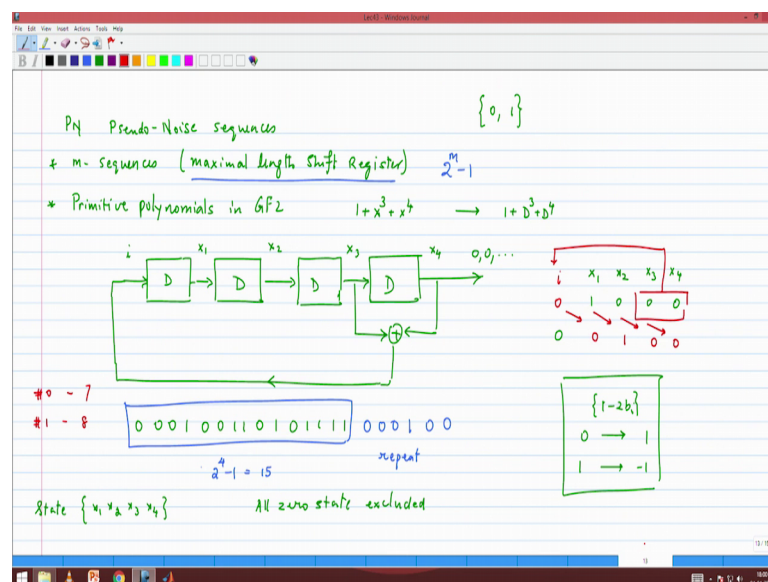


Introduction to Wireless and Cellular Communication
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Lecture - 43
Introduction to CDMA
Properties of Spreading Sequences – Part 2

Lecture 44, but we basically continue from where we left off so that the properties can be built upon. So, one thing that you will notice is that if I initialize with the all 0 state then I will get stuck in the all 0 state I will not come out of it.

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So, in the shift register sequences, if you think of x_1, x_2, x_3, x_4 as a state x_1, x_2, x_3, x_4 as a form of a state of the state machine, then it will cycle through the maximum length shift register sequence basically says that the this interconnection is such that the state we will not repeat until you have gone $2^m - 1$ the power of m minus 1, why is it m minus 1 because the all 0 state is excluded, because once you go into the all 0 state you will not come out of it.

So, all 0 state is excluded all 0 state is not present is in our in this system, all 0 state is excluded except for that all the other 4 states represented by 4 bits. So, that will be $2^4 - 1$ the power of 4 minus the all 0 state are the present in this shift register sequence. So, please do check that you do cycle through all of those. There are some interesting

properties that will emerge that are used by CDMA systems and that I would like to just quickly run through those properties. One of the important points to note is that if you look at the by the way many times when you prove the properties of PN sequences, we will use the following mapping 0 gets mapped to a 1 and a 1 gets mapped to a minus 1.

So, basically the 1 minus 2 b I is the mapping that is used and therefore, we get they. So, just. So, that since I meant told you that you could do both mappings possible, but most of the time when we talk about the properties of PN sequences we are using this mapping. So, take a quick look at the this length 15 which is going to repeat afterwards. So, the number of zeros 1 2 3 4 5 6 7, the number of ones is 8 and this is a universal property again PN sequences should have equal number of zeros and ones, that only then. So, basically this is called the balance property.

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Lecture 44

Balance m-seq $\frac{2^m}{2} - 1$ zeros $\frac{2^m}{2}$ ones

length $2^m - 1$

{ 0001 0011 0101 111 }

'Run' = seq of the same bit

Runs of length 1 = 4

Runs of length 2 = 2

Run Length property

of runs of length 1 = $\frac{1}{2} \times \text{total \# runs}$

$2 = \frac{1}{2} \times 4$

$3 = \frac{1}{2} \times 6$

So, the number of zeros and ones is almost the same and in all these m sequences they will be 2 to the power of m by 2 minus 1 ones sorry. So, many zeros that the number of ones is slightly is 1 more, and 2 to the power of m by 2 ones. So, and you will get. So, that that we will give you 2 to the power of m minus 1 total length of the sequence. So, basically it maintains that balance across all primitive polynomials if we generate you will find that this is the property. And of course, the length of the sequence has to be 2 to the power m minus 1, otherwise the it is no longer a maximum length shift register

sequence and all the properties of talking about do not apply if you do not have that type of a sequence, another important property for which we need to refer to the sequence.

So, let me just write it down 0 0 0 1 0 0 1 1 0 1 0 1 1 1 1 as the this is the length sequence of length 15, and basically we define something called a run. Run is a sequence of successive digits that are the same. So, run represents a sequence of the same bits. So, if it is 0 if you can 0 0 that is a run of length 2, 0 0 0 is a run of length 3 of the same bit. So, number of runs of length 1 can you just tell me, this is a run of length 1, this is 1, this is 1, this is 1. So, number of runs of length is equal to 4, runs of length 2, runs of length 2 is this, this combination, this combination. So, that is equal to 2 and you will fine.

So, basically this property is called the run length property and the run length property says the following. It says that the number of runs of length 1 again these are very interesting that these properties. So, this is approximately 1 half of the total number of runs. So, take all the number all the possible runs of length 1 2 3 all of those and then the number of runs of length 2 is approximately 1 fourth of the total, number of runs of length 3 is 1 eighth of the total and so on. So, basically the likelihood of runs off longer length become increasingly less probable. So, again if it is a truly random sequence getting a long string of ones it should be very unlikely and that sort of reflected in the PN sequence as well.

Now, this run like properties not something that we look at much, but the property that we do look at very very closely is this balance property, because that comes to play in a number of proper things that we are interested in. So, let me just give you one very interesting very simple calculation.

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Correlation $\{\pm 1\}$

\oplus

0 0 0		0 0		1	0		0	1	1	1	
1 0 0		0 0		1	0		0	1	1	1	
<hr/>											
d	a	a	d	d	a	d	a	d	d	a	a

Correlation = -1

* agrees 7 $\rightarrow 1 \times 7$
 * disagrees 1 $\rightarrow -1 \times 1$

 -1

Shift property

b
 b_k

$b[n] \oplus b_k[n] = b_{k \oplus n}[n]$

$1 \neq k$

I would like you to do the following correlation. The correlation is between the basic sequence and sequence that is right shifted by one. So, the basic sequence is 0 0 0 1 0 0 1 1 0 1 0 1 1 1 like get at a 1 1 more 1 is that. So, now, do a circular shift. So, the 1 comes to this time then come 0 0 0 1 0 0 1 1 0 1 0 1 1 1 ok.

Now, correlation when correlation for that we will need do plus minus 1 then you can multiply and add, but if you want to do it in the binary field itself you can do exclusive or effectively you will get the same thing and that is a property that I am sure you are familiar with from g f 2 operations, but do the exclusive or. So, basically you have to find out where all the bits agree and where that disagree. So, disagree means the output will be 1, agree means the output will be 0. So, a disagree agree, disagree agree, disagree disagree, disagree, disagree, disagree agree, agree agree ok.

So, number of agrees 1 2 3 4 5 6 7, number of agree 7 which means the number of disagrees must be equal to 8 basically if I have to if I add them up right. So, the each of the agrees corresponds to a 0 so that will basically contribute to a plus 1. So, 1 into 7 these disagrees will correspond to 1 they will come point to minus 1 into 8, if I add I will get a minus 1 as the total. So, this correlation value of minus 1 is a very very interesting property when we do these circular shifts, now there is an reason it is. So, interesting is the following these m sequences have a property called the shift property. Again if you have studied them before I will quickly mention them. So, if I have a sequence.

So, basically this take the original sequence let me call if I call that as b , and let me call another sequence b subscript k ; that means, I have done k right circular shifts of that. So, basically if I now do b of n that is each of those bits exclusive or with b k of n ; that means, the that is an sequence which has been shift right shifted this will come out to be b subscript l of n , where l is not equal to k , it will come out to be another cyclic shift of the original sequence. So, the sequence plus a cyclic shift will give you another cyclic shift. Now the fact that what cyclic shift it is does not matter the fact that it is a closed group basically you add 2 of them, you will get an answer that comes from within the group itself ok.

So, that is an interesting property by itself. So, now, if I combine this shift property and this correlation property, then I get a very interesting and a powerful result which is the take away from this discussion.

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Correlation

$$R_x[k] = \frac{1}{Q} \sum_{l=0}^{Q-1} x[l] x^*[l-k \bmod Q] = -\frac{1}{Q}$$

$$x_1[n] \cdot x_2[n] = 1 - 2(s_1[n] \cdot s_2[n])$$

{±1}

$$x_1[n] = 1 - 2s_1[n]$$

$$x_2[n] = 1 - 2s_2[n]$$

$$= \frac{1}{Q} \sum_{l=0}^{Q-1} 1 - \{s_1[n] \cdot s_2[(n-k) \bmod Q]\}$$

$$s[(n-k) \bmod Q]$$

$$R_x[k] = -\frac{1}{Q} \quad k \neq 0$$

$$R_x[0] = 1$$

So, basically if I now define a correlation I am defining a very specific type of correlation is not the definition R_x of k is defined as 1 over Q , summation l is equal to 0 through Q minus 1 , x of l , x star of l minus k modulo Q . Modulo Q means it is a cyclic shift basically. So, what this says is I am I have defined my autocorrelation in terms of a sequence with cyclic shifts of itself.

So, basically it is a property that you know correlation typically would be used as slide linearly, but this is circular type of correlation that we have done ok. Now correlation of

a sequence with it shift with itself will give me what minus 1. So, this is guaranteed to be to be minus 1 over Q. So, basically if k is equal to 0, $R_x(0)$ you will get 1. So, at 0 lag you get 1 at all other lags you get some small number minus 1 over Q. Now that reminds you of the property of random sequences that is exactly what we have been able to achieve. At least my correlation point of view these pseudo random sequences actually map to the, but the only thing is I am not doing linear correlation I am doing a circular correlation, but it is very important for us to know that and please do look up the basic proof of this correlation property, it relies on the fact that correlation can be relied written in terms of a.

So, in other words if I do this x_1 of n, x_2 of n. So, if where x_1 and x_2 are from plus minus ones. This is the same as $1 - 2 \times s_1$ of n exclusive or s_2 of n and the relationship is that x_1 of n is equal to $1 - 2 \times s_1$ of n is at the right way to yeah $1 - 2 \times s_1$ of n, x_2 of n is $1 - 2 \times s_2$ of n. So, basically s_1 and s_2 are the binary counter parts and you map it to plus 1 minus 1 using this. This is the you can just you can do exhaustively verify because there only 4 combinations possible, you can verify that this is true. If this is true then you can write this step as $\frac{1}{Q} \sum_{l=0}^{Q-1} (1 - \sum_{k=0}^{Q-1} s_1(n-k) \oplus s_2(n-k))$ should be should be minus k sorry this will be $s_1(n-k) \oplus s_2(n-k)$ modulo Q ok.

Now, this we know is another shifted sequence of the same of the length. So, this will be sum of n, $n - l$ modulo Q, some other shift $s_1(n - l)$ modulo Q and basically if I sum any of these sequences what I will get is minus 1. So, basically you can prove that in the general case $R_x(k)$ is equal to minus 1 over Q, if k not equal to 0 and $R_x(0)$ equal to 1. So, that is a general proof or general result you can verify that basically construct the proof and verify that. Now comes the very very interesting and important results the first of all couple of observations these are PN sequences correct.

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Q1 FB taps are known \rightarrow How many outputs observe?

Q2 FB taps are not known \rightarrow " ?

Multiple Users

$m=4$ 15 sequences

Original
+ 14 shifted versions

$2^m - 1$

original
circular shifted versions

If all codes are assigned
 \rightarrow Cannot distinguish between multipath of user
vs multicarrier

Now, if you knew what the feedback taps where. So, question number one. So, you know the feedback taps that you know the shift register feedback taps are known how many outputs should you observe before you can figure out what the feedback taps are. Is the question clear, I have given you the connections I have given you the shift register connections ok.

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PN Pseudo-Noise sequences

$\{0, 1\}$

m -sequences (Maximal length Shift Register) $2^m - 1$

* Primitive polynomials in GF2 $1+x^3+x^4 \rightarrow 1+D^3+D^4$

Block diagram of a 4-stage shift register with feedback from stages 3 and 4 to stage 1.

Sequence: 000100110111 (repeat)

All zero state excluded

Rate $\{x_1, x_2, x_3, x_4\}$

I given you this connections, but how many of output should you observe before you can basically say now I can figure out the rest of the sequence. Think about that you let me

on the answer. So, how many output should I observe. The more interesting question is if I do not know the feedback taps, feedback taps not known are not known in that case how many should I observe. This is the very important question and the reason for that will become known very very soon ok.

Because PN sequences are often used in encryption. So, if you want to crack what the encryption or basically you must be able to synchronize with the with the PN sequence and so, you must be able to figure out what the feedback taps are and what are the current state. So, that you can then track the sequence; so, but that is an aside yeah interesting just for it simple things for you to think about. Now comes the issue of multiple users, take the case where m equal to 4 I had a length 15 sequence, now how many other sequences are there which have good properties with this original sequence all the right shifted versions of it.

So, plus. So, there is the original sequence plus 14 shifted versions am I correct shifted versions. They correct because basically m is 2 to the power of minus 1 is the length of the sequence. So, there is 1 original and then there are these circular shifts all the circular shifted versions. So, how many sequences do I have? 2 to the power of m minus 1 sequences are there. So, now, if I want to have each use have a sequence, I have to give you 1 sequence the next person I give 1 right shifted version of that and the other next person and other right shifted version of that. Now in a multipath environment I am the base station your transmitting let us say 3 of you, have got one shifted version original sequence 1 shift 2 shifts.

Now, it is a multipath environment. Now I am receiving the signal I am receiving bit 1 with the original sequence, bit 2 with 1 right shifted 1, bit 3 with another right shifted 1. Now I do not know whether these 3 are multipath of yours or are they independent use I have no way of knowing, because the multipath will look exactly the same it will look like 1 shifted version and I will not find the difference. So, there is confusion between multipath and multiuser. So, if users are assigned if all codes are assigned I have a problem. The problem is cannot distinguish between multipath and multiuser signals. It looks I mean it looks exactly cannot distinguish between multipath of user 1, multipath of user versus multiuser signals.

So, what is the option, how can I prevent ambiguity with respect to multipath?

Student: (Refer Time: 20:30).

User if the if I can have multipath delay of 2 units of time, then I cannot assign the immediate 2 shifts after that I can assign good very good I am glad you are thinking along those lines, that is it is a correct answer. Now how severe is that and is that going to pose a problem that is what we need to quickly look at, and the best way to do it is through a quick example of that.

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Wideband CDMA 3.84 Mcps \sim 5 MHz BW
 \downarrow
 $T_c = 260.4 \text{ nsec}$
Max delay spread $\sim 5 \mu\text{sec}$
 $\frac{5 \mu\text{sec}}{T_c} \sim 19.2$
available seqs \downarrow
(unable)
Option 2: Assign diff m -sequences
diff gen polynomials
 m $2^m - 1$ # possible diff m -seq max k $\frac{R_{xy}[k]}{R_{xy}[0]}$ m -Seq
4 15 2 0.6 0.067
12 4095 144 0.34 2.4×10^{-4}

So, the wideband CDMA system I will already start to introduce these numbers so that you will become familiar with it before we actually come to that. Wideband CDMA system uses a spreading factor or you know the spread bandwidth is 3.84 mega chips per second MCPS so; that means, the bandwidth of the signal will be 3 around 5 mega hertz.

So, this uses approximately 5 megahertz bandwidth basically you can see that, but the basic signals that is transmitting may be 6 9.6 kilo base per second. So, it is using spreading to get the bandwidth that we are interested in. So, this basically means that the chip duration is 260.4 nanoseconds 1 by the chip rate, 1 by 3.84 mega chips per second gives me 260 nanoseconds. So, supposing if you remember our channel models, one of the common channel models typically says that it can have up to 5 microseconds when we using in outdoor. So, let us say that the maximum delay spread in an outdoor channel delay spread is approximately 5 microseconds. So, 5 microseconds divided by T_c comes out to be 19.2.

So, how many shifts you cannot use? If I use 1 I cannot shift because 19 of the others then. So, the number of codes then becomes very very limited right. So, this is not going to work because you know though pseudo noise sequences I have got this beautiful properties particularly these shift register sequences, this multipath business because the all the codes are shifted versions of each other and the there is a fundamental limitation in terms of this. So, this is in a multipath environment particularly when there is you know these chips are work short duration, I am going to have very very severe limitation. So, the number of available sequences is going to go down very drastically because of the I have to avoid assigning those. So, I not available usable available is full 2^m to the power of m minus 1 are available.

But I cannot use them because I want to do that. So, then somebody says well how did you generate the PN sequence? You took a primitive polynomial a take the other primitive polynomial, what is the problem just you know there are $g f 2$ says there are other primitive polynomials that is a good argument. So, basically take sequences from different m sequences and other words option 2 is a take from or assign sequences from different m sequences. That means, from different primitive polynomials or from different shift register sequences. So, basically these means from different generator polynomials and here again you will find that there are not too many generator polynomials, if you want to take order 4 there is only 2 available.

So, basically there are not too many available, but let us look at the. So, this is m , 2^m to the power of m minus 1 that is what we have how many possible different m sequences number of possible different m sequences; that means, how many different polynomials exist for that, but the most important thing is what is there worst case correlation maximum overall K , $R \times y$ of K that is cross correlation because I need to be able to suppress the multi user interference divided by $R \times 0$ is a normalized cross correlation that we are ask to measure ok.

Where we started off with the example of 4, if I did not have this multipath constraint at I would had 15, 15 very good sequences, but if you take the wideband CDMA case I am out of luck because you know the another 14 cannot be use because the they are because the multipath delays 19 chips. So, then I say how many other m sequences are the only 1 other polynomial. So, total number of forth order primitive polynomials is 2, that is not the biggest factor the cross correlation actually is quite high 0.6. What would it have

been? Had it been and m sequence of this it would have been 1 over 15. So, it would have been. So, basically had you used from within the m sequence within this 1 family, it would have been 0.067. So, it would have been actually a very good system, but this stupid multipath you know ruin the whole thing ok.

Now, again m equal to 4 is only simple example, but you typically you have to go for something much larger. So, let us look at 12, 4095 sequences are available you know cyclic shifts the number of possible sequences primitive polynomials is 144, but if you are unlucky and you pick the wrong combination you can have a cross correlation which is as high as 0.34 when. In fact, the m sequence would have given you 2.4 into 10 power minus 4, if you want to given 1 over 4095. So, basically you can see that you know m sequences are going to be restrictive in their use, then you may ask a question why did spend. So, much time studying m sequences if you are going to say that in at end of the day they are not useful no no actually they are useful they are the form the backbone of the CDMA system and we will now when we will look at that you will see how the.

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cdma 2000

WH sequences

$$H_1 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad H_2 = \begin{bmatrix} H_1 & H_1 \\ -H_1 & -H_1 \end{bmatrix}$$

$$H_n = \begin{bmatrix} H_{n-1} & H_{n-1} \\ -H_{n-1} & -H_{n-1} \end{bmatrix} \quad 2^n \text{ orthogonal seq. of length } 2^n$$

Diagram showing a hexagonal structure with nodes labeled 0.1, 0.2, and 0.3.

Construction of m-seq:

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \rightarrow \text{m-seq}$$

$\left. \begin{matrix} 0 & 0 & \dots & 0 \\ \oplus \\ \text{m-seq} \end{matrix} \right\} 851$
 $\left. \begin{matrix} \oplus \\ \text{shifted m-seq} \end{matrix} \right\} 852$

$2^{15} - 1$ shifted by 64

So, let us go back and say now what are the spreading sequences that we can use for the CDMA systems. So, here where CDMA 2000 we take as our case study, CDMA 2000 says I am going to use Walsh Hadamard sequences and I believe we have already studied Walsh Hadamard sequences in a different context. So, basically the first sequence or the first level sequence is 1 1 1 minus 1, the next level sequence basically will be H 1, H 1,

H_1 minus H_1 where these are all matrices. So, basically that becomes a 4 by 4 matrix and then you can do. So, in general the matrix at the n th level, this is a matrix at the n minus 1th level H_{n-1} minus H_{n-1} ok.

So, basically it goes a power of 2. So, this at this stage you will have 2^n orthogonal sequences of length 2^n you can verify oh H_2 will be 4 sequences of length 4 and H_n will be 2^n orth and their orthogonal and again their properties are very very useful. So, please generate a 4 by 4 matrix $\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$ these are perfectly orthogonal sequences. So, what we look at the cross correlation at. So, if you look at these 2 sequences just as an illustrative example they are orthogonal, but you shift them by 1 what do you get if you shift them by 1 basically do a circular shift you get perfect correlation, you get correlation of 4 this is the worst then I am different m sequences.

Now, because basically it give you as if you are doing perfectly align. So, this is also going to be problem because you know multipath is going to be present and if it. So, happens that my data comes with the delay of 1, I am going to see very high correlation with some other users did. Now here comes the key element now what is it that can make this look different make this sequence, make a particular sequence look different from a shifted version what is it that can make it look like a shifted version. Now this problem was had to actually be solved for a CDMA system. So, basically a CDMA system we will go back to drawing our hexagons, base stations at the center let us just look at this now all these base stations are using the same frequency. Users in each of the cells must be able to estimate the channel and it should not depend on which cell I mean because the method of channel estimation must be the same.

So, the way the system was designed again very brilliant method was that you transmit all zeroes all the base stations then you say how may going to figure out you know did it was it base station 1 2 or 3, 1 2 or 3 they said we will exclusive or this with a m sequence for base station 1 BS 1, and we will exclusive or this with a shifted m sequence shifted or the same m sequence shifted 1 for base station 2 and so on and so forth. So, it is a same all 0 sequences, but each of these m sequences are shifted versions of each other.

Now, remember I told you that we cannot have because of multipath you cannot have summer omitted. So, they said not a problem what we will do is we will take a very long

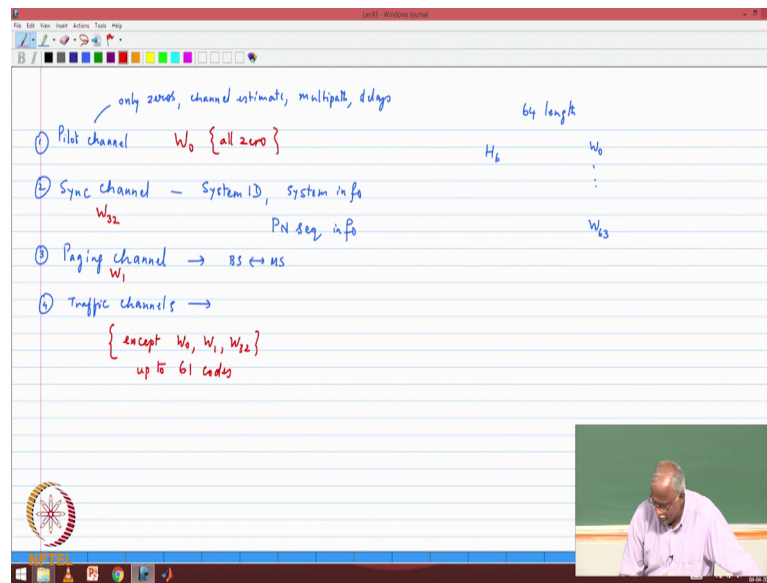
sequence 2 to the power of 15; that means, 15 primitive polynomial of order 15. So, you will get a sequence of length 2 the power of 15 minus 1. So, basically this will be the sequence that will scramble the all 0 sequence and these sequences that each of these base stations are using are going to be shifted by 64 chips, why 64 chips; that means, there is no way you can confuse multipath. So, if you are using the sequence the next person is using shifted by 64. So, your multipath will be long gone before you can I can never confuse your sequence to that.

So, that is where the m sequences have come into play. So, what it did was you could transmit the same all 0 sequence by all base stations, and the property of m sequences are such that they have a beautiful correlation properties. All you have to do is measure the length is long enough and you omit the things that we are confused by multipath. So, shifted by 64. So, all base stations in CDMA 2000 are going to be using the m sequences to scramble. So, it I can differentiate between that. Now the same principle is also used to take these Walsh Hadamard codes and also what you do us you scramble it with an m sequence ok.

Now, the m sequences the pseudo random sequence if I shift by 1 that is multipath that is original sequence shifted by 1 is multipath original sequence multiplying with the next set of m chips that is u user 2. So, I will never confuse user 2 signal with the multi path component because the m sequences going to scramble them differently. So, this particular code scrambled by the m sequence will never be confused with the other code shifted by 1 because the m sequences are multiplying them are different. So, the m sequences rather than being the spreading sequences have become scrambling sequences; the basis on which you will differentiate between multi user and multipath.

So, again very very important element I hope you see the benefit. So, very quickly let us construct the CDMA 2000 system and make sure that we are comfortable with the.

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So, the first channel that we have to design is what is called the pilot channel, this is the channel that will be used for doing the channel estimation. So, pilot channels has only zeros no information, is only used for channel estimation. So, that you can do coherent detection and what are the things that you are trying to estimate? You are trying to estimate the multi path you have to estimate with delays. So, multipath you are estimating the delays all of that that is the pilot channel that is number 1, the second one that we have to transmit is something called the sink channel. Sink channel is actually the one that tells you the operator the base station information all of that.

So, this is what is carried by the sink channel system ID, you have to read it and understand it tells you how to synchronize because you know the data scramble is using the m sequences. So, a lot of system information system information has to be transmitted to that you can then synchronize with that it also tells you what is the PN sequence, basically it will tell you what is the PN sequence information it will provide. So, it you can synchronize to that. So, it has a lot of information that that you need to in order to be able to connect to that this is the same as what we called in g s m the control channel basically the control information is what is called as sink channel here ok.

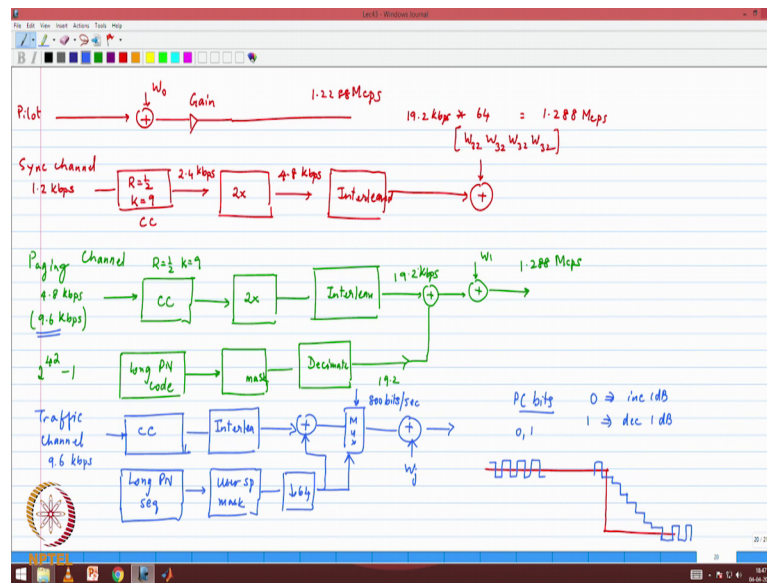
The third information that has to be sent for a CDMA system in as in all cellular systems is a paging channel. A paging channel this is where you know the registration occurs it has the paging it has messages to individual mobiles. So, basically communication

between the base station and the mobiles, but it is not user data, it is basically control information that is going a going forth and finally, number 4 is traffic channels. So, this is user data. Now remember we said that we are using Walsh Hadamard codes basically we use 64 length Walsh Hadamard codes. So, basically we are looking at H 6. So that means, I will have spreading codes starting from w 0 Walsh code 0 to Walsh 63, those are codes that are available to me. So, what is used on the pilot channel is w 0 that happens to be the all code.

So, basically there is no information going on its all zeros the only thing is there will be a scrambling sequence that will make it look like a random sequence and that is what is used for channel estimation. The sink channel is by convention uses w 32 plus 1 minus 1 plus 1 minus 1 that is alternating sequence. The paging channels is usually assigned w 1 spreading code. So, this can be anything except w 0 w 1 and w 32. So, I have a total of 64. So, I can have anything up to 61 codes. So, in other words I can support up to 61 users and the system you know from practical experience you will never run out of codes because you know the cells are designed such that the number of codes are more than more than sufficient ok.

So, now at a top level it seems like this is a reasonable lets now take a closer look at this particular system. So, how is this system constructed again this is where you will appreciate the complexity of the system in order to build a something that is practical. So, this is how it is built.

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So, the pilot channel is all zeros on it you superimpose the w_0 which is also all zeros, and then you apply some gain to it you want to you may want to boost the pilot channels you can have good channel estimation. So, that is your first one that is your I am sorry this is this is pilot channel. So, this is pilot. The second one is sync channel, sync channel this is how it is transmitted in CDMA 2000, the sync channel it does not have very high data rate its 1.2 k b p s is the information rate.

So, you take this information rate do a rate 1 half convolution code R is equal to 1 half, K equal to nine convolutional code this is the convolutional code. So, rate 1 half. So, 1.2 will become 2.4 k b p s correct at the output. Now we are going to repeat the data. So, 2 x repeat this becomes 4.8 k b p s. So, basically each bit or you know block of bits you repeat, this becomes 1.8 kilobits per second then this data is interleaved and this information now we have to apply the spreading code w_{32} . So, each bit will get multiplied by a 64 length sequence, but the what it is the actual the way it is done is you repeat that 64 length sequence 4 times.

$W_{32} w_{32} w_{32}$ you will see repeated length 4 times. So, basically it looks like a 64 times 4 time sequence or you can think of it as the following you can think of it as the sequence that is coming at 19.2 k b p s, this 4.8 multiplied by 4 multiplied by 64 length sequence this will come out to be 1.228 mega chips per second that is the bandwidth of (Refer Time: 41:56) 2000. So, w_0 is at 1.2288 mega chips per second this channel is

also at 1.228 M c p s. So, you will find that all of our channels have to be at the same rate because you know that all of them are part of the same CDMA signal. So, this is straight forward lets now move on to the paging channel; you see a lot of similarities with this, but some differences as well paging channel, now notice that the sink channel there is no in what you call scrambling.

Everybody should be able to read it without much difficulty. So, it is it information is straight present in the straight forward manner. Paging channel 4.8 kilobits per second is the basic rate it can be 9.6 kilobits per second, if it is a large cell depends on how it is can. So, this again is convolutionally coded rate 1 half convolutional coded rate is equal to 1 half constraint length 9. So, 4.8 will become 9.6 kilobits per second, you do a 2 x repeat then it will become 19.2 kilobits per second.

So, 2 x repeat then you interleave this is at 19.2 k b p s of course, at this point you know we are going to do multiply with the spreading factor which is the w 1, but before you get to that there is some operation that is done and the again this is where the CDMA complexity actually starts to kick in. The system is designed such that only users who are connected to their system can actually excess the information. Just by listening to this information you cannot decode and how did they make that happen.

So, they design something called a long PN code. Now long PN code is a length 42 shift register sequence, I mean that takes 37 days before it repeats itself you know at 1.228 mega chips per second it takes a long time to repeat because the that is the length of the sequence and they take this long PN sequence they scramble it based on a user specific mask. So, not only is the sequence itself the original sequence itself is hard enough its scrambled first, and you decimate or down sample by a factor decimate you down sample by a factor of 64 you will get something at 19.2 kilobits per second.

So, this information is going to be exclusive or with a sequence first of all is the long PN sequence it has been further modified down sample and then that is going to scramble your data. Now this one is going to be is spread by w 1 and then this is also going to come at 1.228 mega chips per second that is paging channel. Now what happens if you want to do traffic that is the last one. So, traffic is along the same lines as the paging channel again just for completeness lets write it down. So, that you know if I were you are reading the CDMA 2000 you will actually a appreciate the information. So, traffic

channel is at nine point by the way if it was 9.6 kilobits per second that there is 2 x is not there, because then it will already be to the rate 1 half convolution code it will be at 19.2.

So, traffic channels are at 9.6 kilobits per second convolutional code convolutional code rate 1 half all of them are the same things, already at nineteen point 2 kilobits per second the data is interleaved. Now a very interesting some very unique thing is happening; what it does is it this data is also scrambled. This data is also scrambled by the I am sorry the I did make a mistake this is not user specific it is a mask basically it is for all the users in the system same long PN sequence 2 to the power of 42 , here the scrambling of that subsequent scrambling of that is by a user specific mask then you down sample by a factor of 64 that will make it 19.2 kilobits per second.

Now, use this information to scramble this, and you are going to do something very very interesting you are going to puncture some data out of your sequence this is user data has already put into a very complicated format. Now from that sequence you are going to pull out 800 bits per second it is at 19.2 kilobits per second. So, you puncture second number of bits at 800 bits per second; now which bits you puncture is going to be told by this sequence. So, basically this long PN sequence user specific mask down sample by 64 is going to scramble it and its also going to tell you some random combination of bit oppositions to pull out and this information is then spread by if you are doing it in the binary it is a plus sine basically this is a spreading sequence w_j this can be any of these spreading sequences are done and of course, this is the output.

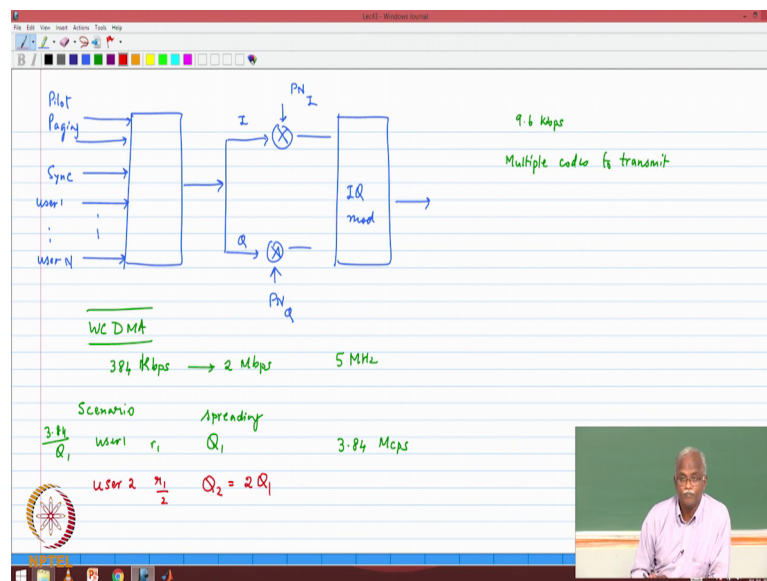
Now what is it that you punctured in and what did you insert, this is what we call as the power control bits. What is the base station trying to it this is the base station is what is sending to you. It is sending you constantly 800 times a second, it sends you either a 0 or a 1. If it sends you a 0 you have to go down by 1 dB sorry 0 is 0 implies increment by 1 dB 1 means decrement by 1 dB. So, supposing you are transmitting at the correct power level that is say you are at correct power level.

So, and the base station is happy with where you are what it will tell you is a keep telling you plus 1 minus 0 1 0 1. So, which means you will be oscillating around this point now suddenly you came of very close to the base station. So, the base station is I do not want you transmitting at this power level, I need you to cut the power level here. So, what will happen it, but it cannot do the jump suddenly. So, it will start sending you minus ones

sorry it will sending you zeros to ones, you each time you will decrease once you reach the new power level again you will oscillate. Now how many times second is the base station controlling your power 800 times a second? Why is it so, important in a CDMA system to control the power? So, so many times and to control it so, tightly near far problem because if you translate with too much power then somebody else signal will get affected because these sequences are not perfectly orthogonal and. So, at the end of the day in order for me achieve the full capacity.

So, you know at actually to build a receiver for this is highly non trivial; because you know first you have to know the long sequence, you have to know the user specific mask with the general mask is there, there is power control the you know the and if you if you puncture the wrong place what we will do you will take user data and you will decode as power control and which will be totally wrong. So, you know. So, you must actually this where you have punctured to insert the power control bits has to be precisely known to the mobile, I not to extract bits and now add all of these things together in ok.

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Now, I have the base station signal, I have paging that is going in then there is the before paging even the pilot is going in, there is the sink channel that is going in, and then I have a whole bunch of users. So, it could be user 1 to user n all their signals basically you know using different codes all of them punctured power control all of that is and I come out with date of sequence and the same data is sent on both the I and the Q

branches this is the I and the Q branch, this is further scrambled by another PN sequence, PN I and PN Q and then basically it goes into an IQ modulator and then you transmit has signal.

So, this is a CDMA 2000 signal, if you have CDMA phone this is which doing this all the time basically listening to the pilot channel estimating the channel look looking at the sink and then getting the information from the paging channel and then going to the traffic channels and then detecting. Now in GSM all of these were on different time slot. So, you basically listen to the signal at different time slots whereas, here all the information is coming at the same time. So, when you want to detect up the traffic signal you must be able to suppress the other signals and that is where CDMA comes in. All the other users signals all the other overhead signals channels or all coming on the same channel and you are suppressing them and taking out the data that you want. So, that is how a CDMA system is CDMA 2000 system is built.

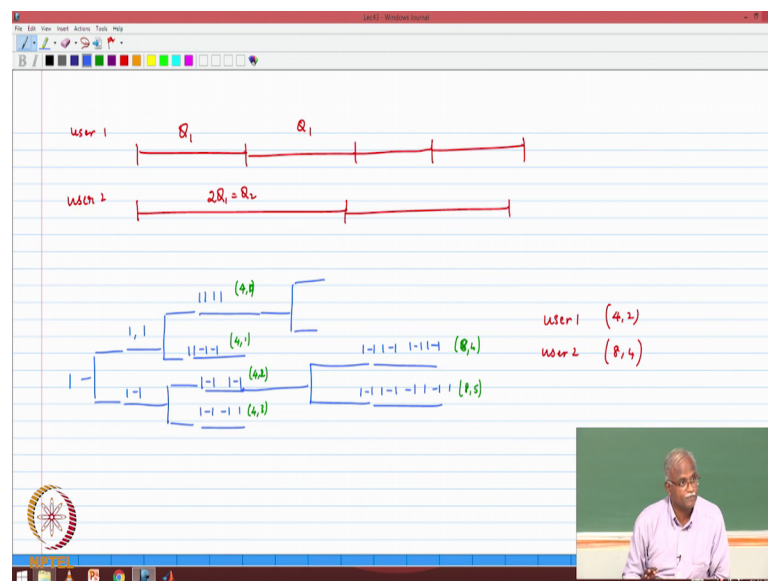
Now, I told you CDMA 2000 and wide band CDMA are competitors. So, what was the basic difference between the 2? In this particular case CDMA 2000 the data rate that you could support was 9.6 kilobits per second. If you wanted to transmit more data rate what are the options available to you? You would have to do you to take more codes you take w , w_3 , w_4 , w_5 and they would not interfere with each other because you are. So, you would have to use multiple codes to transmit more higher data rates right straight forward. But if you if one user says I want ten codes then you will run out of codes very soon right because you have only certain number limited number. So, this CDMA systems are very you would be careful about how.

So, then they said well you know what this is this is may not work all the time. So, how are we going to support users to ask for high data rates and. So, wide band CDMA system came up with this brilliant proposition. So, they said that wideband CDMA system will support anywhere from up to 384 kilobits per second, 384 kilobits per second to 2 megabits per second, so again the bandwidth that is used as a 5 megahertz channel. So, therefore, there is a room for spreading, but how are we going to support these data rates. So, basically here is the proposition, I have a following scenario I have user 1 and is been given a spreading code Q_1 , spreading code and it has to reach 3.84 mega chips per second.

Remember all these signals before transmission must be at the same chip rate. So, user 1 Q 1 and therefore, you can conclude what is the rate of user 1; rate 1 will be 3.84 divided by Q 1 basically that is the rate at which the information is coming in.

So, now if there is user 2; that means, it is a different colour user 2 and the user 2 says no I do not want R1, I am not you know I do not need such a high data rate. So, I want only half of the data rate now there is a tricky question now what you do with this guy, you can do 2 things you can take his data and repeated twice just like remember we repeated. So, we get the same data rate and you can apply the same spreading factor because his rate repeated twice I will give you there. The other thing that wide band c d may said it oh you know what I am going to give you Q 2 which is 2 times Q 1. So, here is the a challenge that we have and again I will just tell you the answer and then build on it in the next lecture.

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So, user 1 says I am going to spread my data using a spreading factor Q 1 this is Q 1, Q 1. Now user 2 says my symbol now is going to require 2 Q 1 this is equal 2Q 2. So, in the time that user 1 transmits 2 symbols user 2 transmits only 1 symbol. So, basically his spreading is different. Now the challenges how do I preserve orthogonality between say I can when it came to sequences of the same length at least I had some control over it. Now if you tell me I am going to have the spreading factors which are quite large and you know it is going to vary over a quite wide range, how do I ensure orthogonality and

the brilliant observation is the following. So, they said what spreading codes to use Walsh Hadamard.

So, here is the Walsh Hadamardry 1, when I split it becomes 1 1 1 minus 1 you remember that is the basic process splitting. Splitting this 1 1 1 1 1 1 minus 1 minus 1 this 1 we will split as 1, minus 1 1 minus 1, second one is 1 minus 1 minus 1 plus 1. So, basically the sequence goes as follows. So, now, if you where to label these let me just call this as length 4 code 1 code let me call this code 0, this is length 4 code 1, length 4 code 2 and length 4 code 3. Now length 4 code 2 I am going to expand the this further this will be 1 minus 1, 1 minus 1, 1 minus 1, the lower branch will be 1 minus 1, 1 minus 1 and then the negative of that minus 1 1 minus 1 1 and if you go through the numbering process this will be code of length 8, length 8 and this will be the code number 4 this week code number 5 ok.

Now, I wanted to just pause for a moment and see if I had given user 1 if I had given user 1 4 comma 2 code 4 comma 2; and user 2 code 8 comma 4 what would be the correlation between the 2 of them? 100 percent because its exactly the same thing or with a with a flip. So, basically the they completely it would mess up my things, but the observation is go to any other branch they the other branches are daughters or basically children of the codes coming from 4 0 4 1 and 4 3 because 4 2 is orthogonal to 4 0, 4 1 and 4 3 it is also orthogonal to any of its children they enough their children. So, the brilliant observation was this designing these codes of different lengths that have still preserve orthogonality is not a problem, I can do that by using this Walsh Hadamard codes I just have to make sure that I do not assigned parent and child I just have to make sure that if I assign 1 here I have to take the other codes from other parents. So, it is a very very interesting way, but what about multipath problem what you solve multipath problem.

Student: (Refer Time: 59:40).

Design. So, you basically took Walsh Hadamard codes parent, but do not repeat any of the children basically they must all have a distinct you know have to roots are orthogonal and on top of that apply a m sequence which will make it robust to multipath, that it will you will not get confused between multipath and that is how the wide band CDMA system is design. So, again we will just spend a little bit more time, I just wanted to make sure that you are confident of the basics and codes are very important part of it, and once

you have a handle on the codes CDMA systems at the end of the day are very very interesting systems to work with.

Thank you very much we will take it up in tomorrow's class.