Fundamentals of MIMO Wireless Communication
Prof. Suvra Sekhar Das
Department of Electronics and Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 03
Overview of MIMO Communication Systems

Welcome to the course on Fundamentals of MIMO Wireless Communication. Today, we are in the lecture number 3 were we will talk about overview of MIMO communication systems.

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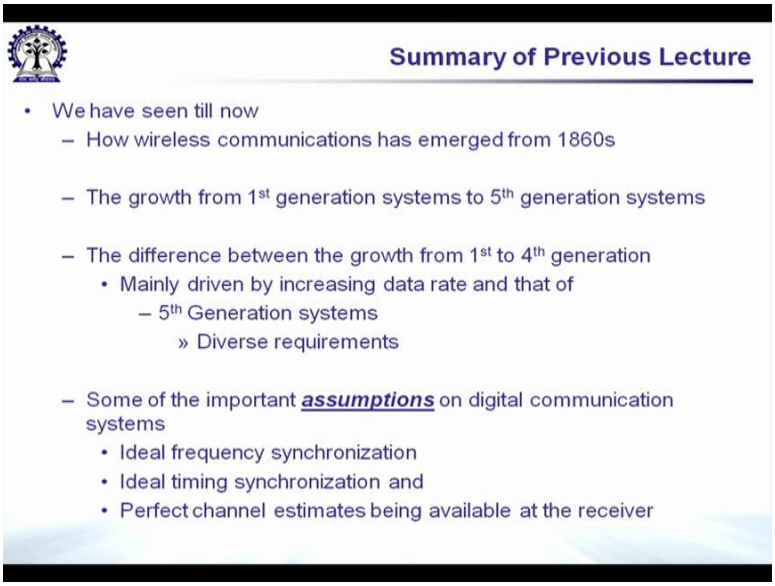

In the previous lectures, we have seen till know how wireless communication has emerged from 1860s starting with the Maxwell equation. Then we have seen how systems are grown from the first generation to the fifth generation system. One of the important things that we may have noted is that between first to fourth generation systems, one of the most important drivers of growth has been high bit rate requirement along with that a special in a fourth generation systems there was requirement to support high mobility whereas, when we looked at the fifth generation communication systems that are currently being designed we saw that there is diverse set of requirements which does not necessarily be in the direction of increase of date rate.

Increase in data rate is definitely one of the means, but there many other requirements which have come up we have also seen some of the important assumptions on digital communication systems that we need to make while undergoing this particular course. One of the first assumptions we talk about was it requires ideal frequency synchronization, second important assumption we made is that it requires ideal timing synchronization that means, there is no inter symbol interference. The third important assumption we made is that there should be perfect channel estimates available at the receiver, so that there is no error due to channel estimation, we can concentrate mainly on the signal processing algorithms and performance analysis of systems based on ideal conditions.

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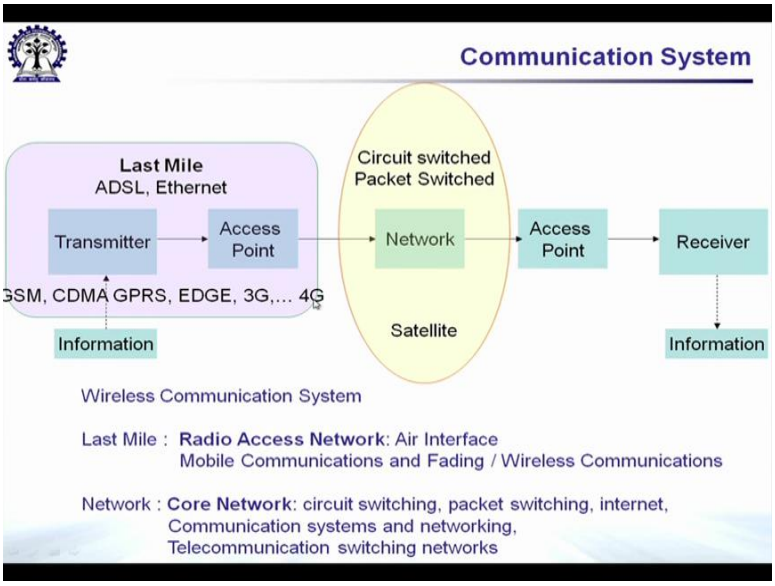

We have also seen what is known as the radio access network, where we have been discussing about the last part which is containing of the transmitter and the access point and we have looked at wireless systems in this part. We are also identified which is the core network. In this course, we will be mainly concerned with this access part of the network.

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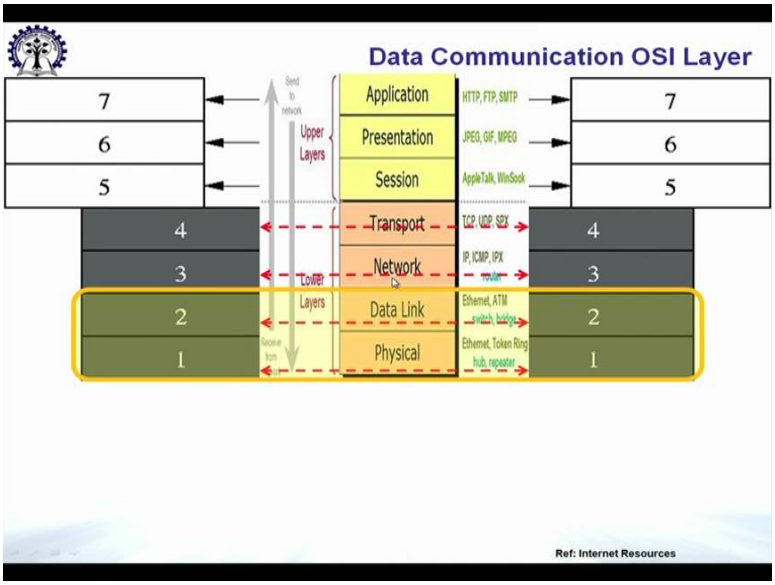

Moving ahead just to summarize, we know the several OSI layers starting with the physical layer then about that there is data link layer or MAC layer, then there is a network layer, transport layer, session layer, presentation layer and application layer. In the application layer you are well aware of things like h t t p, f t p, s m t p and so on. In the presentation layer it is mainly to do data formatting like jpeg, etcetera. Then there is a session layer which control session between communication systems. Transport layer is usually there to maintain quality of service between end to end devices and network layer is there to route a packet from the source to the destination going through different nodes in the network. The data link layer are also sometimes refer to as the MAC layer is critical in controlling the link parameters of or access to the medium finally, there is the physical layer which is the lowest layer and which interacts directly with the medium.

In this particular course, we will be concerned in the lower two layers or primarily will be looking at the physical layer and also some parts of the data link layer or the lower MAC layer specially, we term the work in these areas as cross layer designs most modern communication systems are using advantage or knowledge of the physical layer in the higher layers, so that they can adapt their transitions, as to achieve reliable communication link as well as to reduce the delay between the transmission and the reception.

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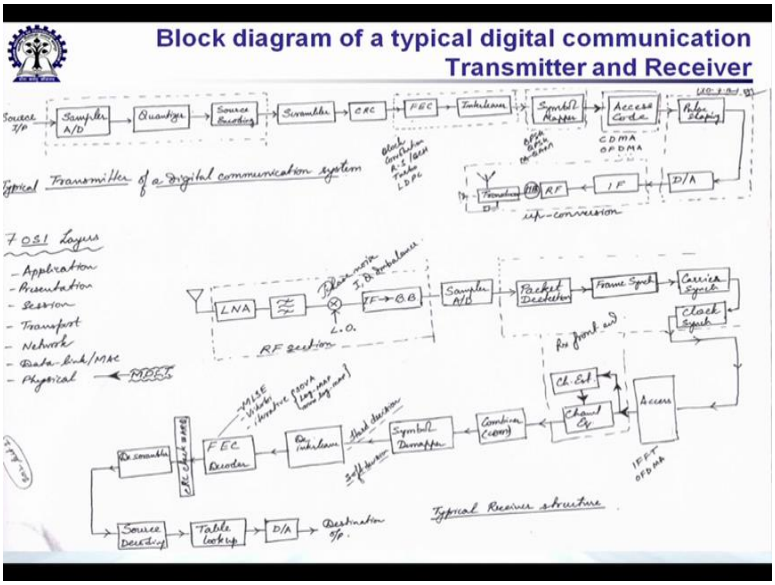

Now, we take a look at a typical log diagram of a digital communication receiver.

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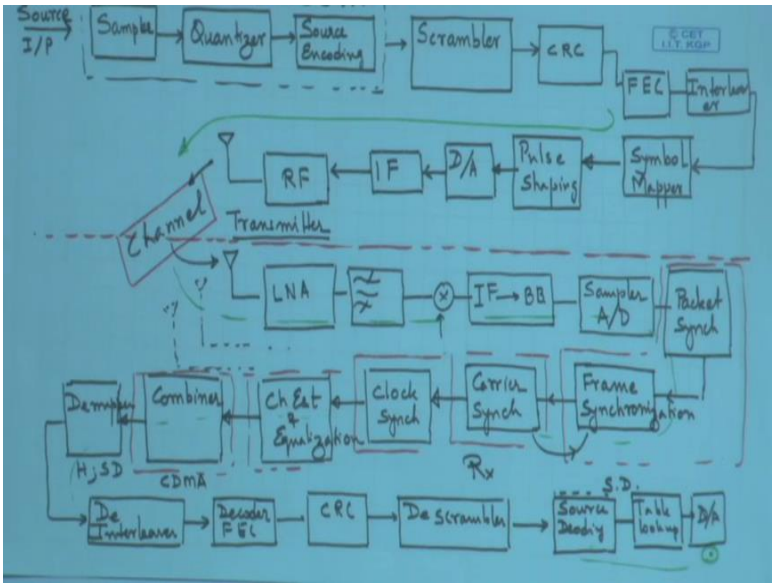

So, we have source at the input, if it is an analog input usually goes through a sampler followed by the quantizer, followed by source encoding examples which to compression of the source what possible could be image compression algorithms. This whole block is

usually termed as source signal processing are also some time referred to as source encoding this is in some systems followed by a scrambler; scrambler is usually present to mix up the sequence of ones and zeros, so that it avoids long sequence of ones and zeros that helps in achieving synchronization at the receiver.

In some systems you will find a cyclic redundancy check being present which helps in checking whether a packet is being received correctly or not followed by the CRC check, there is the forward error correction module and inter leaver at the output. The output of the inter leaver is fade to in in digital communication systems something known as the symbol mapper which the output of which is further put into pulse shaping which may be further fade into converter and then may or may not be presence of an IF stage followed by the RF stage which includes up conversion and spectral mask followed by an antenna or a corresponding trans user depending upon the medium.

This is the typical block diagram of a transmitter in case of MIMO communication systems. This particular section is rather replicated to transmit signal across multiple antennas which we will see very shortly on the receiver front the antenna receives the signal followed by the RF section which includes a low noise amplifier followed by a band pass filter, followed by a down converter through a mixer into either the IF stage or to the base band stage depends upon the kind of mixer and the particular specific communication system at hand followed by sampler or a to d converter. This will also vary depending upon the particular communication system because they could be match filter represented or utilize in the digital domain or it could be in the analog domain.

Then there would be the timing synchronization which would include packet synch. The packet synchronization is important in some systems were burst mode communication is present from the packet synch. They could be going into frame synch packet; synch is sometimes is also refer d to as packet detection it simply presents detects the presents of a packet or non presence of a packet followed by the packet detection. There is of frame synchronization which identifies the exact start of a packet which is followed by the carrier synchronization.

Sometimes, there is iteration between carrier synch and frame synchronization. This carrier synchronization after carrier synchronization they would be the channel estimation equalization block as we can shown in the previous diagram, but before that there would be the clock synchronization followed by the clock synch there is will make one module channel estimation and equalization. After we have channel estimation equalization there could be an important module known as combiner. Now, typically when we talk about combiners, these combiners are generally mentioned for communication systems such as CDMA whereas, when we talk about MIMO these combiners could be related to the combining of signals arriving through multiple antenna part or multiple antenna chains.

So, once we are through with the combiner, then there would be the decision logic for the base band processing or d mapper. This could be hard decision or this could be soft decision from the d mapper it goes into the d inter leaver followed by decoder of the f e c followed by cyclic redundancy check at the receiver we checks whether redundancy added is received in that. So, that it can identify the packet received is correct or not followed by the opposite part what is done at the transmitter de scrambler.

Which is usually done using a seeded random sequence and then passed on to; I will make a large block for this source decoder which would include the corresponding block of the source encoding corresponding to source encoding they would be source decoding ends from the compression it is being to extract the information table look up for container. They should be a corresponding table look up followed by d to a as may be necessary. So, this way we can build up the entire block diagram of the transmitter and the receiver.

We can clearly see that if he compare block diagrammatic representation of the transmitter and receiver the receiver has many more components than the transmitter and some of the important components which are additional at the receiver are the synchronization modules, timing synchronization modules, the frequency synchronization modules, the clock synchronization modules, the channel estimation equalization modules, the combiner modules.

These are additional on top of what is present at the transmitter and hence designing of the receiver is very, very critical and what we can see also from the figure that between the transmitter and the receiver, there lies the channel the design of the transmitter is usually done in such a way, so that the signals which have coming out from this section are matched to the channel the receiver is design in a such a way, that all the distortions which the channel introduces is resolved. So, that when the signal following through all this process finally, comes at the destination. It is with minimum errors compare to any other situation if all these blocks were not present there will be huge amount of errors because of the channel as we move on with this back ground that is already discussed.

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We will now take an overview of MIMO communication systems trying to see how typical MIMO communication architecture are present, which will give us an overview of what we are going to cover in details in this particular course.

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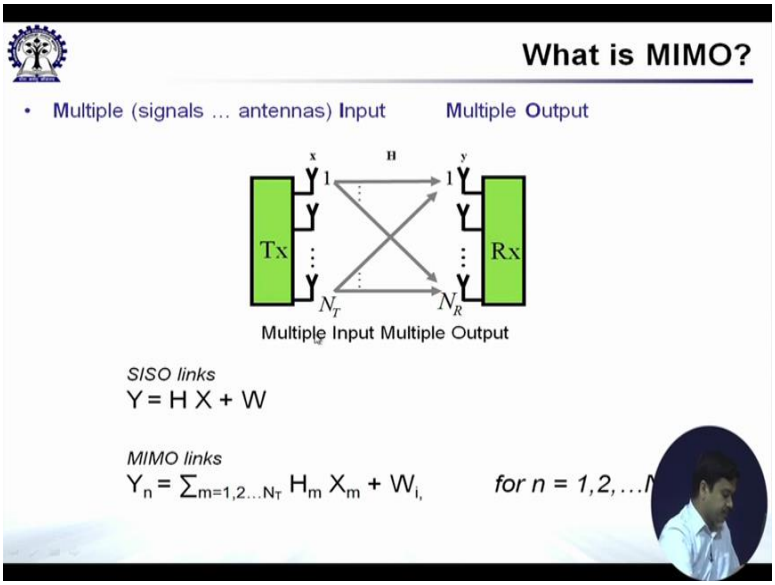

When we talk about MIMO what we mean is we have the transmitter which encompasses all the blocks that we have already described in the previous diagram. Instead of one antenna, what we have describe in the previous figure there are multiple transmitting antennas typically in many references they will be refer d to using n t. These signals are sent simultaneously from these antennas and propagate through the channel. So, instead of one transmit antenna one receive antenna there would be multiple transmit antennas and there would be multiple received antennas at the receiver.

There will be multiple signals which is received and processed instead of single antennas signal partly what we have described in a typical SISO link the received signal Y which is mentioned over here can be represented as Y equals to H times X, where X is the transmitter base band signal and this what we have discussed in earlier class that will not talk about carriers. So, we talk about base band signal plus noise; noise is due to receiver components and H represents the channel.

Typically, you may have studied about convolution, but this is the simplest form of relationship. If it is the non convolving channel or a flat fading channel for MIMO links on the contrary what we have is we have X m going from one to n t; that means, x 1, x 2, x 3 up to x n t each getting multiplied by H m and then at being received at let us say

antenna Y 1. So, if I take Y 1 this is equal to some over all the links that are present all the transmitter signal multiplied by the corresponding channel links and this will be for Y n equals to 1 to n r. So, will be getting several such signals one we get once we get several such signals we have to process them at the receiver. So, that our n goal is will be able to extract the signals that have been sent from the transmitter.

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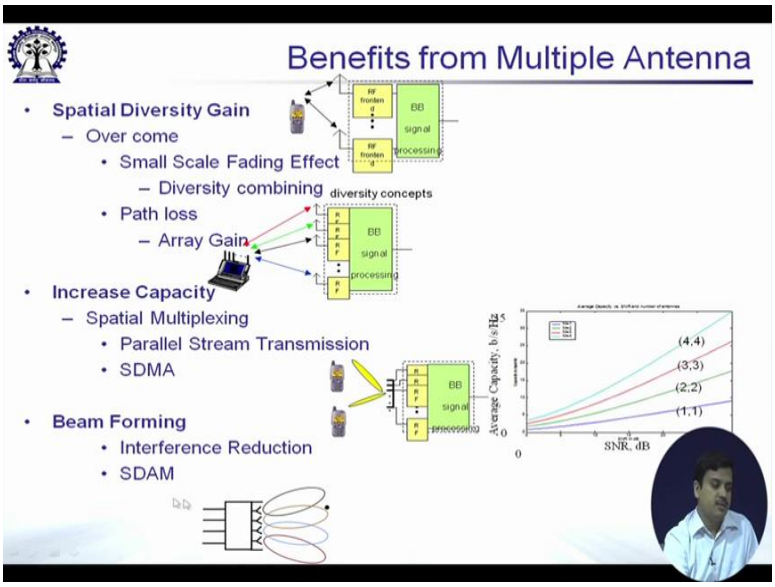

If we look at the benefits from multiple antennas the first important benefit that we gain from multiple antenna transmission is known as diversity gain. When we talk about diversity gain it helps us over come small scale fading details of which we are going to see very soon and the next important benefit of spatial diversity combining is path loss that means, if there is arrays of antennas that are represent at the receiver. So, they will be used to combine this strength of the signals. So, that there is average increase in SNR, we will disuse all this in details when we talk about the diversity gain what we meant is.

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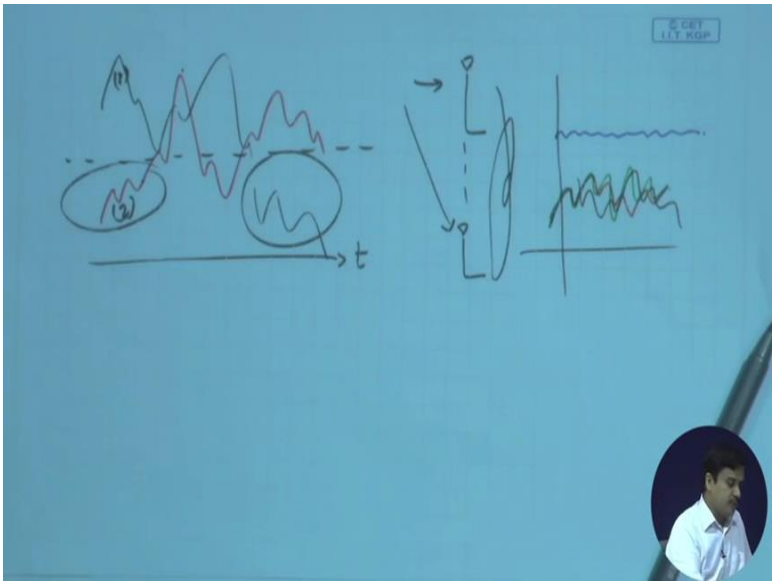

Suppose, I have a signal which is coming in this form and we have another signal which comes in this way. So, by diversity combining what we mean we will of course, see details later is at any one instant of time we considered this time since we have one and two copies of signal either of these two signals will be above certain threshold whereas, if we would have taken only one they would be instances when one of the signals is below threshold or when other is below the threshold that is the advantages of diversity combining whereas, if we look at the array gain there what is been done is the signal that is received from one of the antennas and the signal which is been received by the other antennas. They are all combing in such a way that whereas, each signal was arriving at different SNR values after combining the combined SNR can be at a much higher level and we get an increasing average signal strength thereby improving the performance of this communication systems.

If we take a look at the second important gain which MIMO provided that is with increasing in capacity that means, this is achieved through something known as spatial multiplexing which will again see very shortly. So, as the name suggest there is multiplexing that is going on. So, multiplexing means simultaneously or mixing up several spatial streams, so that they can go together. So, there is parallel stream

transmission that means, at the same time using multiple antennas it can send two more than one user or even to one user it can send two different data streams.

The next important method of using multiple antennas is through beam forming as shown in this particular figure that specific beams are formed which are very, very directional and users can be present or addressed in each of the beams separately and this would also help reduce interference that means, if one user is radiating from this direction another user is radiating from this direction because of forming separate beams for this users the interference from one user can easily be taken care of by forming the spatial beams. This also can be use for space division multiplexes and other techniques.

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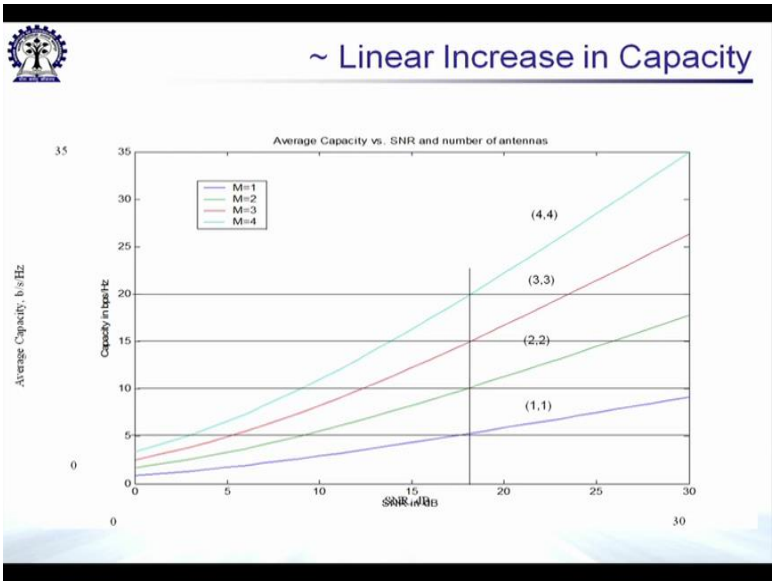

If we look at the benefit that MIMO brings is this is one diagrammatic representation of one of the results which we will see of course, later on the x-axis. So, shows SNR in d b, the y-axis shows average capacity in bits per second per hertz again will define all these terms m equals to 1 means that is one transmit antenna, one receive antenna typically this is a SISO system what we are usually used to as we go to m equals to 2 that means, we are going to this particular curve that means, there are two antennas at the transmitter two antennas at the receiver we see that as SNR increases the spatial elections increases in a such a fashion that compare to SISO link here, the SNR increase is significant as we

move to the next one, which is m equal to 3 or 3 cross 3 system then we get another significant jump and then when we move to 4 cross 4 system or 4 transmitters and 4 receive antennas we reach here.

So, apparently what we see there is a proximately linear increase in capacity or linear increase in spectral efficiency as we increase the number of antennas from 1 to 2 to 3 to and 4, this is one of the biggest canes that MIMO brings to us and in this course, we are going to study how we are going to achieve this particular gains.

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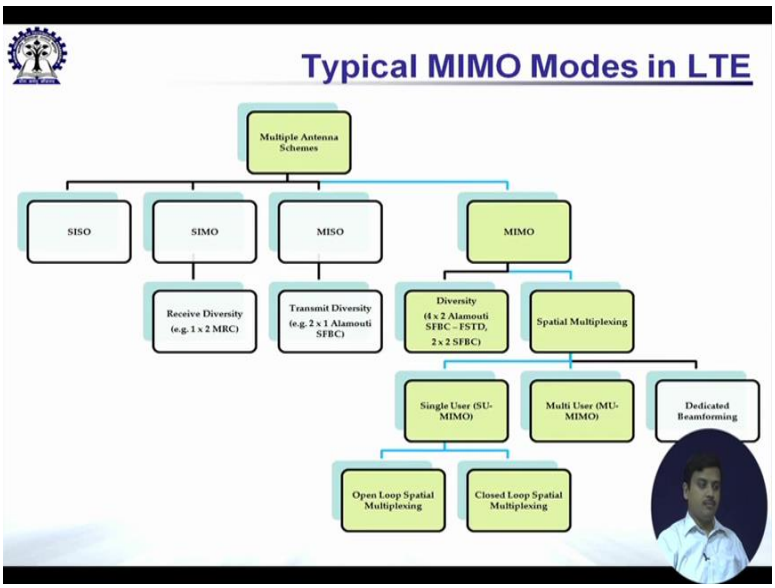

If we take a look at how MIMO is used in commercial systems for example, LTE or others MIMO antenna systems can be broken down into one of the sub cases, SISO; single antenna single output, SIMO; single input multiple output that means, one transmit antenna multiple receive antenna multiple receive antenna single output antennas and finally, multiple input multiple output; MIMO systems can provide us with diversity gain and spatial multiplexing gain. As we have discussed in spatial multiplexing we have single user and multi user scenarios as well as dedicated beam forming in single user scenario we have open loop spatial multiplexing closed loop spatial multiplexing one of the objectives of this course is that we will cover these parts as highlighted in this particular slide.

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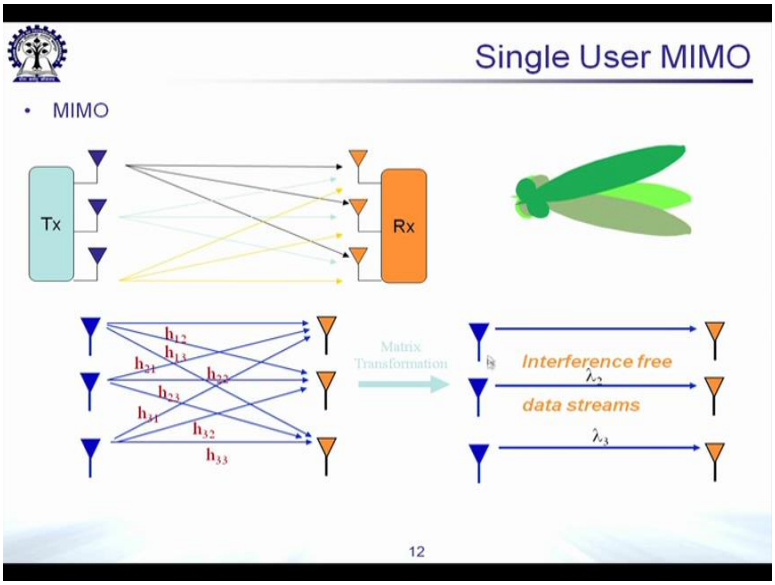

In this diagram will try to briefly discus what the overview about what is single user MIMO. In single user MIMO, we have multiple antennas at the transmitter multiple antennas at the receiver and signals are all mixed up when it comes to the receiver at the receiver due to signal processing and due to prepossessing at the transmitter it may be possible to create parallel interference free channels thereby separate streams which do not interfere with each other may be possible to be transmitted from the source to the destination and we will be able to receive separate us interference free data streams at the receiver. One of the important objectives of this course is to understand how this can be realized and what capacity gains are achieved because of such processing.

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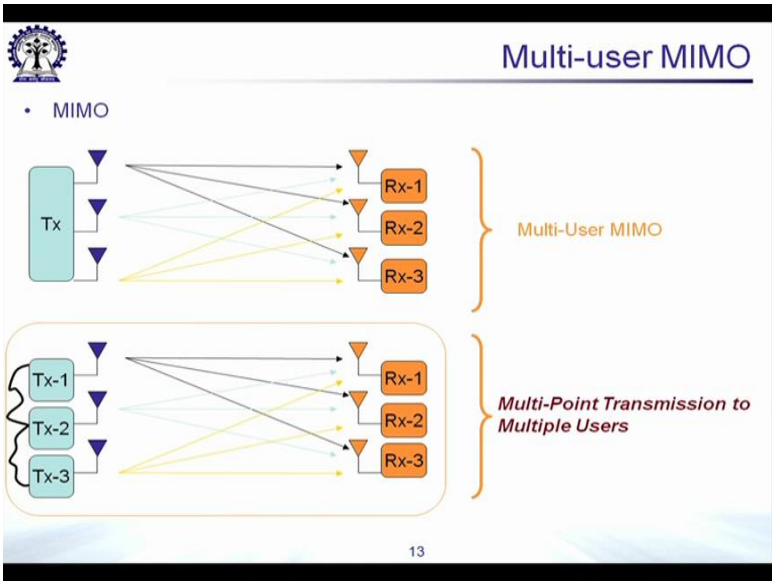

If we move further, if these receivers instead of being connected together if they are now separated whereas, at the transmitter the antennas are co located in that case what we have is a multi user MIMO is these will be multiply users and this will be the base station, for example, in this mode the transmitter would be able to send separate streams to user 1 to user 2 and user 3 simultaneously using similar, but improved signal processing algorithms and when we move further taken additional step at the transmitter if we have these antennas now distributed, so that they form parts of different antenna systems and there are different receivers whereas, the source they are somehow connected to each other what we have is a multi point transmission to multiple users which is one of the most complicated part of MIMO systems.

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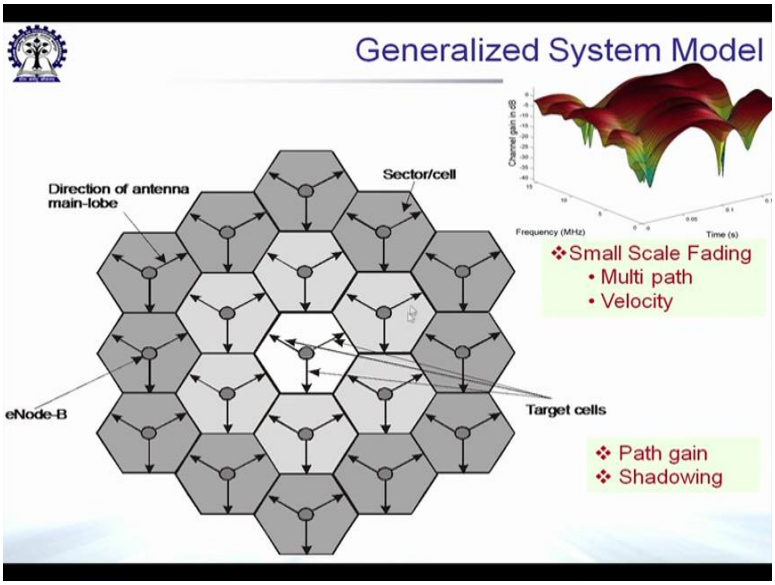

Moving ahead further will take a brief look of how, a typical communication system work. Then will see what complex it is MIMO adds to this system and understanding of MIMO would help resolve designing this complexity complex communication systems design better algorithms at the transmitter and at the receiver a typical communication system has experiences channel which is describe by this particular figure. Of course, will spend significant time try to understand what we briefly see is that across time and frequency domain there is fluctuation of signal strength across this whole space we have a typical cellular structure were there might be base station across at this central part of the nodes and there would all been transmitting simultaneously.

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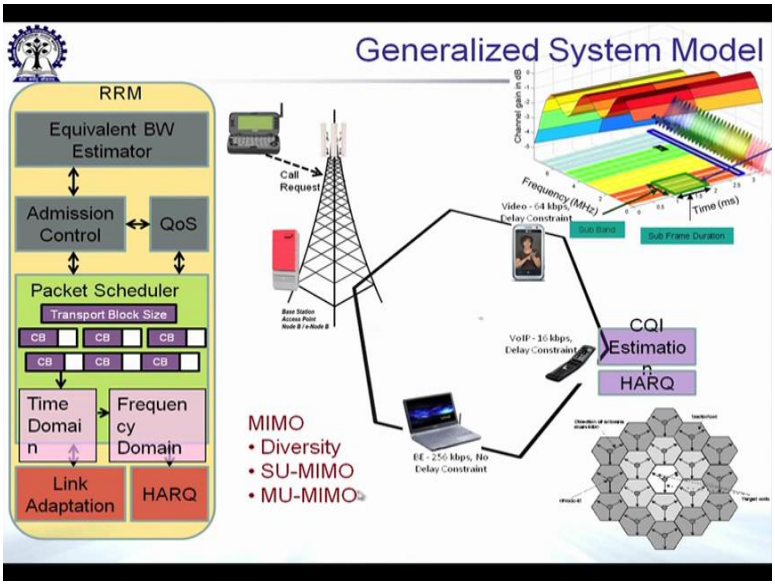

One of the central nodes over here is the base station which connects to multiple users, this signals the users send back channel quality indicator. At the base station there is cycle of events that happen which include link adaptation followed by packet scheduler in both transmit and frequency domain there is transport block formation there is QOS adjustment there is beam forming or they could be spatial multiplexing or diversity mode there is call admission control. So, all these process keeps on happening in one of the base stations and these keeps on happening at all these base station simultaneously with the advent of MIMO one, etcetera processing comes in is selection amongst these different modes and even when we go multi user MIMO one has to select between multiple users.

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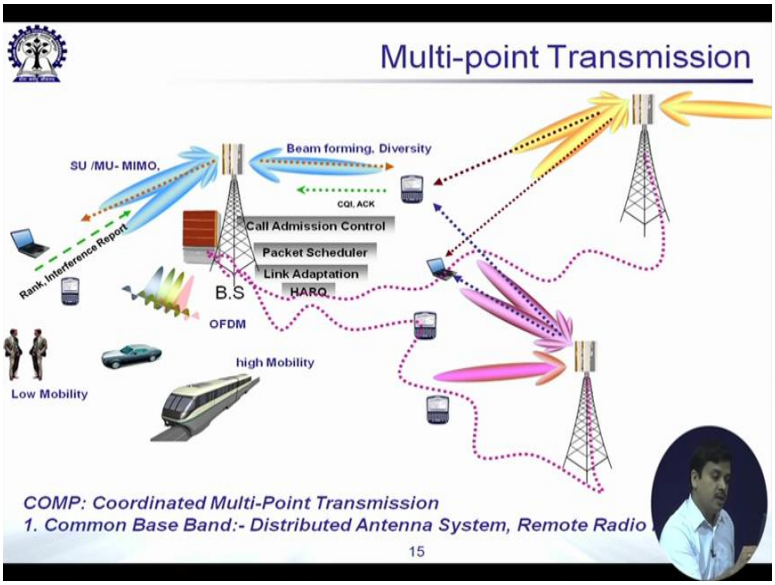

If we look at when this gets added when the MIMO techniques which briefly describes get added toward typical large communication system, what happen is all the processing that we have discussed goes on at the base station of one of the cells and there are other cells which are nearby and a typical multi point transmission, these base station 1 and base station 2, they would typically communicate to one central processing unit where by base station 1, 2 and 3, for example, would jointly sends signals to these users in such a way that there is no interference from these which apparently there is huge amount of interference whereas, there is a constructive generation of the signal, so that huge increase in spatial efficiency is achieved outage is re dude especially at the cell age which is otherwise not possible without the use of multiple antennas and coordination between these base stations.

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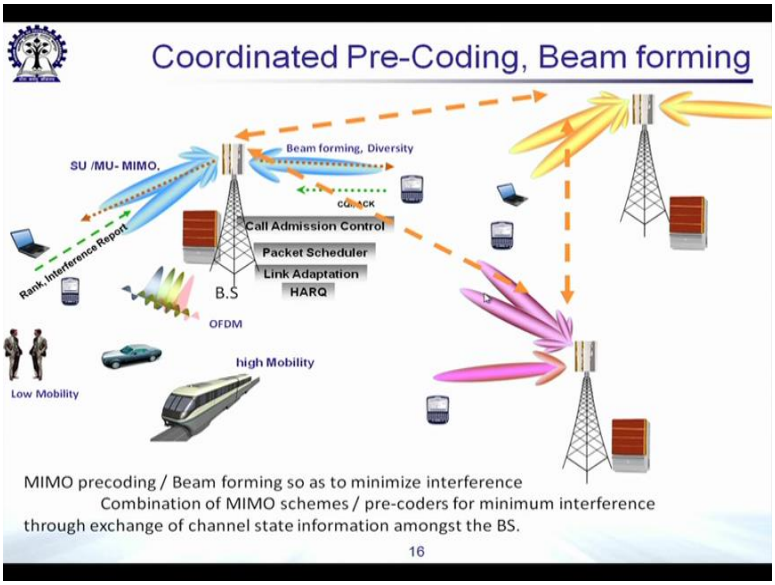

As we move further, the other forms of coordination could be that there are typical processing going on in the base stations and these other base stations, they do not do joint processing, but there is communication amongst these base stations, but they send independent signals, but they doing such a way the selection of MIMO mode which is also known as MIMO beam forming is done in a coordinated fashions so that they reduce interference specially at the cell age thereby improving the quality of service.

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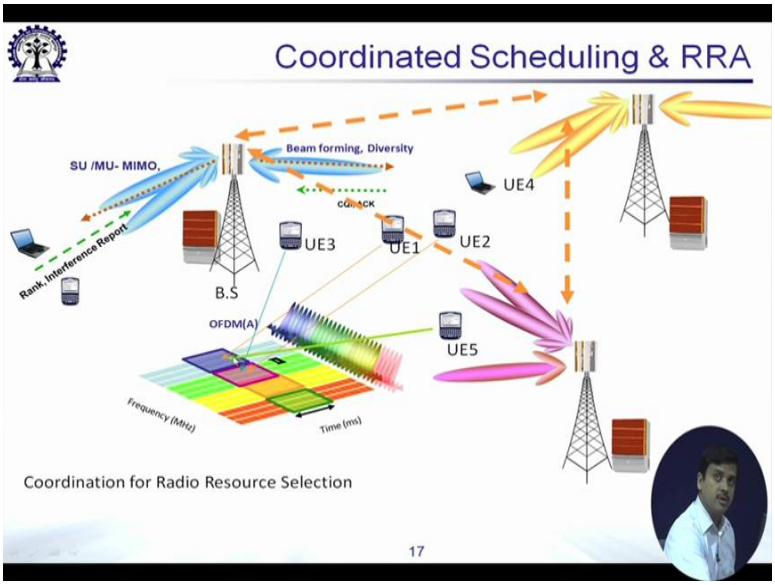

The other mode of coordination which is known as coordinated scheduling and radio resource allocation. Again these base stations do talk to each other, but they generally do not do joint signal processing, but through coordination they exchange information about the channel conditions and they together solve the problem of allocating resources. To users in this space who would be actually hearing to transmissions from all these neighboring base stations they solve it in such a way. So, that the interference is reduced resource allocation is maximized and overall there is gain in the performance of the systems.

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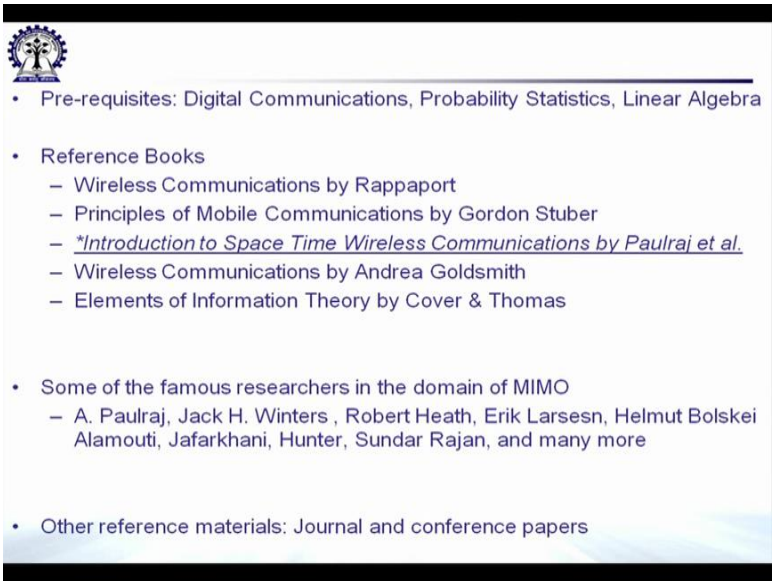

Just last few minutes for today's lecture were we talk about the prerequisites for this subject. So, as we have been discussing till know we would require you to revise digital communications. We have briefly touched upon some of the concepts we would require lot of probability and statistics. So, your understanding of probability and statistics is important linear algebra it is required to be revised the books which we will follow some of the books would be wireless communications by Rappaport principles of mobile communication by Gordon Stuber.

These ones will specially refer in the beginning part were will talk about the channel introduction to space time wireless communication by Paulraj et al are is one of the most important references which we are going to follow through out when we will talking about MIMO channels as well as MIMO signal processing. So, this is one of the important books to be followed, there are other books like wireless communications by Andrea Goldsmith elements of information theory by Cover and Thomas which will also be necessary.

Below there is list of a few important researches in this domain who have been prolific authors. So, beyond the course work I would encourage you to go across and find even more authors of in the domain of MIMO communications who have been producing rich

literature. So, that this domain has been improving and we are at a stage where we are able to take it as a course. Other reference materials if you do not limit yourselves to these materials feel free to go into journals and conferences which keep on getting published to provide latest results.

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So, we stop at this particular point in the third lecture and will discuss some more things in the coming lecture the fourth.

Thank you.