

RECON2=zeros(M,I);

for o = 1:M

for j = 1:I

p= imag(RECON(o,j));

if (p>=0)

RECON2(o,j)=1 ;

else

RECON2(o,j)=-1 ;

end

end

end
```

```
RECON3=RECON1+(RECON2*i);
err = D-RECON3 ;
no_errs=0;
for o=1:M
for j=1:I
if(err(o,j)~=0)
no_errs=no_errs+1;
end
end
end
ber(snr)=no_errs/(I*M);
end
ber
 snr=1:20
```

```
plot(snr,ber);
```



CDMA OVERLOADING:

The number of users supported in a DS-CDMA cellular system is typically less than spreading factor (N), and the system is said to be underloaded. Overloading is a technique to accommodate more users than the spreading factor *N* for mobile applications. This is an efficient way to increase the number users in a fixed bandwidth, which is of practical interest to mobile system operators. In fact this type of channel overloading is provisioned in the **3G** standard. Among the approaches described in the literature, the most efficient ones use multiple sets of orthogonal codes For the first N users, the system allocates orthogonal codes drawn from the first set of N codes. When the number of intending users exceeds 'N', the excess users are accommodated in the system by providing suitable codes drawn from a second set of M codes. In this way, we are able to accommodate more number of users than the spreading length N (K>N), and the cell becomes overloaded.

System model:

In the sequel we will consider the DS-CDMA system with processing gain *N* and the number of users *K (=M+N)*. The waveforms of the first signal set in O/O scheme are assigned to the first *N* users, and *M* waveforms from the second set are assigned to the next *M* users. We assume that signal spreading is performed by means of user-specific spreading sequences. Let us denote by

$$S = [s_1, s_2, s_3, \ldots, s_k]$$

the $N \times K$ matrix containing the *K* signature sequences of length *N* associated to the *K* users. Here, we consider schemes where the sequences assigned to users in the same group are orthogonal. In this work, we have considered two different orthogonal Gold code sets as the spreading waveform for users.

The following notations are used to describe the transmission model:

X=(x1,x2,x3,.....,xk)^T is the set of BPSK transmitted bits associated to the K users during a given CDMA bit period,

A = *diag(* a_k $k \in$(1....k) is the matrix whose coefficients k a denote the k-th user's complex channel attenuation.

$$\mathbf{r} = \left(r_1, r_2, \ldots\ldots, r_N \right)^T$$

is the received signal block.

Assuming that the channel attenuations do not vary within one symbol interval, the received signal block can be written as follows:

$$r_n = \sum_{j=1}^{K} s_{nj} a_j x_j + z_n \quad n = 1, \ldots\ldots, N \qquad (1)$$

This is equivalent to **r = SAx+z** (2)

where z =(z_1,z_2,z_3,....$z_{N)}$^{T} is the vector of AWGN samples of variance

$$\sigma_z^2 = N_0 \, .$$

We notice that the case of an AWGN channel is obtained by taking k **A = I** . The Rayleigh fading channel model can be described by fading amplitudes generated according to

$$a_k = a_k^{(I)} + \mathbf{j} a_k^{(Q)}$$

,

where a_k(I) and a_k(Q) are independent zero-mean real Gaussian distributed random variables with variance

$$\sigma^2_{a_k^{(I)}} = \sigma^2_{a_k^{(Q)}} = 1/2 .$$

ITERATIVE INTERFERENCE CANCELLATION RECEIVER:

In this work, an iterative interference cancellation receiver is used to remove the MAI between the two sets.The basic principle of this receiver is to iteratively remove the estimated interference from each set due to the users of other set in multiple stages such that near single user performance is achieved. Let us consider the *k* th user to be detected. If we correlate the received signal with the sequence assigned to the considered user (dispreading operation), we obtain:

$$v_k = \sum_{n=1}^{N} r_n s_{nk}{}^* a_k{}^* = \left|a_k\right|^2 x_k + I\left(k\right) + z_k^{'}, \qquad (3)$$

$$I\left(k\right) = \sum_{\substack{j=1 \\ j\neq k}}^{K} x_j \sum_{n=1}^{N} s_{nj} a_j s_{nk}{}^* a_k{}^* \;, \qquad (4)$$

$$z_k^{'} = \sum_{n=1}^{N} z_n s_{nk}{}^* a_k{}^* \qquad (5)$$

and the superscript denotes complex conjugation.We observe that **z’** is a Gaussian noise, with the same variance as **z**. Furthermore, we notice that because of the orthogonality of the spreading sequences in each set of users, the expression of the interference caused by the other users on the *k*th user reduces to:

$$I(k) = \sum_{j=N+1}^{K} x_j \sum_{n=1}^{N} s_{nj} a_j s_{nk}{}^* a_k{}^* \quad \text{for } k = 1,2,\ldots\ldots,N \qquad (6)$$

$$I(k) = \sum_{j=N}^{K} x_j \sum_{n=1}^{N} s_{nj} a_j s_{nk}{}^* a_k{}^* \quad \text{for } k = N+1,2,\ldots\ldots,K \qquad (7)$$

These expressions are used in the iterative interference cancellation presented in the next section.

B. Soft-Decision Interference Cancellation

First of all, the correlator outputs, i.e. the v_k 's, must be computed for each user ($k = 1, 2, \ldots, K$).

First iteration: To begin with, the v_k 's obtained for set-1users ($k = 1, 2, \ldots, N$) are divided by $|a_k|^2$ and sent to the detector, which provides the first estimations

$\hat{x}_j^{(1)}$ ($j = 1, 2,$ N) of set-1 symbols. Next, the estimated interference of set-1users on each set-2 user is synthesized by substituting $x_j(1)$ and x_j in (7). The estimated interference terms are subtracted from the values of v_k associated to the set-2 users ($k = N+1, \ldots, K$). The resulting signals are then sent to the detector after division by $a|k|^2$, giving symbol decisions $\hat{x}_j^{(1)}$ ($j = N+1, \ldots, K$) for the set-2 users. In an AWGN channel, we consider

$a_k = 1, k \in \{1,\ldots\ldots,K\}$.

.Iteration i ($i > 1$): The symbol decisions made for set-2 users in the (i-1)th iteration

($\hat{x}_j^{(i-1)}$, $j = N+1, \ldots, K$)

are used to synthesize the interference from these users on each set-1user, by substituting for $\hat{x}_j^{(i-1)}$

for x_j in (6). The estimated interferences are subtracted from the v_k 's obtained for set-1 users (k = 1, 2, …, N). After dividing by $|a_k|^2$, improved decisions

$\hat{x}_j^{(i)}$ (j = 1, 2, …, N) :

are made for the symbols transmitted by the set-1 users. These decisions are next used to synthesize the interference from set-1 users on each set2 user by using (7). The estimated interferences are subtracted from the v_k 's associated to the set-2 users (k = N+1, …, K).

After dividing by $|a_k|^2$, the symbol decisions correspondingto set-2 userss at iteration

i ($\hat{x}_j^{(i)}$, j = N+1, …, K)

arecomputed.
To make soft decisions, we have used the piecewise linear function described in [7] as the nonlinearity involved in the decision device, except for the last iteration, where hard decisions are made. The piecewise linear function is parameterized byθ and has the following expression:

$$\phi(x) = \begin{cases} x/\theta & |x| < \theta \\ \operatorname{sgn}(x) & |x| \geq \theta \end{cases}$$

The value of θ is selected so as to minimize the bit error rate (BER) after 10 iterations. This non-linearity is used in the detector to provide the soft values corresponding to BPSK symbols.

%MATLAB CODE for CDMA OVERLOADING

```
clc ;

clear all ;

close all;

d = randn(1,4*20000) ;

c=1;

for o = 1:4

for j = 1:20000

if ( d(c)>=0)

D1(o,j)=1 ;

else

D1(o,j)=-1 ;

end

c = c+1 ;

end

end

for o = 1:4

j=1;

for k = 1:10000
```

```
D(o,k)=D1(o,j)+(D1(o,j+1))*i;
j=j+2;
end
end
d1 = randn(1,4*20000) ;
c1=1;
for o = 1:4
for j = 1:20000
if ( d1(c1)>=0)
D2(o,j)=1 ;
else
D2(o,j)=-1 ;
end
c1 = c1+1 ;
end


end
for o = 1:4
j=1;
for k = 1:10000
```

```
D3(o,k)=D2(o,j)+(D2(o,j+1))*i;
j=j+2;
end
end
C = [ -1 -1 -1 -1  ;
-1 1 -1 1;
-1 -1 1 1
-1 1 1 -1];
C1=[ -1 -1 -1 -1  ;
-1 1 -1 -1;
1 1 1 -1
1 -1 -1 1];;
M = length(C);
M
Y = size(D);
Y
N = Y(1);
N
I = Y(2);
I
```

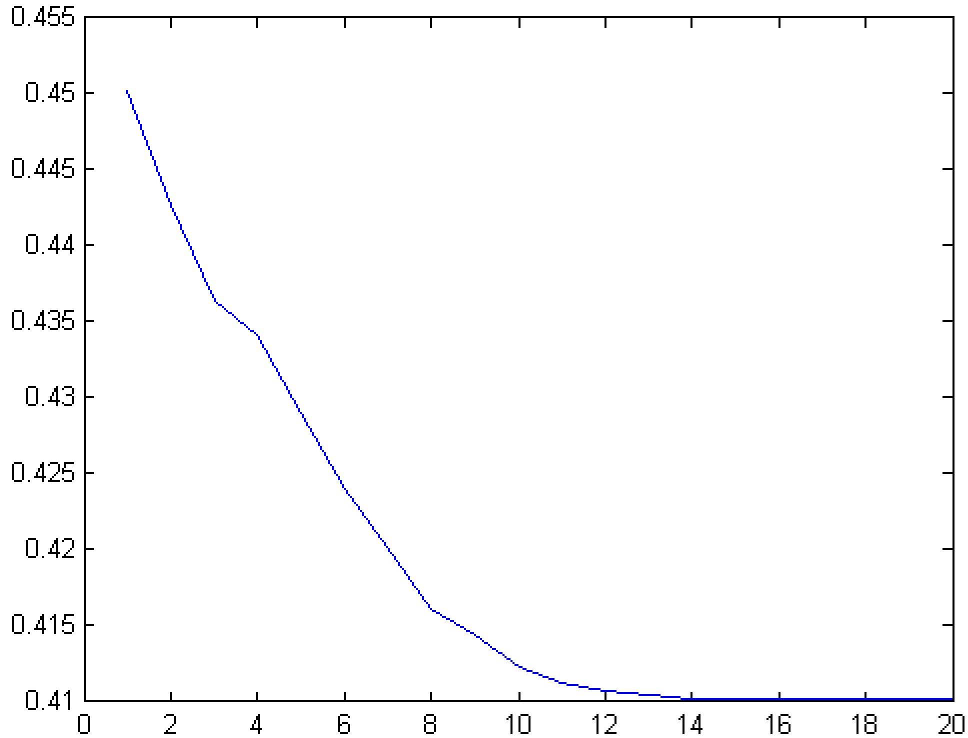
```
T = [];

G = zeros(I,M);

for n = 1:N

Z = zeros(I,M);

Z1 = zeros(I,M);

for o = 1:I

for m = 1:M

Z(o,m) = [D(n,o)*C(n,m)];

end

end

for o = 1:I

for m = 1:M

Z1(o,m)=[D3(n,o)*C1(n,m)];

end

end

G = G + Z+ Z1;

end

for o=1:I

G1(o,:)=ifft(G(o,:));

end
```

```
for snr=1:20
for o=1:I
G2(o,:)=awgn(G1(o,:),snr,0);
end
for o=1:I
G3(o,:)=fft(G2(o,:));
end
RECON = [];
for n = 1:N
TOT = zeros(1,I);
R = zeros(I,M);
for o = 1:I
for m = 1:M
R(o,m) = G3(o,m) * C (n,m);
TOT(o) = TOT(o) + R (o,m);
end
end
RECON = [RECON ; TOT / M];
end
RECON;
```

```
RECON1=zeros(M,I);
for v = 1:M
for j = 1:I
p= real(RECON(v,j));
if (p>=0)
RECON1(v,j)=1 ;
else
RECON1(v,j)=-1 ;
end
end
end
RECON2=zeros(M,I);
for o = 1:M
for j = 1:I
p= imag(RECON(o,j));
if (p>=0)
RECON2(o,j)=1 ;
else
RECON2(o,j)=-1 ;
end
```

```
end
end
RECON3=RECON1+(RECON2*i);
err = D-RECON3 ;
no_errs=0;
for o=1:M
for j=1:I
if(err(o,j)~=0)
no_errs=no_errs+1;
end
end
end
ber(snr)=no_errs/(I*M);
end
ber
snr=1:20
```

plot(snr,ber);



The Application to CDMA Wireless Technology:

A cellular telephone system is designed to serve a large number of users whomay be in the same geographical area, and may be attempting to talk at thesame time. The term “cellular” refers to the fact that a very large service area isdivided up into “cells”, where each cell has a relay tower to pick up and forwardcalls from its local region. For mobile users (e.g, someone talking on a cell phonewhile driving), the system must provide a way to “hand off” this user from onecell to another, preferably without the user being aware that this transition iseven occurring. (It is called a “soft handoff” if the user is communicating withboth the old and the new base station before the old one is released.)With simultaneous users in a limited geographical region, the obvious problemis the interference of the calls with each other.

The earliest proposed systemsaddressed this problem either by assigning different radio frequencies to the varioususers (called frequency division multiple access, or FDMA), or by assigning different time slots (necessarily recurring soon enough to maintain call continuity) to different users (called time division multiple access, or TDMA). However,by nearly universal agreement, a superior approach, used in some “second generation”(2G) cell phone systems, and planned or already implemented in virtuallyall “third generation”(3G) systems, is known as code division multiple access,or CDMA for short.The basic idea of CDMA is to use a wide frequency band common to all theusers, whose signals are made distinguishable by assigning mutually uncorrelatedcode modulation patterns to the various users. Communication systemsfor point-to-point military communications using this basic type of code modulationhad been in use since the 1960’s, and were known as direct sequence spread
spectrum systems; but CDMA was invented to handle the multi-user situationwith many telephones transmitting simultaneously We have previously mentioned a number of ways to obtain fairly large sets of binary sequences with mutually (pairwise) low cross-correlation values. However,the first CDMA standard to be implemented was the IS-95 standard,introduced by QUALCOMM, INC., where the modulation was based on theuse of m-sequences. Specifically, if a particular m-sequence of period 2n ¡ 1is used, each of its 2n ¡ 1 cyclic shifts are very nearly uncorrelated with oneanother. It is these shifted versions of the same underlying sequence that providethe set of mutually non-

interfering signals for the IS-95 standard and inmany of its successors, such as CDMA2000. (Actually, with a spreading sequenceof period 242 ¡ 1, true orthogonality is not achieved over the shortintegration period involved.

The cross-correlation achieved in practice averageson the order of 1=pm, where m is the number of terms in the integration period.)Observe that for this approach to work, it is necessary to maintain overallcommunication coherence. If the signals of different users are allowed to driftrandomly in time, some of advantage of the low-correlation may be lost.

when a handoff occurs the new base station is prepared, so that the user terminal acquires immediately, without a prolonged search. The individual users have different—known—offsets, but due to position and velocity they may driftamong themselves by as much as several sequence terms, or "chips".This isalso accommodated by a very brief search. Such imperfections in the relativetiming do not noticeably affect cross-correlation between different users, whichis on the order of 1=pm because of partial period correlation.)Note that the basic idea will work in exactly the same way if the m-sequenceis replaced by any other binary sequence corresponding to a cyclic Hadamarddifference set. Thus, the many basically different constructions described in thisbook for cyclic Hadamard difference sets can be viewed as alternative ways toimplement CDMA code modulation. While linear shift register sequences areextremely easy to generate, advances in computer technology have rendered this advantage relatively unimportant.In the European standard for 3G, called WCDMA (for wide-band CDMA)or UMTS, the main difference is that the base stations are not mutually synchronizedby GPS. Hence each user terminal must fully resynchronize with anew base station when it enters its sphere of influence. (Once it is synchronized,it operates essentially like CDMA2000, including soft handoffs.)It would be conceivable to field a fully non-coherent CDMA system, butthis would entail many new difficulties.

The cyclic shifts of a single binarysequence would no longer guarantee that the users would be mutually distinguishable.Instead, sets of sequences, like the Gold codes, which have favorableautocorrelation individually and favorable mutual crosscorrelation, would berecommended.

In view of the Welch-Sidelnikov bound on simultaneous correlation(see the work of Sidelnikov and Welch), the coherent system using cyclicshifts of an m-sequence should outperform non-coherent systems constrained as to both autocorrelation and crosscorrelation. (The terms “coherent” and“noncoherent”normally refer to phase, but in this section we use them with referenceto chip position in the modulating sequence.)

It is unlikely that anyone wouldchoose to implement a “non-coherent” system for CDMA. (In recent years, a extensive literature has grown up around signal sets with simultaneous autoandcross-correlation constraints called “optical orthogonal codes”, from one ofthe early suggested applications to optical communications.) In order to field a practical CDMA wireless telephony system, many additionaltechnical problems must be solved. For example, the information to beconveyed must be incorporated into the signal. The “soft handoff” issue mustbe addressed. Signal fading and blockage due to obstacles in the environmentmust be dealt with. Interference from sources other than competing cell-phonecalls must be overcome. These engineering issues are beyond the scope of thepresent book. However, for an excellent account by one of the leading pioneersof QUALCOMM INC.’s original CDMA system, see (Viterbi’s book).The “multiple access” aspect of CDMA refers to the possibility of a numberof users operating in the same signalling environment at the same time, withoutdrowning out each other’s signals.

A family of combinatorial designs which we have named “Tuscan Squares” in Golomb and Taylor (1985), originally introducedfor frequency-hop multiple access applications, has already become thesubject of an extensive combinatorial literature.Signal design problems in communications almost invariably correspond tointeresting combinatorial problems. Conversely, almost every major family ofcombinatorial designs can be interpreted as the solution to a family of signal design problems.

CONCLUSIONS:

We have given the description if CDMA and also its comparision with TDMA,FDMA. We have shown its matlab code and simulation results (ber vs snr plot).we have given an overview of recently developed channel overloading concept that is applicable to both multi users and single user communications.The higher channel overloading rate achieved on multiple access channels is due to the fact that BPSK with complex spreading is employed.

References:

[1] F. Adachi, M. Sawahashi and H. Suda, ” Wideband DS-CDMA for Next- Generation Mobile Communication Systems”, IEEE Commun. Mag., vol.36, pp. 56-59, September 1998

[2] P. Kumar, M. Ramesh, and S. Chakrabarti, “ Overloading Cellular DS-CDMA: A Bandwidth Efficient Scheme for Capacity Enhancement” Springer-Verlag LNCS, vol. 4904, pp.515-527, 2008

[3] H. Sari, F. Vanhaverbeke, M. Moeneclaey and “Multiple access using two sets of orthogonal signal waveforms,” *IEEE Commun. Lett.*, vol. 4, no. 1, pp. 4-6, Jan. 2000

[4] H. Donelen and T.O’Farrell, ” Methods for generating sets of orthogonal sequences”, *Electronics Letters*, vol. 35, pp. 1537-1538, Sept. 1999

[5] T. ***S.*** Rappaport, "Wireless Communications: Principles and Practice," lEEE Press, New York, andPrentice Hall, New Jersey, 1996.
[6] H. Sari and G. Karam, "Orthogonal Frequency-Division Multiple Access and its Application toCATV Networks," European Transactions onTelecommunications (ETT), vol. 9, no. 6, pp. 507-***5*** 16, November-December 1998.
[7] N. Ahmed and K. R. Rao, "Orthogonal Transforms for Digital Signal Processing," Springer Verlag, 1975, BerlidHeidelberg, Germany.
[8].SI E. H. Dinan and B. Jabbari, "Spreading Codes for Direct Sequence CDMA and Wideband CDMACellular Networks," IEEE Communications Magazine, vol. 36, pp. 48-54, September 1998.
[9] RR Mueller and J.B. Huber, "Iterated Soft-Decision Interference Cancellation for CDMA," in Digital Wireless Communications, M. Luise and **S.** Pupolin(Editors), pp. **1 10- 1 15,** Springer-Verlag, **1998.**
Authorized