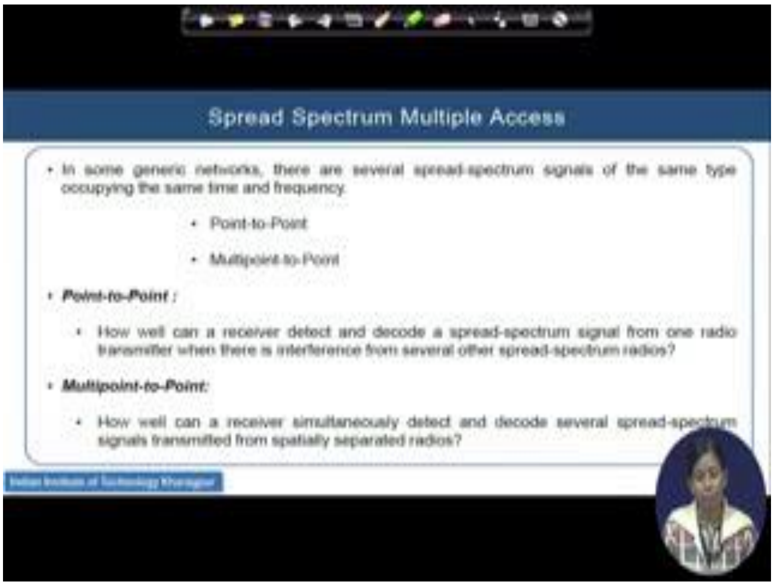
Spread Spectrum Communications and Jamming
Prof. Debarati Sen
G S Sanyal School of Telecommunications
Indian Institute of Technology, Kharagpur

Lecture – 51
Spread spectrum Multiple Access

(Refer Slide Time: 00:34)



Hello students, today we will discuss on spread spectrum multiple access techniques. We have learned already the different wireless communication characteristics and we have also learnt about the diversity. We have learned about the rake receiver techniques, and we have little bit understanding that in a wireless communication domain in a spread spectrum supported system. So, for example, a code division multiple access a based systems, we will have multiple users in a network where simultaneously they will try to access and they will try to send their data to the intended users and that is a general nature of any wireless communication networks.

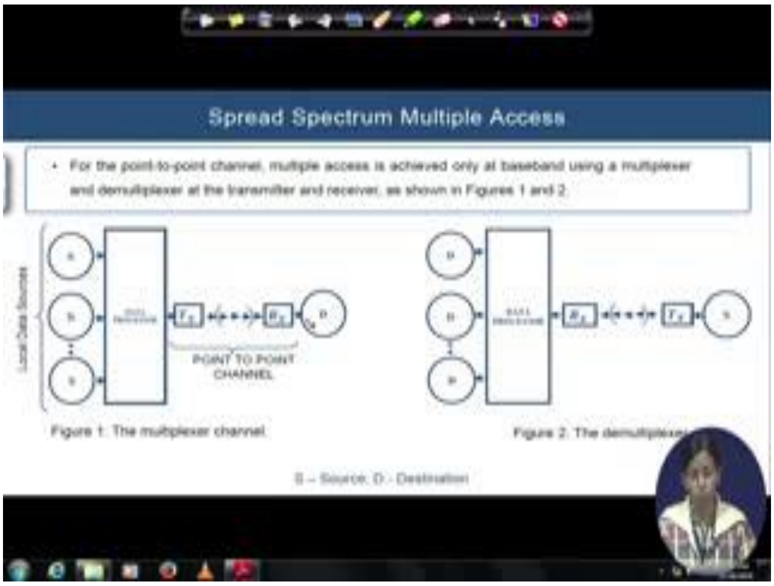
Today, we will try to see when this multiple users try to access the medium wireless medium, basically to transmit their independent data, and how will it happen and what are the different techniques and the mechanisms are there to support this access will communication between two users over such a network. We understand that in a spread spectrum communication system, multiple users can access the networks and the transmit their data at the same time at the same frequency, and they will be segregated by each other from each other by the use of unique key or unique spread spectrum sequence.

Actually the communication that happens in a network, if you try to see it may be a point-to-point I mean one user targeting another user, or it can be a multiple users targeting sending data to a point. A good example of multiple point targeting to a user is the multiple users trying to send their data to the base station from your handset, he was trying to transmit to the base station like you. Multiple such users can try to target there, trying to send their data from the mobile handset to the base station that is the multi point to a point communication.

When point-to-point communication goes on, then it may be a single user directly communicating to another user, or it may happen that one base station is communicating with another base station directly. Whatever it is, if it is a point-to-point communication then the equation is you will sometimes called station-to-station communication also. So, this point-to-point communication, the main major problem is when you are sending your data to your intended user, how in a receiver you will detect and decode your own intended signal when all others are also transmitting their radio signals, and they are giving severe amount of interference to your signal.

So, because we understand all the users can simultaneously transmit over the same time on the same frequency. So, interference is obvious to happen. And the question is how do you will detect your own signal maintained a signal in presence of the other users who are suppose to be the interference to low. Multipoint-to-point, in that situation, your target signal, you are main problem is sitting in the base station in the receiver, how will you detect each and every user signal separately, how will you detect, how will you decode the several spread spectrum signals separately

(Refer Slide Time: 04:10)

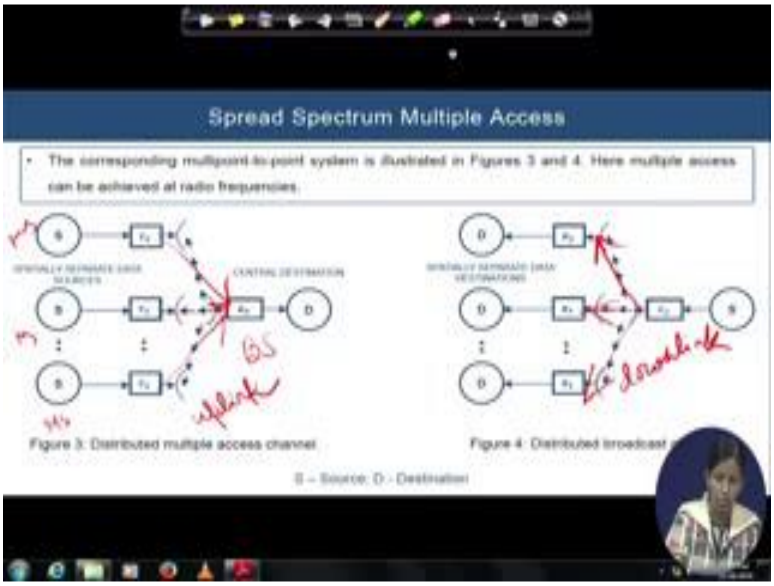


So, the problem definition is different in a point-to-point communication interference is going to play a role to detect your own signal, and where you do not have a loads to sometimes into a detecting the other interference signals you may or you may not also. But in the base station receivers, so multipoint-to-point communication is going on sitting in a base station receiver your point the problems (Refer Time: 04:37) to detect and decode each and every user signals in the presence of the other interference signals.

So, we have given an example in the figure 1 and figure 2 as an example of your point-to-point and multipoint-to-point receivers. See, this figure is basically for point-to-point we have shown that in figure 1, it is a multiple data sources, s stands for the sources; here is the destination. So, multiple signals once they are coming, they are called data sources they can be multiplexed, and this is a node, inside a node is the multiplexing going on. And hence in the transmitter output, you are getting one-to-one communication, because destination is fundamentally getting a multiplex to signal from multiple source, it is a point-to-point channel.

So, in the receiver, so from transmitted to receiver, after receiving in the receiver, what is happening is receiver is demultiplexing the data to separate how the different source signals. And it can target your difference destination also. So, this is a typical a channel itself is a point-to-point channel. So, there is no concept of multiple transmitters that are interfering your rejection it is not like that. So, this is the multipoint point-to-point channel and because of this it is basically based on a multiplexing and demultiplexing of the signals where to separate a multiple sources and multiple destinations. So, this is one kind of we are handling the multiple access in a over a point-to-point channel.

(Refer Slide Time: 06:27)

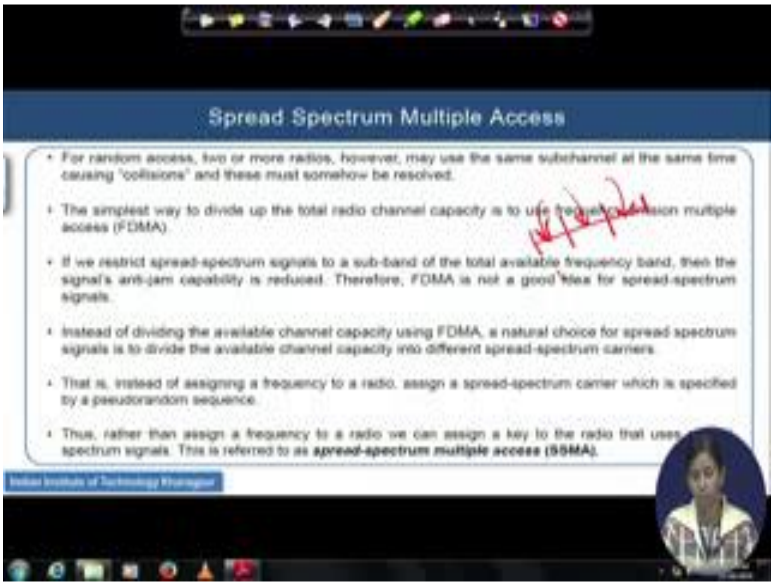


Next is the multipoint-to-point communication, let us see how will it happen. So, the corresponding multipoint-to-point, it is we call sometimes it is a distributed multiple access mechanism, where your channel will be have multiple point channel or multiple access channel. Where what we will find is they are a specially separated data sources and each of they might having there independent transmitters, all of them will be transmitting, and hence the receiver is bound to get the signal not only from the intended transmitter, but also from the other transmitters. And this is the central destination, if I am targeting it may be a base station, and these are all the mobile handsets or the mobile stations that you are carrying, and this is the very typical wireless communication scenario that that we face in your day-to-day life.

It may happen now opposite way also. Suppose, if it is the base stations to multiple mobile stations the communications is going on; then from the same transmitter single base station transmitter, it will be broadcasted. So, once it is broadcasted, the signal will be received via to the different receiver via different kind channels. So, the channel of the receiver one and receiver two and receiver three they are not exactly same and that is down link channel that we call. The channel like this when mobile stations to the base station communication is going on we will call it and up link channels as we have discussed earlier also. And this things that downlink channels when the transmission will be going on from the base stations to the mobile stations.

So, multiple access here also is received their channels is basically the distributed multiple access we call it that is why the mechanism is; and this is a distributed way this is the distributed multiple access channel and this is a distributed broadcast channel, you are broadcasting receiving data to multiple receivers. So, these are the basically two different types of the access that we face in a wireless communication network and that we will also be facing when the spread spectrum communication is going on over that network.

(Refer Slide Time: 08:43)



So, now, it is obvious that if two users are using the same channels, same wireless environment over the same frequency at the same time, so two packers release from such two users, they are there is every provision that they will be colliding with each other. So, but this collisions needs to be resolved because otherwise for both the users the package would not be able to detected in the intended receiver. And one possible solution of that or I should say the one of the possible solutions of this problem is something like this. You have channel - wireless channels, it has a maximum capacity. And what you can do it, the total radio channel capacity is to use you can actually divide the available whole bandwidth of the channel which is equivalent to proportional to the capacity. And we can utilize the whole bandwidth of the channel, we can divide it by multiple sub bands and we can have a frequency division multiple access.

So, the users who are will be allotted in the first band, and users who will be allotted in the band number two or band number three, they can reward actually collide the packets of these three users can never be colliding with each other. So, like that you can actually divide a available bandwidth over several sub bandwidths and sub bandwidth will call them with smaller bandwidths. And allocate the each smaller bandwidths to each and every user to multiple user, so who are intended to send their data over the wireless communication channel, and thus you can avoid the interference from user 1 to user 2 to user 3 to user n.

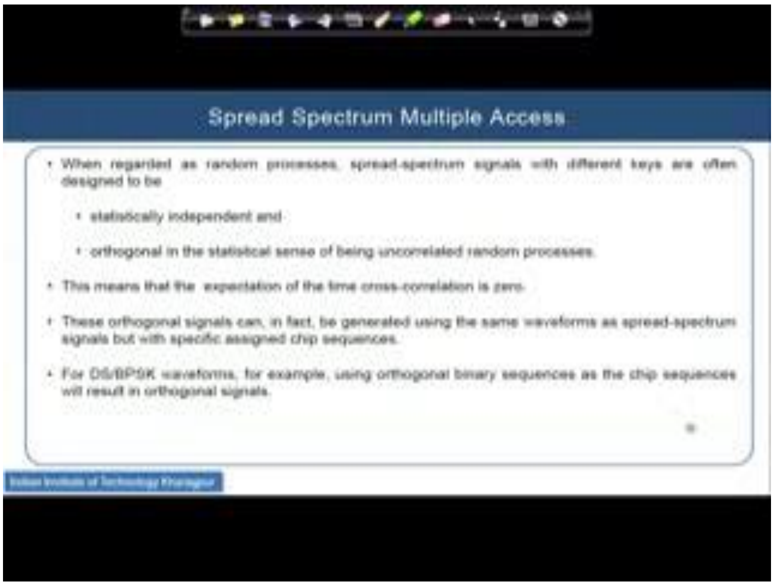
But remember one thing actually whenever you are dividing the whole available channel into the small as sub bands. So, basically you are not doing good over the anti-jamming capacity of this spread spectrum communication which fundamentally comes from the fact that you are using a very wide bandwidth where the narrowband jamming signal will be rejected once actually you are spreading there transmitter signal over the wide bandwidth you compare to the narrower interference.

So, if I am reducing, I am restricting the bandwidth of my spreading definitely if I am dividing the total available bandwidth by smaller sub bands, so the bandwidth having gate for spreading over for each and every user where allocated in the sub band that will be much much less compare to the total bandwidth available. And hence, it is capacity its capability sorry its capability to avoid the anti-jam activities, and it capacity to proof the anti-jam activity for the receiver that will be definitely reduced. So, that is why actually we do not refer the frequency division multiple access as a preferable or natural choice for the spread spectrum communication systems. Because in spread spectrum communication, our fundamental motto of designing is designing is a secure communication design, where by default you will get by signal, by the means of signal processing you will get a protection against the jamming activities over the environment.

So, if we are in not prefer in the frequency division multiple access techniques as a preferable solution for the spread spectrum communication, so let us go a little bit forward. And next option itself is instead of dividing the available frequency over the bands, so let us (Refer Time: 12:35) assign actually each and every user radio with spread spectrum carrier. I mean you divide with a available capacity over the carriers spread spectrum carriers. And this is specified by some pseudorandom, this carriers or the spread spectrum carriers are the pseudorandom which is specified by the pseudorandom sequences.

And hence this is key not only a key assigned to each and every user it is also assigning the spread spectrum carrier to each and every user, who all will be spreading their signal using their independently key or pseudorandom sequences and they can actually parallely start their transmission because all those keys will be designed in orthogonal fashion. So, we the whole mechanisms this way we call it as spread spectrum multiple access mechanisms. Remember that the key should have some there is specific fundamental properties and what are those properties we will see in the next slide.

(Refer Slide Time: 13:40)

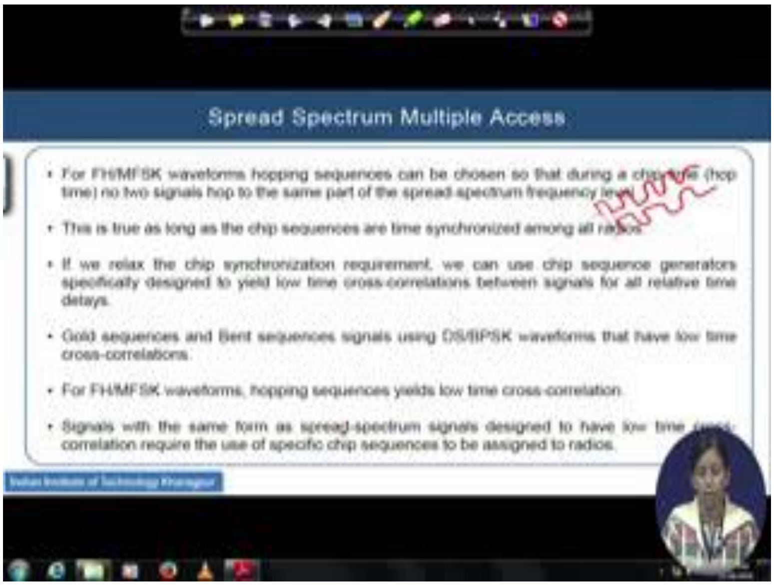


To avoid actually the multiple user interference over the network we should be very much the aware of the fact this spread spectrum signals with this different keys, the key should be designed in such a way that all the keys that should be statistically independent to each other. And this should be orthogonal also in the statistical sense.

For example, the actually they should be completely uncorrelated random processes; each and every key should be a completely uncorrelated random processes. It means actually their expectation if you do the time cross-correlation and that you take the expectation of this time cross-correlation values it should be prefect 0. And this orthogonal signals, in fact that can be we have understood actually lot of the ways also generating such orthogonal signals in the last few modules and these are the signals with we will be utilized now for the spreading your original signal And they can be having a different lengths based on the data rate requirement giving you the flexibility of varying the data rates inside the network.

For example, see actually this orthogonal signals, when we generate. So, using some same kind of you can generate by some kind of the waveforms as the spread spectrum signals, but remember that we always actually define this spread signals or and they spreading waveforms by terms of some chip sequences. And as orthogonal signals and the relation of the chip sequence is fundamentally after spreading signal with this chip sequences, remember that you are finally coming up with not in the good domain, you are be finally coming up with the chip domain and the property of the spread spectrum of the property of the spread signal will be governed by the property of these orthogonal chip sequences. And these are some known facts to us already.

(Refer Slide Time: 15:49)

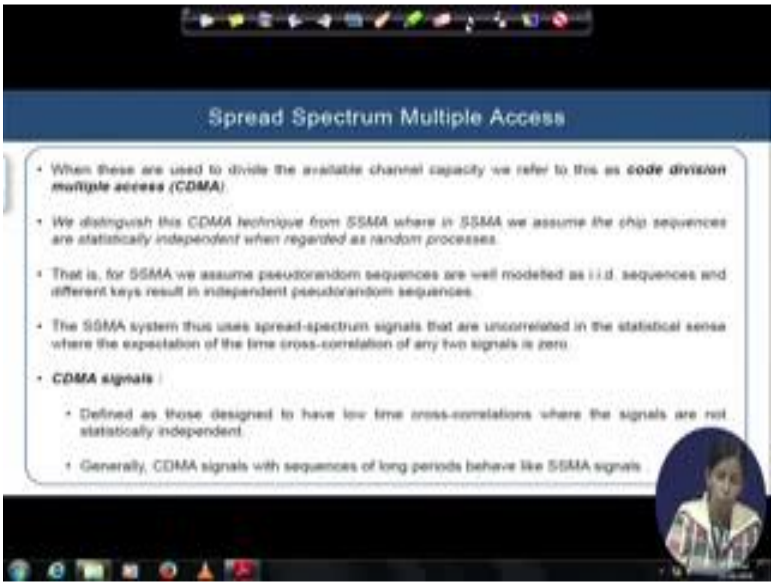


We have heard about the frequency hopping MFSK systems and frequency hopping MFSK waveforms, they are hopping sequences we can choose such that during a chip kind or a hop time it may be equal to hop time also. They no two signals they should hop over the same hop duration. So, if this is that can be ensured then definitely you can provide the protection against the multiple access interference. Suppose, you have designed two signals in such a way that a the hopping pattern for the first signals though it is something different from the hopping sequence of the next one. And such a way that within a two chip sequence or within a hopping duration two such hopped sequence are never coinciding or never falling with each other, they are never be overlapping with each other, then definitely you can avoid the interference from each other such two users.

And this phenomena will hold good as long as the chip sequences are time synchronized among all the transmitter reduce over the network, which is very hard really to maintain in a practical scenario. And if you relax little bit the chip synchronization requirement, we can use the chip sequence generation in such a way that they would not yield perfectly zero cross-correlation values, but they will generate a very low cross-correlation then also the system design is possible. And in such a sequence for example, we have heard about the gold sequence priori and bend sequence is also another sequence who can give a serve very, very low cross-correlation values.

So, for FH MFSK waveforms, so the hopping sequences they yield (Refer Time: 17:48) very low time cross-correlation values. And hence it is a at least, we can assure that if two sequence such sequences are given to two difference users, they would not provide zero interference to each other, but they will maintain a very low interference profile over each other. So, signals with this as a same form as the spread spectrum signal designed to have a very low time cross-correlation, they are basically used to it, they are mostly utilized in the graphical system designs. And we do not prefer to use, usually do not get the flexibility to use a perfectly having the perfect statistical property over the multiple codes.

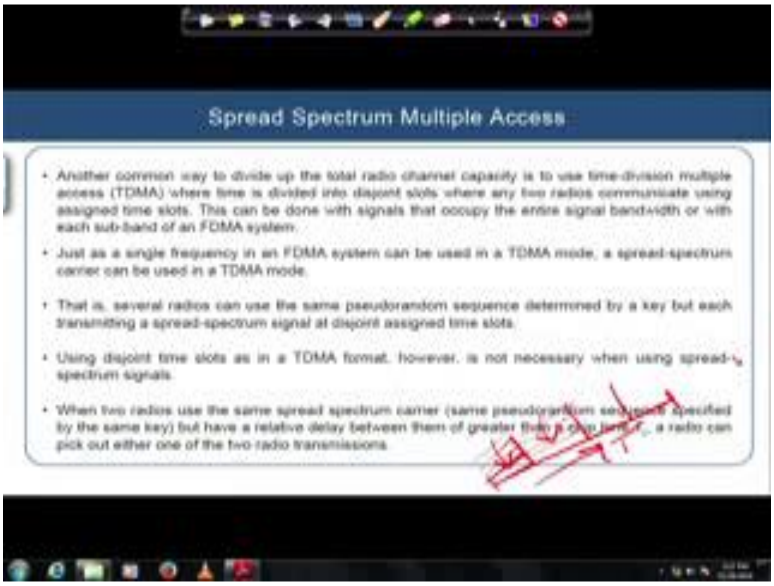
(Refer Slide Time: 18:23)



So, when we continue the design with a condition that the codes that are getting used in the spread spectrum systems, they are maintaining a low cross-correlation property rather than assuring a zero cross-correlation time cross-correlation we then call the system as a code division multiple access not the SSMA. So, the distinguish factor between your CDMA and SSMA is something like this. In a CDMA system, we can expect that the codes that are getting used their will profile there will have a low cross-correlation profile. Whereas in your SSMA, you will have the will assume that the chip sequences are (Refer Time: 19:17) statistically independent with each other, and they will be regarded as the random process independent identically distributed then that completely such independent random processes.

So, this is very much I should say this is very ideal situation, and this is the close to the practical situation. So, the CDMA signals, so that we will be coming here, the signals that we will utilizing here, they are defined as those you will having a low time cross-correlation values as I have already mentioned. And if you see that if the CDMA signals are having very very long period they will be asymptotically coming close to the SSMA signals, because in that case is the low cross-correlation values will be so low that it can be approximated as almost 0, which is the case of the SSMA.

(Refer Slide Time: 20:12)



So, we have learnt about FDMA then we came to SSMA and CDMA. Now, the time is to go for discuss about the other kind of the multiple access techniques which is called the time division multiple access or the TDMA. What we do in the TDMA is that the total capacity the total capacity of the channel actually it is over the whole available bandwidth of the channel is a allotted all the users, they can use the same frequency also, but the time of their operation is not same. So, what I can do is now if this is my time access, what I will do is where the time access I will allot the user number one sometime being. Then I will allow the user two to access my channels, the next time being and the like that the time scheduling will be associated with each and every user. There all of them users given actually the time he with that within a time he has a flexibility to use the full channels full bandwidth of the channels and the same frequency

So, this is the time division multiple access where the disjoints slots are exploited and they are assigned to different radio the communicating channels they are actually given to different users. And remember unlike if the frequency division multiple access systems, so here the time difference between two users actually ensure that you would not get any interference from would not get any interference from each other. So, just as a single frequency in a frequency division multiple access system, it can be used in the TDMA also, but remember one thing in the frequency division multiple access the central frequencies of the every sub band is to be different here you are not doing that. And here similar to the (Refer Time: 22:24) similar to the SSMA and the CDMA close to they are both close to the SSMA and CDMA, but you can nicely club actually the CDMA with the TDMA or you can also club with FDMA with TDMA or you can also club with CDMA with FDMA.

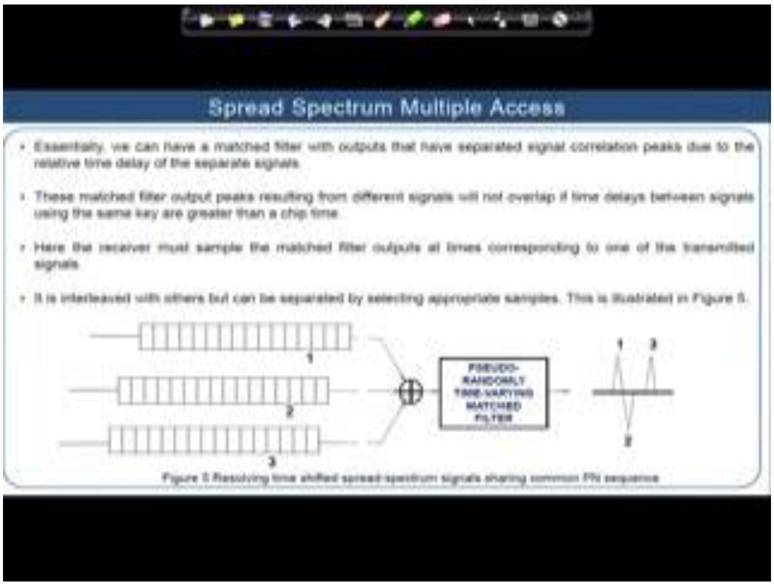
So, whatever be the way actually depending upon the application scenarios and the kind of deteriorate demand and the quality of service, the multiple such techniques are actually exploit in the practice to get actually the prevention against the interference experience over a network by the by the users. So, is in this because of this disjoint slots already we have designed already we have discussed that the TDMA format and the TDMA itself can ensure you the different the interference protection.

And another important thing to remember here, so as we are having a different time slots so the pseudorandom sequences that we are using for the users who are operating in this time slots, the same set of the pseudorandom sequences, I can allot to other set of the users in some other slots provided the data transmissions of those users where using this set of the pseudorandom sequences, they are data transmissions is over. So, once the data transmissions is over, as these pseudorandom with times are orthogonal to each other they are disjoint. So, sequence can be repeated over the multiple time slots like this.

So, the number of the keys you need now to operate over the channels, they are not actually not they number of the sequence number of the codes require to operate are really not as high as the CDMA. So, it is a nice actually process on the nice situation actually, but definitely the TDMA involves a high delay, and the waiting period to get the access of the channel. CDMA is not providing you any delay, you can all means everybody can have an access of the channel almost is continuously, but to remember you have to have a huge set of the orthogonal keys or orthogonal codes to segregate the users and the data. And this is really a very big question because getting a huge number of the orthogonal codes simultaneously to density the networks mainly is a very big question is a hard to get all so such a big number of the orthogonal code sets for a separating the users.

The third point was our frequency division multiple access it has its own limitation. We saw that you cannot get that much protection that much anti-jamming capability as you are deducing the transmission bandwidth and which is only a part of the total available bandwidth. So, these are the three different; four different kind of that techniques including SSMA. They are four different kind of the techniques and they are having their own kind of the pros and cons and based on the service application is based on the data rate requirement and quality of the service, we choose any one of them or a combination of them in a practice to design the networks.

(Refer Slide Time: 26:01)

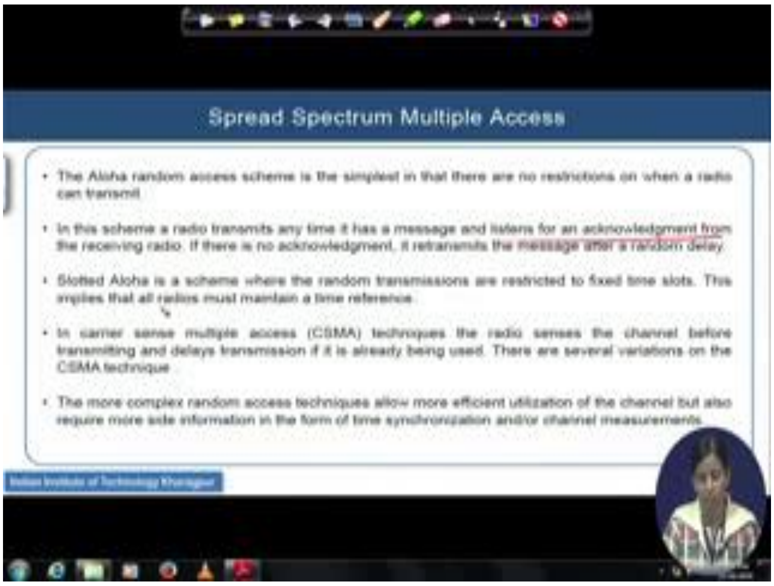


Another point to make here is if you are using a TDMA system, and we will discuss here actually with respect to that point. Suppose that essentially if we have a match filter architecture in the receiver that have the separated correlators parallel correlators that can detect the peak of the different signals with their relative time delays are happening. And if this delays is more than the chip delay if you see of with respect to one each other then what we can do is that all this independent correlation peaks uniquely the time varying match filter it can detect.

So, what we can do is if I understand that this is the peak of the signal one correlated output one. So, I can follow actually regularly the peak of corresponding to the one to actually capture the signal from our definite users. Similarly, to get the signal from the user two I should always follow the peaks corresponding to the two for a regular interval and same for the three. So, basically each the time division multiple access, if the two chips are if the two signals are separated out or they are delayed from each other more than a chip duration, so they will can be treated as a separate signal and there is basically no interference from one signal to the next signal always.

So, if you are having a chip, if you have are having some interleave within a chip duration only then this kind of the interference, the problem of the interference will come in to picture two users transmit in using the same the frequency same code and you are same frequency same code and same time. And more over we are having some interleave are also into the in the circuit. So, it will also take care of the fact that you get actually a pretty good resilient again through interference.

(Refer Slide Time: 28:13)



So, the different random access schemes are there in practice and aloha is a very very popular one out of that. And it does not explicit this aloha random scheme is such that it has no restriction over the number of the radios and when a radio can be transmit kind of. And in this aloha scheme, the radio transmits at any time and it has a message whenever it has a message and it can listen also the acknowledgment. So, it can transmit whenever it is having a message and it keep on listening whether some acknowledgment is send from the intended receiving radio, but the intended receiving radio if no acknowledgment is there. So, it will keep on transmitting its own signal, so in a random fashion.

Then actually a lot of collision may happen because of everybody will try to send their message in a random fashion. In order to improve the performance people came up with slotted aloha scheme. And in the slotted aloha scheme you wherever this random transmission is going on, this random transmission is restricted always by the some fix times slots. And this implies that all radio must maintain that fixed time reference and then you can keep on randomly transmitting your signal and keep on waiting for the keep on listening for getting the acknowledgment from the intended receiver. But after that actually the carriers is multiple access this days which is used mostly in these days, they are the most popular and advance version of this aloha and this slotted aloha, they give a much better performance in terms of accessing the wireless channels.

In carriers sense multiple access, you everywhere which says that which tells that every receiver or every nodes who is having some data to transmit you first listens the, it was listens the channel and try to understand whether some transmission is going on or not in the same frequency. And he waits till actually the channels gets free, once he senses that there is new transmission and that frequency is going on, at that moment only he where starts releasing his own packet and he starts establish a link over the channels. So, that the carriers sense multiple access each and every user obeys this typical rule of listen before talk, it is listen before talk also.

The most where complicated and the more complex random access techniques that we will be that can be actually also allow the part from the CSMA, and that are the utilize for utilization of the channels. But remember actually to better utilization means, you have to have better channels setting from information or side information also to get the information a pride information or access the condition of the channel. And that extra information that we was required to give this information about the condition of the channel is not bandwidth efficient communication I should say, so that is called actually how much complicated calls you wish to go ahead with.

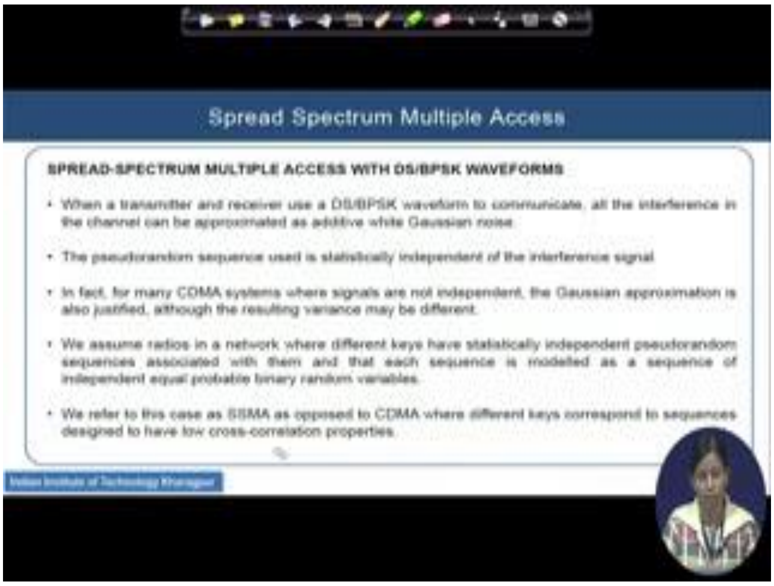
(Refer Slide Time: 31:23)

And now this collision so CSMA is a scheme actually say is spread spectrum signals are generate difficult very difficult to detect. So, the CSMA is scheme is not that much preferred for the spread spectrum. Slotted aloha requires some time synchronization among different reduce that it may be done by the GPS, but that also actually cannot be hundred percent guaranteed. So, it is also difficult to achieve. So, though actually that is why sometimes actually we prefer to go ahead with the though where with prefer to go ahead with the slotted aloha basically and or some advance version of the CSMA for the spread spectrum communications.

And signals and the notations of this non overlapping time slots and all that is not very much useful because we have understood that if actually they are one chip duration away from each other, the collision cannot be can be actually avoided. So, they do not collide with the same spread spectrum carriers if they are having a say same interval also if they are having with the time delays are more than the chip duration.

And with pure aloha random process also the two spread spectrum radio signals can cause a collision at receiving radio, but only if both of them using the same key. So, you can (Refer Time: 32:51) if they use aloha and if you are can hundred percent confirm that the keys are perfectly orthogonal from each other. So, otherwise that so that is why actually basically in a jamming environment or in a multiuser environment we can feed the other users then other user signal than the from maintaining signal to be behaving as a just like a independent jamming interference.

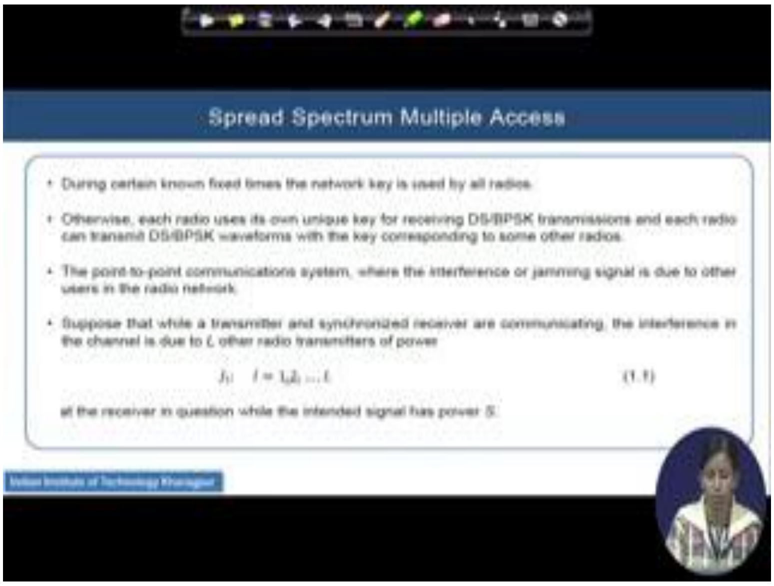
(Refer Slide Time: 33:22)



The spread spectrum multiple access now with this direct sequence BPSK waveforms, if we try to see. And here when you transmit and the receiver using the direct sequence BPSK waveforms, and you are receiving the signal with an additive white Gaussian noise, and all other interference multiple users are on. So, all other interference where can be modeled also as a additive version having a Gaussian distribution. And the pseudorandom sequences are statistically independent to come back the interference signal, I am compare reduce the effect of the interference. And for many CDMA systems, so their signals are where the signals are not perfectly independent. This Gaussian approximation also can be justified if the large number of users are present in a networks.

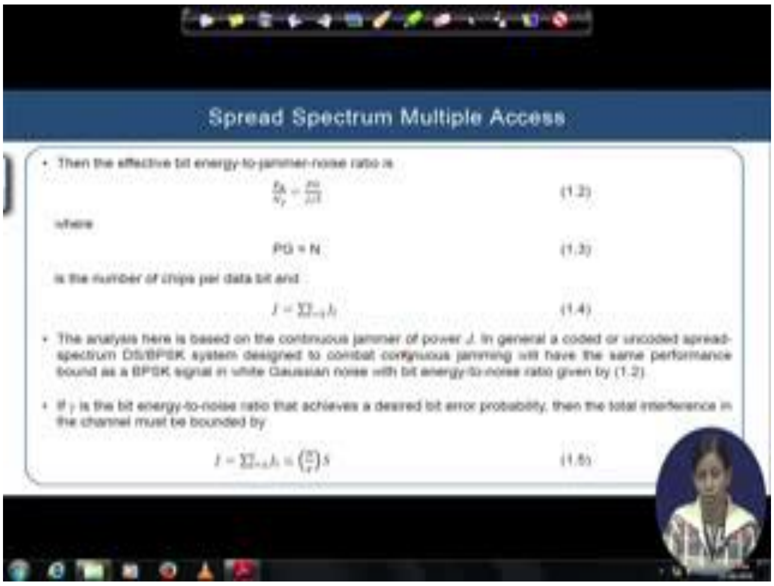
And we also reduce assume for this analysis that the radios in the networks where the different keys have the statistically independent with pseudorandom sequences, and this sequences are modeled as a sequence of independent equi-probable binary random variables. And let us consider that we are considering with the low autocorrelation values of those sequences and it is not a SSMA system, hence it is a CDMA as where actually it is a CDMA system it will be. Then for that typically for this have though the practically most of the situations will be following the CDMA system. For this situation, for this analysis, we will consider that the condition is following the SSMA I mean the keys are perfectly orthogonal to each other for each of the analysis only.

(Refer Slide Time: 35:06)



So, for known fixed times, the networks key is issued by all the radios; and otherwise each radio uses its own unique key for receiving the DS BPSK or for receiving the DS BPSK transmission. And they can transmit also either using the same key or by different key that is already provided by the networks. The point-to-point communication system if it is going on that the interference or the jamming signals or coming due to other users present in the networks. And suppose we are having the capital L other number of the users on. So, the total jamming power the J L that will be varying is a summation of the power actually released by the user 1 to user L.

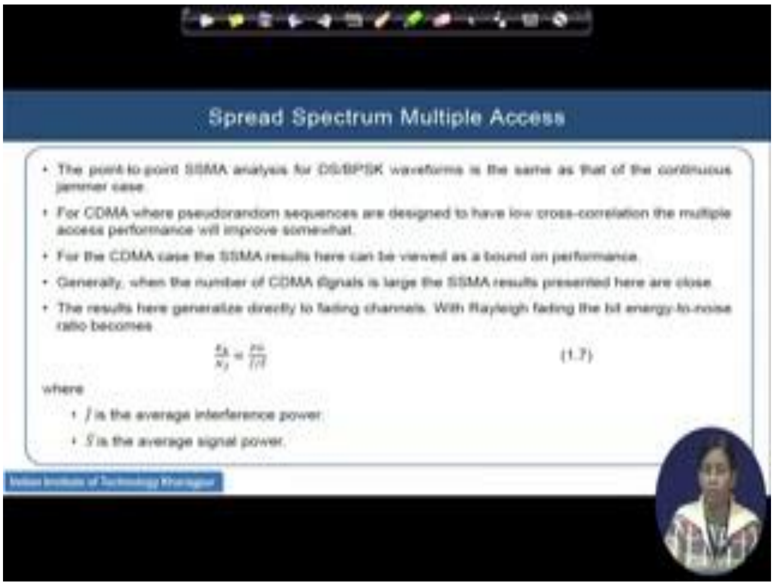
(Refer Slide Time: 35:59)



So, at the receiver in the question when the intended signal has a power of the S, we can have the effective bit energy to the jammer noise given by this expression. This is a known expression for us. This bit energy to the jamming noise power is nothing but the gain divided by J by S, where this P G is equal to the processing gain and which will be giving by the number of the chips present within one bit. And J is nothing but the summation of the all the other users power, so summation of all the Jl’s.

Remember this analysis is considering, whether is a continuous jammer of power j. And the additional gains because of the coding channels coding and I mean the coded or un-coded in the spread spectrum communications we have not considered that gain will be additive to this processing gain coming into picture. And we know that if gamma is bit energy-to-noise ratio that achieve as a desired bit error probability, when the total interference so this J l should be always less than equal to this N by gamma which can be lower bounded by actually. It can be lower bounded by the N gamma multiplied by the signal transmitted S.

(Refer Slide Time: 37:18)



Thus if the analysis whatever we have done for this point-to-point SSMA analysis that actually for CDMA analysis and the SSMA analysis. So, for both DS BPSK will be having a approximately the same way. And difference mainly actually we will be in the way that you are doing the averaging and generally when the number of the CDMA signals are really very large we understand that it goes close to the performance of an SSMA signal. So, in that situation, there will be an averaging going on directly over the fading channels.

If I consider there is a Rayleigh feeding channels, this ratio of the bit energy-to-the noise power will be now given by the average jamming power to the average signal power. Because you are now considering you are now considering the fading channels and the multipath the powers that are received over the multiple paths from each and every user, now you are taking a mean value over that. So, that is not the instantaneous power of the instantaneous values over each path that you are dealing with.

Hence, actually the average values of the signal power and average value of the noise power is coming or interference power is coming into picture in the expression. So, this is about the fundamentals of the different multiple access techniques, and very little discussion about how the error probability of the received signals-to-noise ratio we will (Refer Time: 38:53) signal to interference ratio rather to say. We will behave in a multiple access environment in a spread spectrum communications.