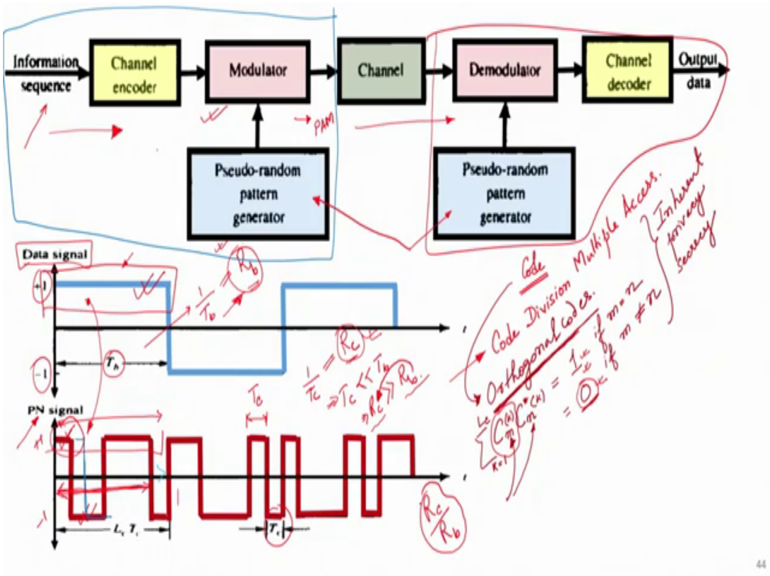
Evolution of Air Interface towards 5G

Prof. Suvra Sekhar Das
G. S. Sanyal School of Telecommunications
Indian Institute of Technology, Kharagpur

Lecture – 15
Waveform in 3G (Contd.)

(Refer Slide Time: 00:25)



Welcome to the lectures on Evolution of Air Interface towards 5 G. Till the previous lecture we have discuss the Waveform for 2 G as well as of also laid the foundation for the waveform structure for 4 G and beyond and we have also started discussing about the waveform for 3 G. So, we will briefly conclude the air interface properties that are there in the 3 G and will soon translate into the foundation for the multi carrier systems, which is essential for understanding the 4 G wave air interface waveforms as well as the 5 G waveforms.

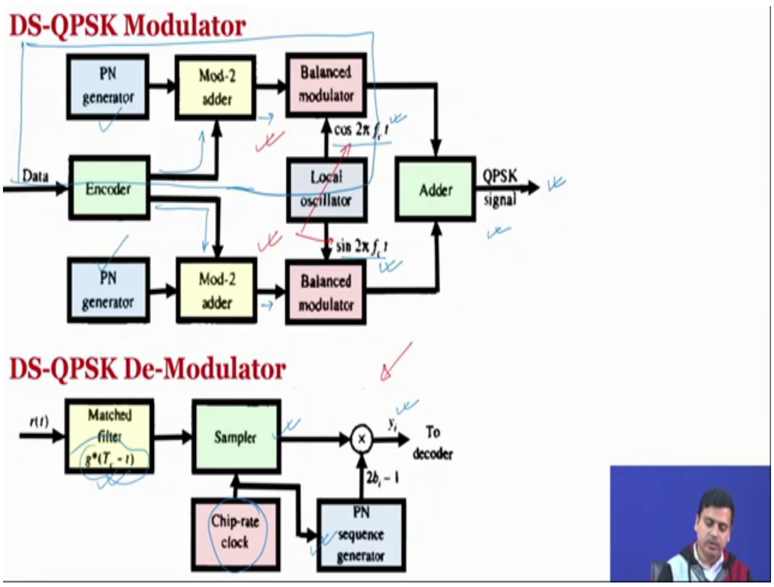
So, what we were discussing in the previous lecture was essentially the transmitter structure, which we have laid down over here. And, we talked about the modulation part then there is the channel and the receiver part, which we have identified over here.

And, we have discussed in details how the signal which is of duration T b gets multiplied by chips, where each of the chip is of duration T c and we talked about the expansion of the bandwidth, because T c is the chip duration is much much smaller than T b duration. And, hence when we look at the rate of bit compared to the rate of the chip.

So, we will find that the chip rate is much larger than the bit rate. Effectively the signal that goes out into the air has a much larger bandwidth compared to the original bandwidth of the base band signal for a particular user. And, hence there is an expansion of bandwidth, and typically these kind of systems are known as spread spectrum communication, and this is an example of direct sequence spread spectrum. We also discuss briefly upon the codes very very briefly upon the codes, where we said there could be orthogonal codes, which has the property like if one uses 2 different codes with different code indexes, then only if the code indexes are same you get the end result of summation as 1 otherwise it is 0..

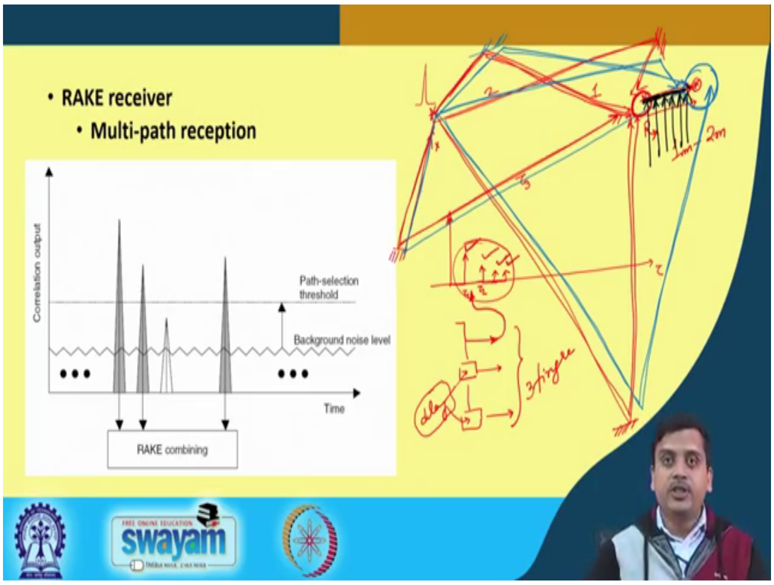
And, we also said that there could be other ways of designing codes where by the same code is used you get a very high value, whereas when other codes are used you do not get a 0, but you get a very small value that is very small cross correlation properties and very good auto correlation properties.

(Refer Slide Time: 02:36)



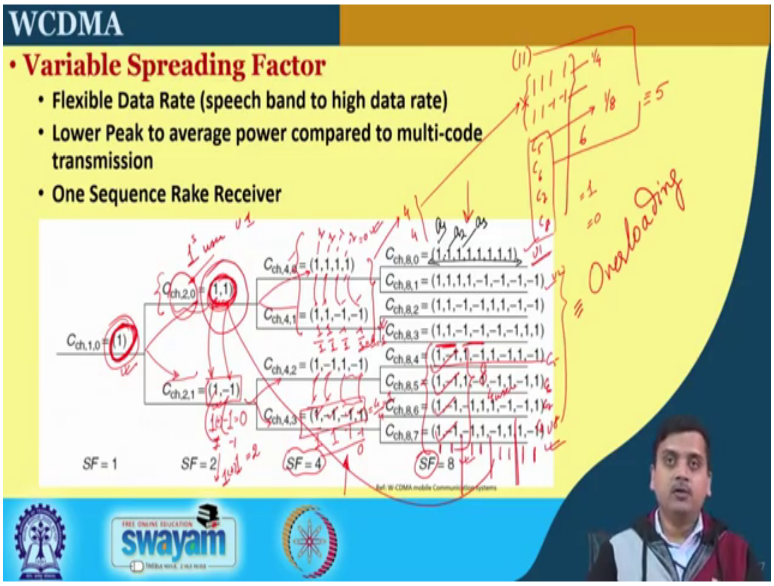
We have also extended the same structure towards the QPSK modulation, where we said that they would be one channel and another channel in 90 degrees with respect to each other by virtue of having 2 different carriers; one is the cosine one is the sine so, that is the quadrature carriers. And we have also represented a typical receiver structure.

(Refer Slide Time: 02:59)



We also discussed about the possible receivers we did not go into the details, but briefly out lined the way it captures multi path signal. And we briefly said that it uses the rake receiver architecture, we do not intend to get into the details because that is a complete discussion and a detailed architecture in self our intension is to go into others other models, but just to know about the differences, that is present in the other systems.

(Refer Slide Time: 03:27)



So, going beyond whatever we have discussed there is also a method for allow allowing variables spreading factor. So, when we say variable spreading factor, what we mean is if you look back into the signal model. The number of chips that are available during a bit period can be modified; that means the code length in other words, the code length can be varied.

So, instead of having a fixed code length where by R b sorry R c by R b is constant otherwise, we can have a variable factor ; that means, the code rate is not constant it can be a varying code rate. The only advantage that we have is that in in such a situation 1 can use a higher data rate.

So, for example, the original codes can be split I mean I mean if you have 1 if you begin from 1 you can generate 2 code sets, which have the first code as 1 1 and the second code as 1 minus 1. And, if you see what has been happening with the previous discussion at the receiver side, if we correlate with 2 different codes as we were discussing, we get a 1 multiplied by 1 and 1 multiplied by minus 1.

So, 1 multiplied by 1 is 1 1 multiplied by minus 1 is minus 1 when we add together if we add them together you are going to get a 0. Whereas, if if this was your original code and you multiplied by the same code; that means, plus 1 and minus 1. Your multiplication would result in a 1, here it would also result in a 1, and if you sum them it would result in 2, which you could normalize by the number of chips. So, essentially if it is the same code you get a 1 otherwise you get a 0.

So, here now what we are discussing is that instead of using a code length of 2 right, which is described over here; that means, as given over here instead of using code length of 2. If we use code length of 1 what happens is that the bit duration is the same as the chip duration. So, if chip duration is my fundamental entity. In that case my bit rate is as good as the chip rate whereas, if I use a code rate of 2 my bit rate becomes half that of the chip rate.

So, proceeding further this particular code can be split again into a code of 1 1 1 1 and 1 1 minus 1 minus 1. So, once again what you see is that, if we correlate these 2 codes; that means, multiply the chips against each other. For the first we are going to get 1, for the second we are going to get 1, for the third we are going to get a minus 1, the fourth we are going to get a minus 1. So, when we add up all of them you get a 0. Whereas, if you correlate with the same code once again you get a 1 a 1 1 and 1 and when you add up together we get a 4 normalized by the number of chips you are going to get the end result as 1.

So; that means, once again cross correlation results in 0 and auto correlation results in 1 in this particular case as well. So, this way in this particular branch what we have seen is that the code is 4 times larger than that of the bit. And, hence we have one-fourth the bit rate.

Similarly, this code can also be enlarged and you have 2 other codes. So, 1 minus 1 we have 1 minus 1 1 minus 1 expanded further with the 1 minus 1 and minus 1 1. So, if you do the same procedure as discussed over here; that means, we multiply these 2 cross multiply the end result will be a 1 a 1 a minus 1 and a minus 1 if you add them up you going to get a 0. Whereas, if I multiply by the same code you are going to get a 1 minus 1 minus 1 will give a plus 1, same as with all others you going to get a 4 add them up divide by 4 again you are going to get a 1.

So, this property is maintained. However, at this stage where your spreading factor or the code rate or the code length has become 4 times that of the original bit length; that means, the code has been 4 times faster or in other words the bit rate will be 4 times slower than the chip rate. So, now, you can proceed further and go to stage 3, where you have the spreading factor of 8. So, this may you can proceed further and make a variables and make many number of codes, which are orthogonal to each other.

So, if we are in this stage and we allocate different codes to different users; let us say this is user 1 this is user 2 and so on this is user 8. What we will easily find that if any one user's information is correlated with any other user's information the end result would be a 0. Otherwise when you correlate with the same user's information you are going to get an end result of 1 whereby you can decode the data, that is first stage.

The second stage now what we also have we can look at is that, here at this level one can think of assigning users these few code words; that means, there are 4 users who will be using a code length of 8. Whereas, here we can give to 2 users each having a code length 4 each; that means, we now have a total of 6 users into the system whereby 2 users; that means, these 2 users there will be using a code of 1 1 1 1 and the second one over here 1 1 minus 1 minus 1. And, the other 4 users sorry this will be 4 users so, 8 is a chip length 4 users.

So, they will be using the corresponding codes if I call it C 5 C 6 C 7 C 8. So, they will be C 5 C 6 C 7 C 8. So, in total there will be 6 users these users will be having one-eighth the bit rate of the chip rate. Whereas these 2 users would be having the bit rate of one-fourth the bit rate of the chip rate. Same way what one can also do is instead of giving to 2 different users in this stage, one can think of giving this code 1 1 code to 1 user and giving these 4 different codes to 4 users. So, in that case we are going to have C 5 C 6 C 7 C 8 along with it we are going to have the code 1 1 only and we will not use these 2.

So, in that case we will find 1 and 5 4 over here which will give us 5 users. What we will find is that this 1 1 code will remain orthogonal to these codes always. Because, we can check with this when 1 1, that is what we have over here. We have 1 1 over here this 1 1 if you multiply by the first 2 ok. If, you multiply by the first 2 it will always result in a 0 because they have 1 minus 1 1 minus 1 1 minus 1.

Again, if you check the the second 2 what we going to get 1 minus 1 1 minus 1 minus 1 1 minus 1 and so on and so forth. So, in that manner whenever we take the second this particular users code 1 1 and we try to correlate with any other users bits C 5 C 6 C 7 and C 8 will always result in a in zeros.

Whereas when we correlate it with 1 1 it will always result in a 1. So, effectively here what we have to do is in the first 2 chip durations this particular users code will be 1 1. The second 2 chip durations that users code will be again 1 1 in the third duration again this users code will be 1 1, and again in the final set that users chip will be 1 1.

So, effectively the first user let us call this as the first user or U 1 in this case. It will be orthogonal with all other users, the second time interval, it will again be orthogonal with all users, third time inter interval it will be again orthogonal to you all users, fourth time interval it will again be orthogonal to all users.

Now; however, if you assign this particular code which is 1, which is actually not a code to any use 1 user, then one will not be able to use any other codes, because all other codes are generated from the parent code. So, if we remember the structure then we can easily generate a combination of users, whereby different users can different can get different data rates. Now, why would at all one do this because this would depend upon several factors among which the link quality is one of them. So, if the link quality is very bad or is in the situation is in a heavy interference in that case the particular user can be using a larger code length.

So, when one uses a larger code length a one can when one is accumulating the entire energy, one is able to get some bandwidth expansion gain or a spreading gain, which is also another term which can be used instead of the word spreading factor, by which one can increase the signal to interference ratio or signal to noise ratio, where by the receivers signal strength is increased and by increasing the signal strength 1 is able to finally, decode.

So, it is kind of one can also look at it as taking benefit of the diversity combining. So, as we discussed in the previous lecture, that there are different combining strategies which are also possible when designing the receiver, but end of the day where we stand is this gives us a flexibility in allowing different data rates. Even the same user can be allocated different code rates, at different connections, or different duration of time, whereby the user can achieve different data rates. This is one of the vital factors that was introduced in 3 G; however, if we look at the second generation or when will go to the fourth or fifth generation such facilities are not available.

So, this is a unique facility and is it has it is own advantage, but; however, if we look at the complexity of processing for such things. It grows tremendously as one increases the bandwidth. So, if one increases the original signal band width let us say to 20 megahertz or even to 100 megahertz. This particular method of receiver processing becomes impossible or becomes very very complicated which will cause lot of other problems at the receiver. So, for other reasons as well this got restricted to use in the third generation system. And, we should be open that this particular methodology has various advantages and special features, which are not possible in other systems, which are T D M F D M based architecture.

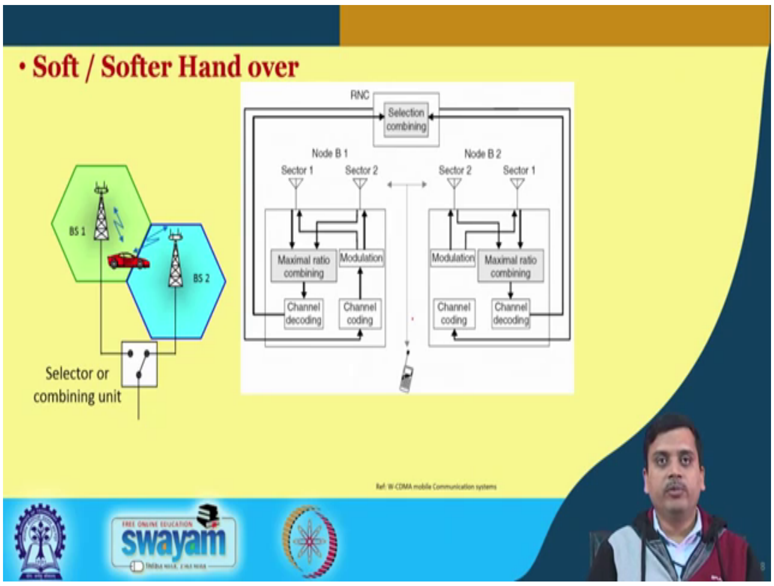
So, we should be open towards using the facilities and combining them towards providing in your access schemes in your multiplexing schemes and new radio access technology. Now, this spreading can be used on top of other mechanisms and at some point of time there was the concept of over loading. So, if one uses over loading mechanism; that means, there is already some kind of signal which is going through. Then one can use a spreading mechanism in order to put another data layer on top of whatever is existing and which will cause minimum interference to the others. Because these codes as we are seeing it is generated from a pseudo random number generator pseudo noise generator.

So, when it is generated through pseudo noise or if we have pretty large lengths it can appear noise like. So, in that case other signals to other signals this would appear like noise. And, only to the desired signal it would appear as if there is some message content in it. So, when it now when it comes to this particular method, this will see other users noise and it can re combine it is signal using the spreaded code in order to capture maximum energy.

So, whereby even under heavy interference conditions this can work in a pretty good manner. The other advantages is that this can also work in an asynchronous manner which is difficult in case of TDM FDM based system.

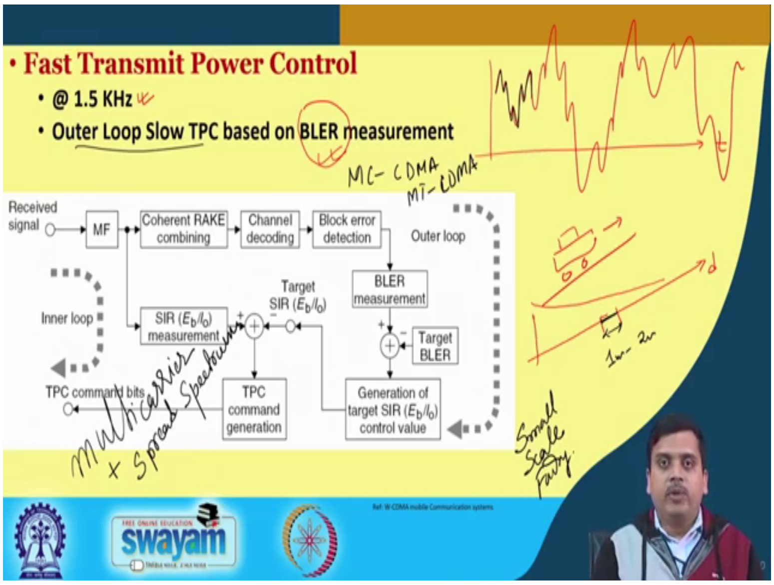
So, there is various advantages. So, it is strongly recommended that if one has to actually make certain contributions towards or one has to investigate look into future generation systems, one must understand the basic methodology how this kind of systems work do that, that can be taken advantage of in a significant manner.

(Refer Slide Time: 16:32)



Moving at further there is also possibility of soft hand over; that means, because it is the single frequency network, the user equipment simultaneously combine with more than one base stations. And handover failure probabilities are significantly reduced in this case, because they can be assigned different codes, from different base stations and they would the receiver simply has to switch the code and it can translate to the next base station.

(Refer Slide Time: 16:57)



The next another important thing which was introduced in this system who was the HARQ turbo codes was already introduced. And, the HARQ mechanism what it does is that, we have already said that ARQ is a mechanism of automatic repeat request, but when we talk about hybrid repeat request. It can do multiple things amongst several other things what it can be do is when you are asking for a repeat transmission ; that means, say the receiver has failed to receive proper amount of data. So, what typically it does is that it rejects the data what he has, what it has received and it asks for a fresh transmission.

So, if the link condition is very bad, then the probability that the second transmission is received correctly is also the same as the probability that the first transmission is received correctly. So, in other if the first transmission has a very low probability of being received correctly, the second transmission also has a low probability of being received correctly. However, it is also believe because of the randomness, that the joint probability of receiving the signals correctly over multiple trials increases as we increase the number of trials.

So, it is basically increasing the probability because they are assuming independence. Whereas when we talk of hybrid mechanism this goes in a slightly different manner that when we are transmitting the second time. So, some modifications are made in the link parameters. The modifications made are such that the code rate; that means, the FEC code rate could be reduced the modulation format could be reduced.

So, for example, one is a one is at a certain SNR condition, where the probability of error is very high. Under that situation if the receipt packet fails; that means, fails a CRC and the receiver asks for a retransmission. So, since it knows that with a previous modulation and coding rate combination. So; that means, if the code rate is let us say half and modulation is let us say 16 Q A M so; that means, this would indicate 4 bits per signal multiplied by half. So, you effectively have 2 information bits per signaling unit. So, since you know that 2 bits per signaling unit has caused an error. So, when you are asking for a retransmission one can think of reducing these 2 bits to a lower level.

So, on way of achieving that would be to reduce the modulation to may be QPSK, whereby per bit you will be getting per symbol you will be getting 2 bits half and you end up getting 1 bit per symbol, one can also think of changing this rate half to let there be 16 qam multiplied by one-third. So, that would result in 1 and one-third bits per symbol. So, this is higher bits per symbol than this, but this is still lower than this ok.

So, this is greater whereas, this is kind of greater. So, one might choose to try this particular bit rate or this particular bits per resource element unit. And, if one finds that the probability increases one would be successful, because one not only successful in receiving, but one is also more efficient because it produces more number of information bits per signaling interval.

So, another way of doing it is instead of simply changing the modulation or and the code rate, one can even think of preserving the previous set of data. So, if let us say there is x t or let say we say x vector with underscore we indicate it as a vector is received from the previous transmission. And, in the next transmission you are asking for another transmission with the same information that is same modulation coded that is also possible, but you do not throw away the information which is received in the previous instance. So, this method is different.

So, you have stored whatever is received and you ask for a retransmission. So, when you have received the second information. So, this is in the first trail and x vector that is received in the second transmissions. So, by one we mean the first transmission and by 2 we mean the second transmission.

So, then these 2 can be combined together. One particular way of combining could be called the MRC combining or the Maximal Ratio Combining, which we will seen again when we are discussing multiple antenna methods. So, there one can think of using x 1 1 1 1 indicating the first chip or the first data element of the first transmission multiplied by x. So, you can take the conjugate of it x 1 of 2.

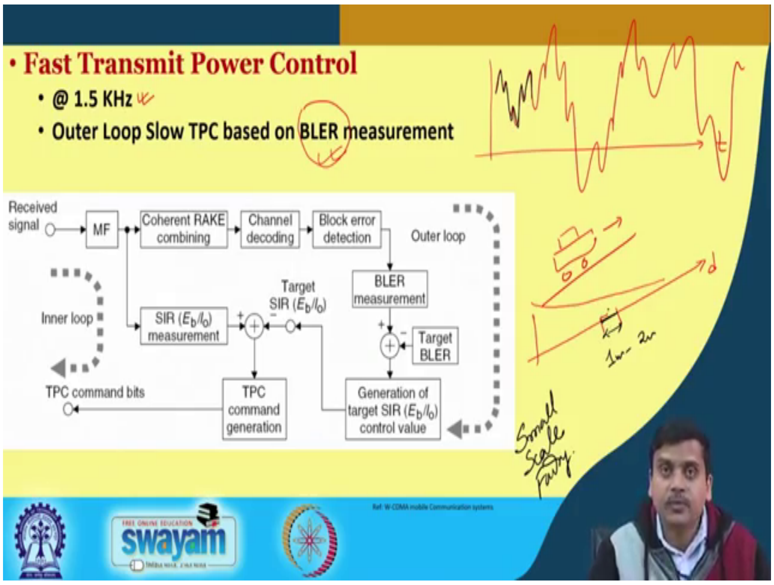
So, this 2 would go to the this 2 and this 1 would go to this 1 plus x 2 of 1 multiplied by x 2 of 2 conjugate plus dot dot dot dot dot up to the total length of the number of symbols that have been received. So, in other words we are saying that if you have received 2 sets, then let k be equal to 1 to L L is the number symbols that got transmitted in each of the packets. From the first packet you take the k th symbol. And from the second packet also you take the k th symbol you take the conjugate you add them together and then you finally, divide it by L, that is the normalizing factor and this whatever you get will be the variable which can be fed to the decision factor.

So, what as happened effectively? Is that you have simply doubled your signal to noise ratio ; that means, whatever I mean provided than signal to noise ratio which has remain the same in the 2 transmission the average signal to noise ratios remain the same. So, whereby you could simply increase the signal to noise ratio and since you are at now at a higher, let us say the double signal to noise ratio, the probability of the packet failure decreases by a significant manner. So, we can discuss the outage probability or probability of retaining correctly when we discuss a MRC transmission at a later stage.

So, please remember to use that same philosophy to calculate the probability of error or probability of outage or probability of packet drop, if we are using the mechanism of such kind of combining techniques instead of another technique where you can change the modulation and code rate. So, here by in summary instead of simply asking for retransmission, we ask for retransmission with either change in the link parameters or at the receiver side we store the previous received signal. And, we combine with whatever is received a fresh and the combined signal the post after combining there is a post combined signal would appear at a higher signal to noise ratio, which can simply improve the probability of correctly detecting the entire packet.

So, these are some of the important mechanisms which have been introduced in the third generation system.

(Refer Slide Time: 24:30)



They was also a mechanism for a fast power control at the rate of 1.5 kilo hertz and there is outer loops slow TPC based modulation turbo coded modulation, based block error rate measurement block error rate measurement; that means, when you are sending the packets. Then you can check the block or the packet error rate and you can adjust the thresholds for link adaptation, whereas you do fast power control mechanism.

Now, why is this one important this is important because if you look at the signal fluctuation over time ok. If, you look at signal fluctuation over time then this e under mobility condition; that means, when one is moving at high velocity we have discussed this, that the signal fluctuates significantly ok.

So, if the signal fluctuates significantly then there are two kinds of things that happen; that means, one can expect that as the distance increases if you talk about distance the average signal strength decreases.

However, if you look at the small duration of time let us say in orders of seconds or half a second within that period the distance that is effectively covered is very very small. It may be a few meters. Now, within that few meters the average receives signal strength usually remains constant. If within that period the average received signal strength has remained constant? However, because of the mobility, because of the multi path we had drawn the picture of a multi path scenario. So, one can take a look at this picture and just imagine that the receiver has moved a few meters may be 1 meter to 2 meter distance not even that within that each of the this paths are going to change.

So, these are positions of reflection diffraction and scattering. So, obviously, when the receiver has moved from that point to a new point this path length has become different. So, we can take different color in order to indicate that. So, this path length will be different ok. So, this path length will be different. So, this is the path length and this point would also come from a different point; that means, the reflection point would be different. So, similarly this would also come reflected from another point.

So, if all the path lengths have changed the way this signals would combined at this location compared to the way the signal would have combined, when the receiver was here is completely different. So, this combination keeps on happening as the user moves from one location to another at every instance of time. So, when the user is moving from here and it is slowly going towards this direction at every physical point these kind of combinations are happening and which are changing at a every instance.

Now, because of such a change what we will find is that the signal strength fluctuates over time in a short distance of 1 to 2 meters, which is also termed as small scale fading. Now, if you look at the chip duration it is 3.84 mega chips per second effectively indicating that the chip duration is very very short in order of milliseconds.

So, when it is very very short in within that duration; that means, when the vehicle is moving from one point to another, the signal strength fluctuates heavily to the order of 30 to 40 d v because of small scale fading. We will discuss briefly about a little bit more details when we go into the multi path propagation and (Refer Time: 28:46) before we understand any other things in future.

So, in order to maintain the same level of average received signal strength over the short distance, because if that is not done these this chips that we are talking about and the orthogonality that we have discussed or the correlation properties that we have mentioned earlier over here, that instead of 1 0 it can be high correlation or also low correlation. What would happen is that these properties would simply change. One can think of that a some of the chips are getting high gain let us say a one another chips get a low gain a 2 another gets a different gain a 3 because of fast fading conditions.

So, this orthogonality property gets destroyed and the entire design which was based on orthogonality or high auto correlation and low cross correlation gets destroyed. To avoid that during the entire symbol duration of the entire code it is desired that the signal level remains constant. So, in order to do that a fast power control can help in a significant manner in maintaining the performance of the system, in maintaining the quality of service so on and so forth. Along with this there is the outer loop slow control, which was also adjust the SNR switching thresholds based on which one can modify the code rates, one can modify the modulation order, and one can even do other adaptations also.

So, with this we will stop the discussion on the waveform for third generation. And, from the next lecture onwards we will discuss the foundation of multi carrier especially OFDM, which is the base for the fourth generation system as well as for the fifth generation system. So, it is a an advice that one goes through the details of this particular method, because we will not discuss this in a any details further beyond this thing.

However, a this is every important many interesting methodologies have been have developed, because of these WCDMA systems and we should understand that we can take advantage of these things in few design of future generation system. And just a short note that at some point of time there were lot of proposals, which combined multi carrier systems, plus spread spectrum systems. And, many schemes like multi carrier CDMA multi tone CDMA and many others were developed which combined the benefits of both the different systems.

So, there are several literature available. So, one should feel free to get into the details of them to understand how the different special properties of the different schemes were combined together to come up with a newer waveform architecture, which would meet the demands or would have properties, which are very special and can be designed in a way which can meet very special requirements.

So, thank you for this particular lecture we will meet again in the next lecture.