Fundamentals of MIMO Wireless Communication
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Lecture - 04
Layered View of Transmitter and Receiver: Introduction to the Channel

Welcome to the lecture on Fundamentals of MIMO Wireless Communications. Now we are at the 4th Lecture, we begin with a brief overview of what we have seen in the previous lecture and then continue to look at the layered view of communication systems which will give us a peep into the channels or how we look at the channels from different perspective before going into the detailed channel models.

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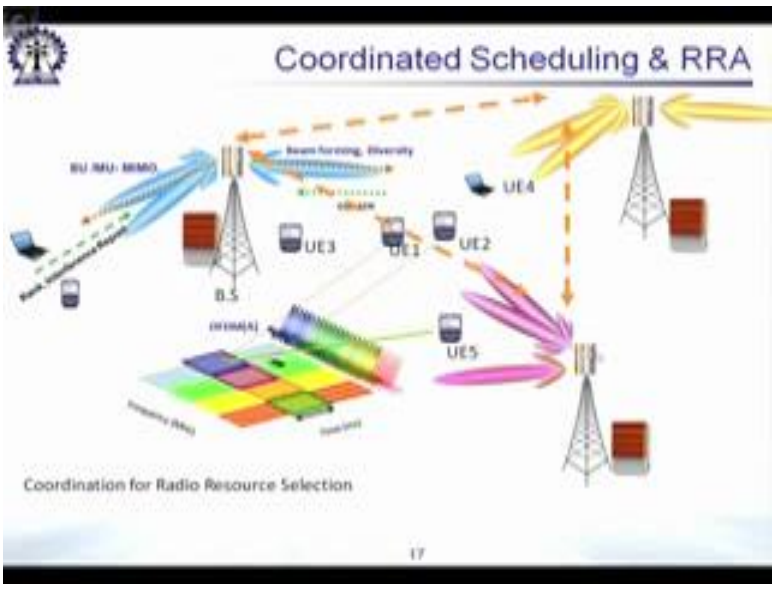

So, what we have seen in the previous lecture, the last few things we were trying to see is when MIMO is used in a communication system especially a mobile communication system or a communication network we have multiple transmitters enabled with MIMO. And what we would desire is that to exploit the full capability of MIMO the coordinate transmission amongst themselves.

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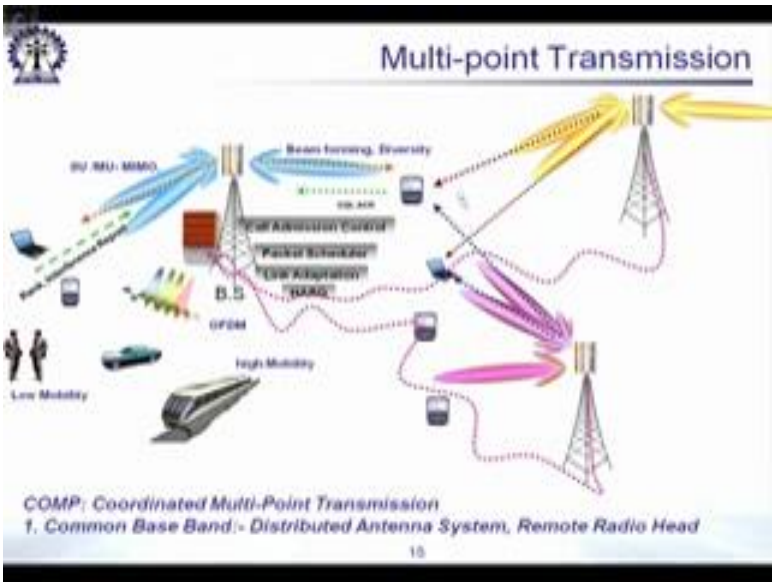

One of the modes could be joint transmission, where they would be coordinating the signals through a central processor and transmitting in such a way that instead of interfering they get mutually beneficial signals.

The next what we saw quickly was they do not have a central joint processor, but they coordinate to use the different MIMO modes so as to reduce interference. The last one what we saw is along with MIMO they connect to radio resource allocation. That means allocation of resource units to users combined with MIMO mode selection, again through coordination of channel information amongst these base stations. However, signal processing at the individual base stations.

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What we were seeing at the last was some of the prerequisite I will repeat we require revision of digital communication systems which we have revised very very briefly so that those who have a not in touch with it are requested to revise some of the concepts. Probability in statistics we will require like distributions linear algebra we will require in this particular course we will spend a very short on linear algebra if necessary. The books would be the Wireless Communication by Rappaport and the Mobile Communication by Gordon Stuber in the initial part where we talk about the channel. The main book of this course would be Introduction to Space Time Wireless Communications by Paulraj and Wireless Communication by Andrea Goldsmith is also another important book which you can use. There are many many other books on MIMO communications also.

So, there is no such restriction in this particular course feel free to refer whatever material that is available with you. And we would also need elements of information theory and of course we will present it in such a way that we are able to cover the basics before we go into the details of MIMO communication.

We will also list it down some of the important famous researches in this particular domain so that you can go to the web page and collect sufficient material which are quite fundamental and which are since the earlier days of this particular domain. Of course, do not limit yourself to whatever I am pointing out here. There could be many many other

resources so feel free to take as many resources as possible provided you are able to give appropriate time.

Because this is particular subject which have been evolving a lot of things have been done and if you would refer to the fundamental words you might feel more motivated they might be additional information which you might be able to capture which goes beyond the limitation of this particular course.

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This is an important suggestion which I would like to provide especially on how to prepare. But, before we talk about that this this is how it is organized we have already talked about introduction to MIMO wireless communications today telling you about the broad overview of how things are of you have revised some of the important assumption of digital communications. And then we will go into the propagation channel models because without understanding channel models it is impossible to design any communication system.

We would need information theory for MIMO wireless communication systems this is also very very important. We do not require thorough understanding of an information theory, but we will require some important tenets from information theory. Of course, we will revise them that will give you sufficient preparation to undertake the results that are very well critical for MIMO communication system. Then if necessary we will look into fundamentals of linear algebra as then applicable in particular situation. We will study

capacity of MIMO communication systems we will look in to diversity mode of MIMO communication system and also multi user MIMO communication.

Now, the most important part it is how to prepare, I would strongly recommend that read references especially the once that have been pointed out and not limiting yourself to these books. The first three references that I have mentioned here are very very critical. Sometimes this book is also useful this quite easy to read these books are more detailed, so I mean whatever you feel more comfortable with you follow that. This is what we will follow throughout the second half especially of this particular course. This will be required as a supporting material in the course.

So, please read references I would strongly recommend you should do parallel reading beyond going through this lectures. Work out simulations, so we will be giving out a simulation samples and simulation assignments as to say which you should try yourself. And they might be some possibilities of using virtual labs in certain cases which again would give you some practice and understanding of things, and if it is possible to get hardware laboratory facility I would strongly recommend using those facilities we do have one over here and I do not know how to explain the facility to the rest of the masses if you are attending any course at IIT Kharagpur you can also come and use some of the facilities here.

So, this is very very important to remember you should read references and you should workout simulations, because without this case is very difficult. Because when we are talking about communications unlike other domains this requires a lot of imagination. So, you have to be imaginative because you cannot touch or feel the signal. And to do this you may require lot of complex instruments so imagination is necessary simulation is one step beyond imagination a little bit closer what is reality. So, if you are able to do that that would be highly recommended.

So, with this we move forward to our next details. So, we will be talking about the layered view of transmitter and receiver and introduction to the channel.

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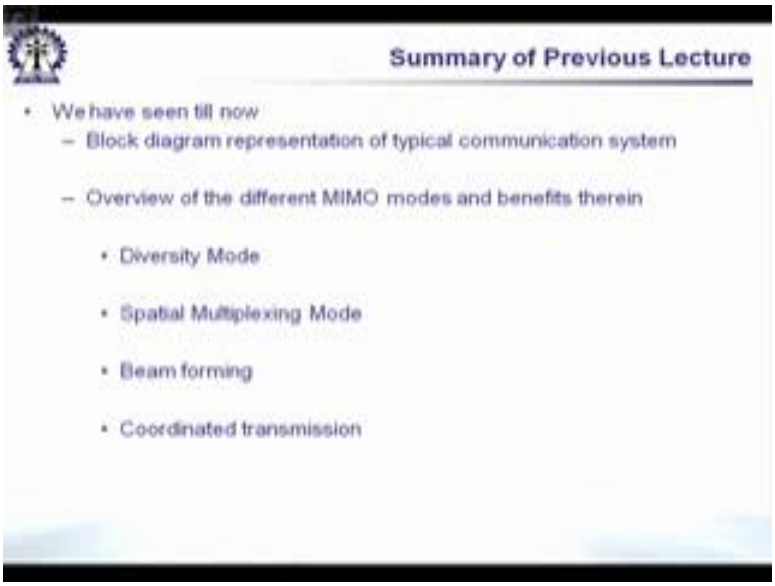

So, we have already talked about what we have discussed in the previous lecture.

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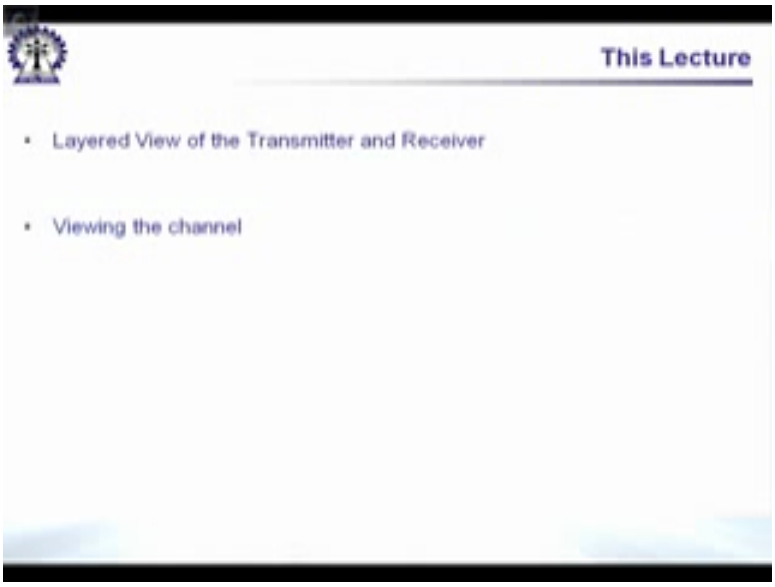

So, today will be talk about the layered view and looking in to the channel.

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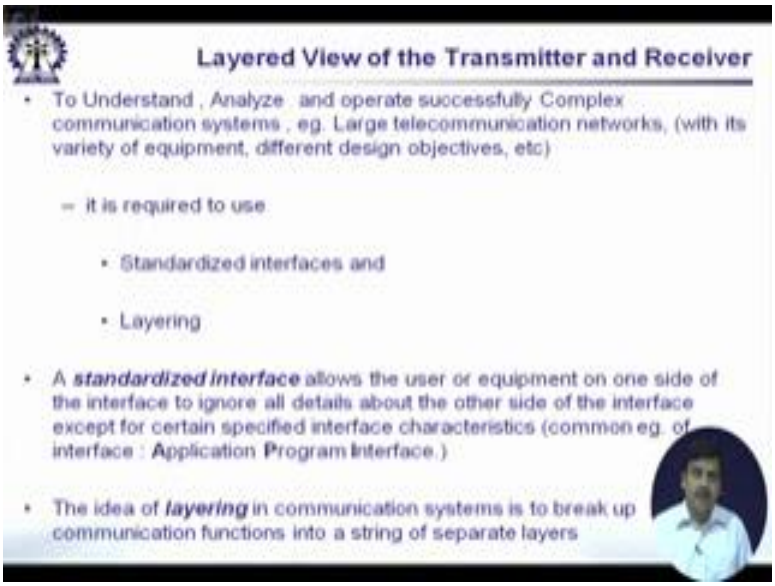

Now why do we have layers or a interfaces, because what we have is very very complex system today. If you look at a typical telecommunication network or the way you access internet it is like you are a mixing many different devices which operate in various ways, we have various design procedures and they are really complex to analyze. Now because it is very very complex to analyze performance of such systems it is important that there is layering approach and there are standardized interfaces.

So, we will see what these two important things are. Standardized interface allows the user or the equipment on one side of the interface to ignore all details about the other side of the interface except for certain specified interface characterized characteristics. Those who are used to programming for them the application program interface is one of the things, a very very simple thing would be like functions.

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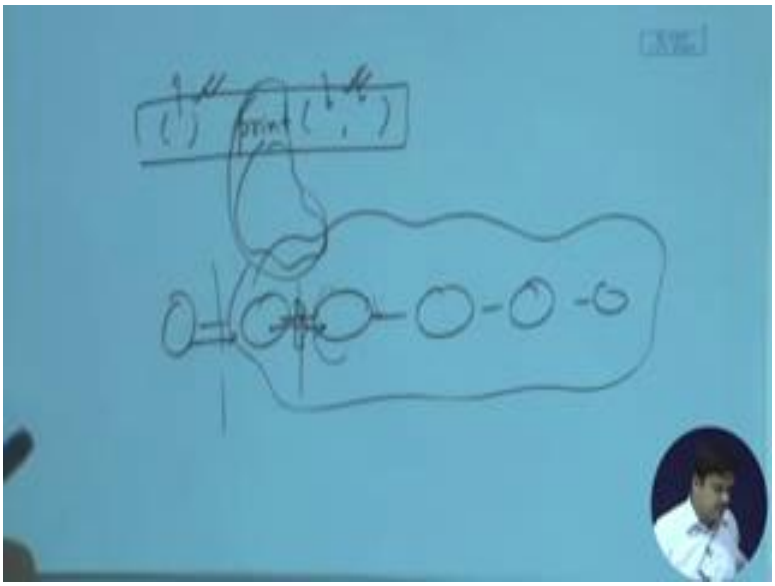

For example, we often use the print function I am taking completely odd example but you may be used to this print. Print function requires certain input parameters and it also has l output parameter. We never try to understand the details of the print function we try to use the print function by its input and output which are its interfaces. The details of this print function vary from different operating systems and different hardware facilities.

So, these are interfaces to this particular module this particular function that is what I mean by interfaces. Now when we have a large number of a modules inter connected, if an interfaces properly defined this device need not know about what lies ahead of it; it just needs to talk to this through this particular interface that is it nothing beyond. And this device needs to know how it is going to send information to the next one. That is it and you need not understand the details of it, only the interface specification is required. That helps us in studying complicated systems.

The idea of layering, again layering in communication system is to breakup communication functions into a string it separately layers. Now we are already seen the seven (Refer Time: 10:11) layers today we are going to see some other way of looking at communication system.

So, we now move on to look at the typical block diagram or typical structure of how this layering concept is used in a communication system

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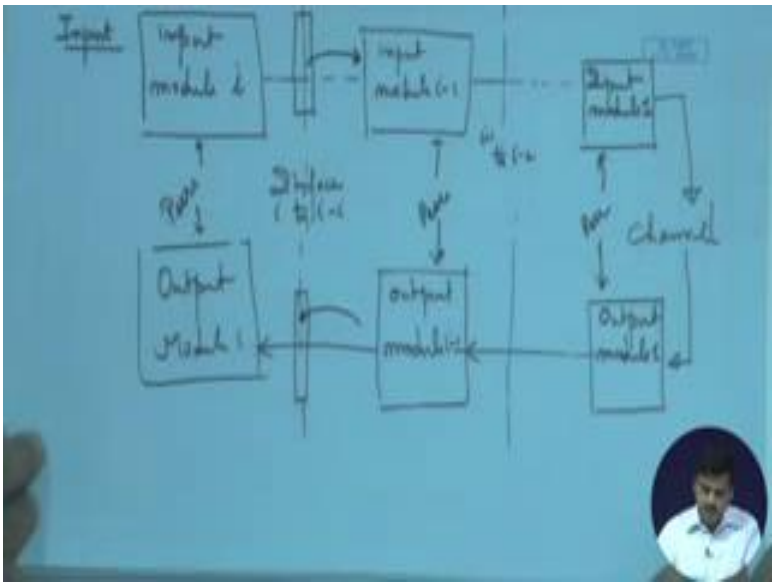

So, we have already drawn in the previous lectures the input that comes into the system. Let us say there is a module which we call as input module i, it has an interface to the input module i minus 1, so this is the interface between i to i minus 1. This goes on and on until we are at the last stage which is the input module 1 which is the last module of the transmitter. From this signals go in to the channel, from the channel it goes in to the receiver or you can also call it the output module 1. There is this interface corresponding to each module at the transmitter they would be an output module at the receiver this is minus 1 and there is this output module i.

So, this is input interface from i minus 1 to i minus 2, signal flow between these interfaces. This and this are peers this and this are peer of each other, again this and this are peer of each other. So, when this input module sends a signal it needs to know this particular interface or in what format data will be received by the next module. Similarly, the corresponding output module needs to know in what format it should give data to the next higher module so that this is able to process. This module did not know what goes on in details in this particular module.

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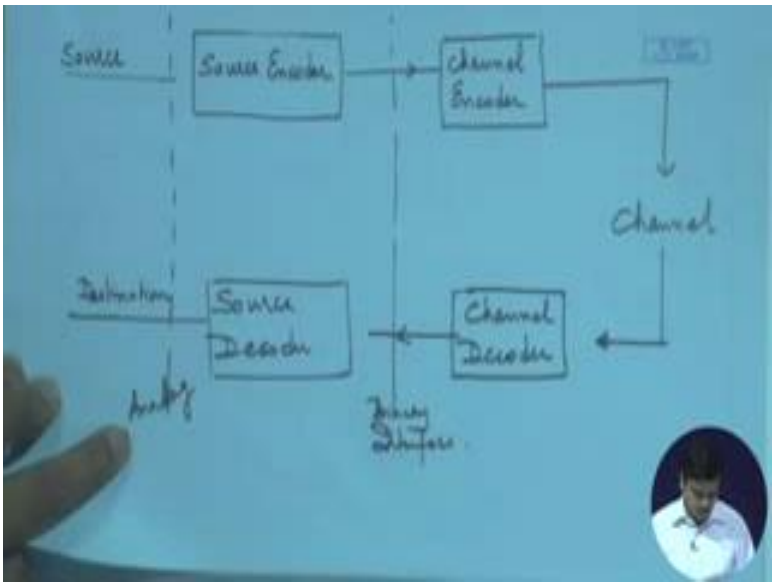

If we take exact look instead of this particular abstract look what we have is again the same picture what we had seen earlier source sending information to source encoder, source encoder sending information to channel encoder, channel encoder sending signals out into the channel, channel feeding information into the channel decoder, channel decoder giving it to the source decoder, this is be destination.

Now if we look at these interfaces; this interface could be analog or it could be digital depending upon the source or the destination. This particular interface is usually a binary interface.

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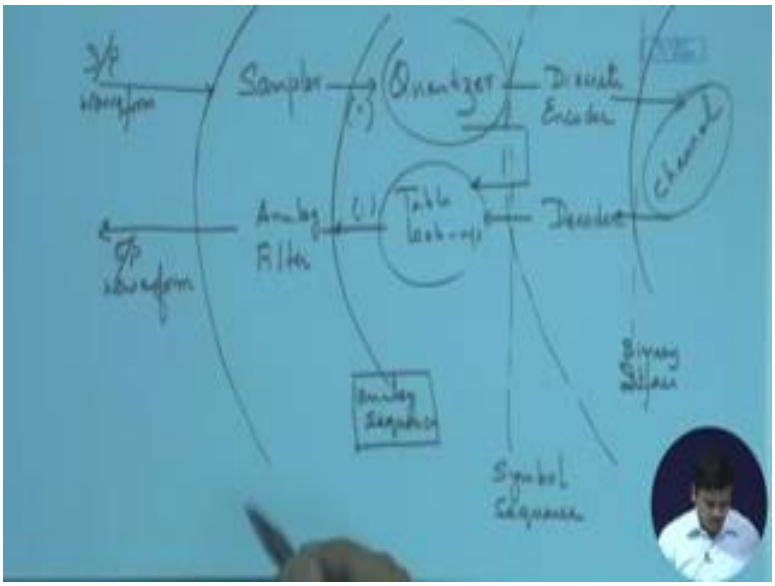

Moving ahead further if you try to expand only this particular section of the communication link what we will get is I will write in short input, let us say wave form going into the sampler into the quantizer then to discrete encoder followed by the decoder table look up, analog filter, and of course output wave form. Interestingly, what we can say is in this section that means what goes out and what comes in we can refer to this entire part as a channel as being viewed by the discrete encoder and the corresponding discrete decoder.

Whatever distorted signal it receives it is because of the channel that the encoder and the decoder experiences. Now these would be encoded signals, so one encoded or the code could get modified to another code because of the channel characteristics. So, here this particular interface as you have seen here is a binary interface. Therefore, the channel that you could see is a binary interface again and therefore the channel would be a binary channel in this particular case.

This particular interface is basically a symbol sequence and if you take this portion out and we are talking about the quantizer and the table lookup only the channel would appear as a symbol input symbol output, so symbols would go in to the channel symbols would come out. The job of this module at the receiver would be to generate whatever was available here at this point with minimum error. If you look at the sampler and the analog filter and we try to see the system at this perspective. That means, you have block

out this and see sampler is sending something in to the system and the system is giving out which is to be filtered, so basically what we have is an analog sequence.

Therefore, the channel at this point is again an analog channel. Basically, what we can say is it depends on from what is your perspective on which part of the communication system are we looking at so the channel will get a representation accordingly. If we move further down beyond what we have discussed and go into the details of the channel encoder.

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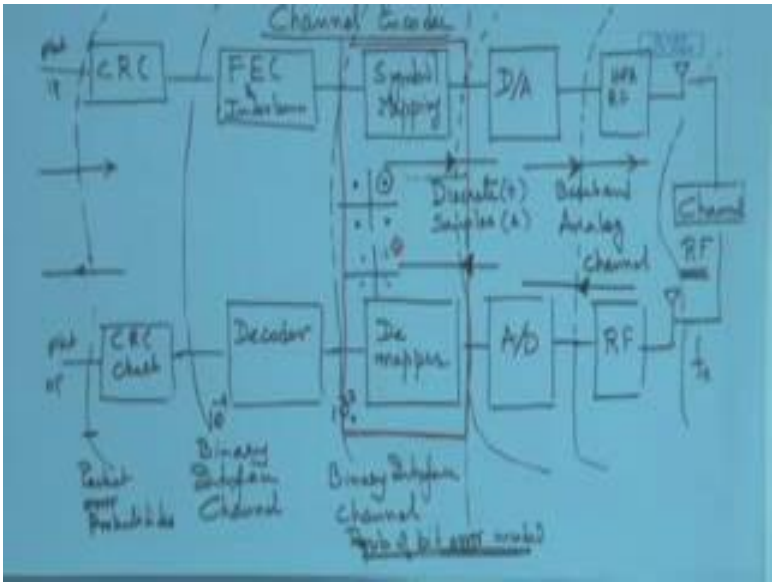

Let us say if you are expanding the channel encoder, so what we can have initially is the cyclic redundancy check at the transmitter, then we have the forward error correction encoder and inter lever in this time we are grouping them together followed by symbol mapping followed by D to A we will be reducing some of the components for the sake of discussion and is followed by high power amplifier and RF section etcetera. And then the antenna from the antenna we have always written as the channel.

At the receivers side we again have the antenna followed by the RF section of the receiver followed by A to D converter, again we are not following exactly all the components because our interest is something little bit different in this particular lecture compared to what we have discussed before, so this is basically the de mapper followed by the decoder and then there is CRC check. Here we get packets as input, here we

packets as output. If we start to take a look at this channel that is the actual channel what we usually talk about what we have is basically the RF channel, this very very important.

We have the radio frequency channel in this section, so it is depended upon the (Refer Time: 21:31) frequency of operation. For instance, if we are talking about few hundred megahertz the channel property is may be different if we are talking about gigahertz range or millimeter wave communication the channel properties would be different. So, basically at this point it is the RF channel what we are considering.

If we move down a little bit and take this section , so that means we will not model the RF part as typically in a digital communication system we done to, but here at this point since we have baseband analog. Therefore, we can say we have baseband analog channel. That means, analog baseband signals are going in, analog baseband signals are coming out from the channel. Now if we take a look at this section what do we have is discrete samples, that means discrete in time and continuous in amplitude. So, here also we are going to get baseband, but discrete time analog input and output as the channel. So, at this point we will not be concerned with D to A and A to D or the RS section everything is captured in this part. Most of the channels which we encounter in our systems of study are at this interface.

So, what we have is symbol mapped, that means constellation points going in. What comes out is another signals based, that means probably if I take q p s k constellation this goes in to the channel, let us take this point going into the channel; what comes out from the channel would be if this is my reference point and this is my signal space what comes out from the channel could be anything which is there or it could be directly on top of this or it could be here. The received signal is on this base.

If we move a little bit left this is the binary interface. Now this binary interface is little bit different from the other binary interface that we have said. So, this is also a binary channel so we can it is a binary channel, but when we look at this the typical performance matrix would be probability of bit error of uncoded systems, because in this section there is no error correction coding is taken to account. Most of the performance analysis we do is in this part of the link. That means, will take discrete time samples of the channel or the wave form of the channel this is also known as the wave form channel interface and we might be studying error probabilities of the link at this point.

When we move down further we are again it is a binary interface, but here the probability of error is different compared to the probability of error at this point. So, definitely what we can see or what we know if probability of error over here is around 10 to the power of minus 3, the probability of error over here is going to be 10 to the power of minus 4. Although this is a binary interface channel the error probabilities or the channel properties are different at this point compared to this point. So, what I am trying to say in this picture or through this explanation is that it is very important to see in which part of the communication link or which part of the physical layer we are located and what kind of interface are we doing with a channel.

The last thing that we can see suppose we are seeing things from this point it is again kind of binary, but here what the channel would be kind of packet error probabilities. So, instead of a bit going in to error here what we will be getting at this interface is a packet going in to error. So, packets would be sent in to the channel and packets would be received from the channel or we will be getting values, what is the probability of the packet being in error at this particular interface and we can encapsulate everything that lies on the right hand side.

In this particular course we will be mainly concerned with this section unless otherwise specified; this will be our most important part that we are going to cover in this course.

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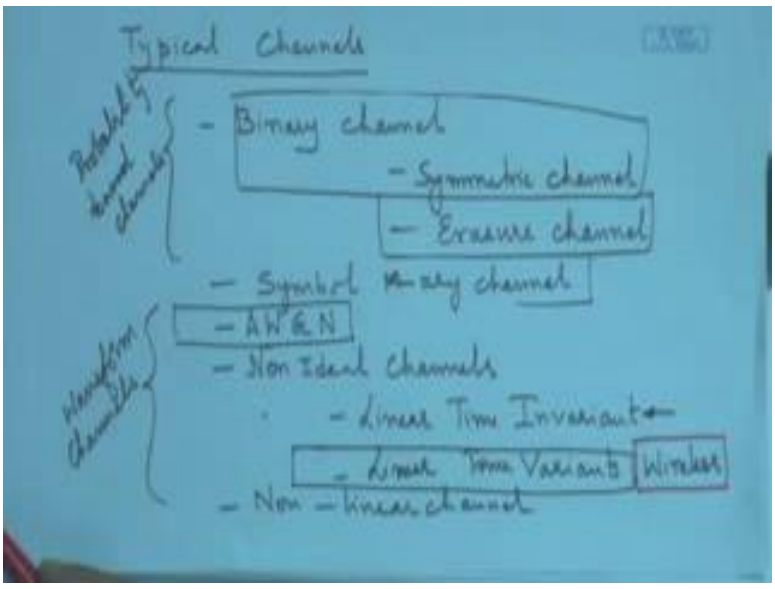

The different kinds of channels which you may have seen till now or if we try to write down the typical channels which you may have come across or which you may come across in future are, first try to write down the binary channel. In the binary channel it could be a symmetric channel, it could be erasure channel, instead of binary it could be a symbol level m ary channel which could it can be a symmetric or asymmetric. We could have non ideal channels, sorry before that I would like to write we have Additive White Gaussian Noise channel. Then we can have non-ideal channels; then under non ideal channels we could have linear time invariant systems and we could have linear time variant channels.

And of course, we can also have non-linear channels. Typically in digital communications one encounters additive white Gaussian noise channel or a binary symmetric channel. Sometimes people come across erasure channels and on rare occasion one would come across m ary channels. So, these channels are usually also referred to as wave form channels, whereas these are binary or probability based channels.

In our communication systems we would be using mostly linear time variant channels. In wire line system one would encounter linear time in variant channels, but in wireless communication systems we would be usually encountering linear time variant channels for reasons what we will shortly see.

In the next lecture we will be talking little bit more details about what kind of time variant channels are usually available and what are the different kinds of models, what are the different kind of features, and why do we need to study the channels, and what is the importance of the studying these channels.

Thank you.