Fundamentals of MIMO Wireless Communication
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Lecture – 02
Elements of Wireless Communication System

Welcome to the course on Fundamentals of MIMO Wireless Communications. Today we are into the Lecture 2, where we will talk about Elements of Wireless Communication Systems. We will have a brief look on different types of wireless communication networks and then go into make certain important assumptions which are very critical towards our journey on MIMO communications.

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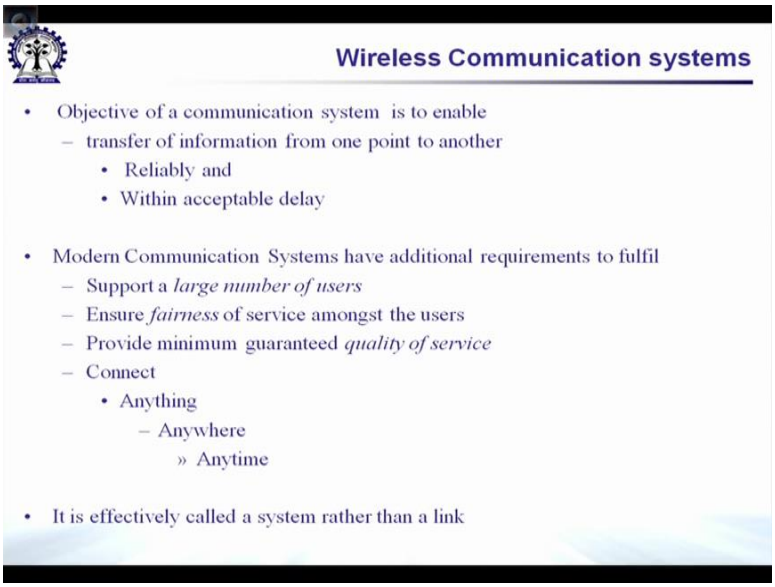

The objective of communication systems is to enable transfer of information from one point to another and also within acceptable delay. And this second criteria has come up of recent years when real time services have become more and more important. If we look at modern communication systems they have to even fulfill additional requirements that are they have to support large number of users within a service point. They have to ensure fairness of service among users for instant users who are close to the access point and the users far away from the access point are expected to get same kind of service.

That is still a challenge today because you would be experiencing different signals strength as you move away from the base station. And accordingly typically the bit rates usually falls as you go further away from the transmitter. There is also requirement of providing guarantied quality of service. Along with this there has been growing demand to connect anything which be usually known as internet of things machine to machine communications. You would like to connect anywhere, on the surface of the earth or even in space and we would like to be always connected.

So, with these requirements what we have today is rather a communication system rather than a communication link as used to be the typical studies of digital communication systems.

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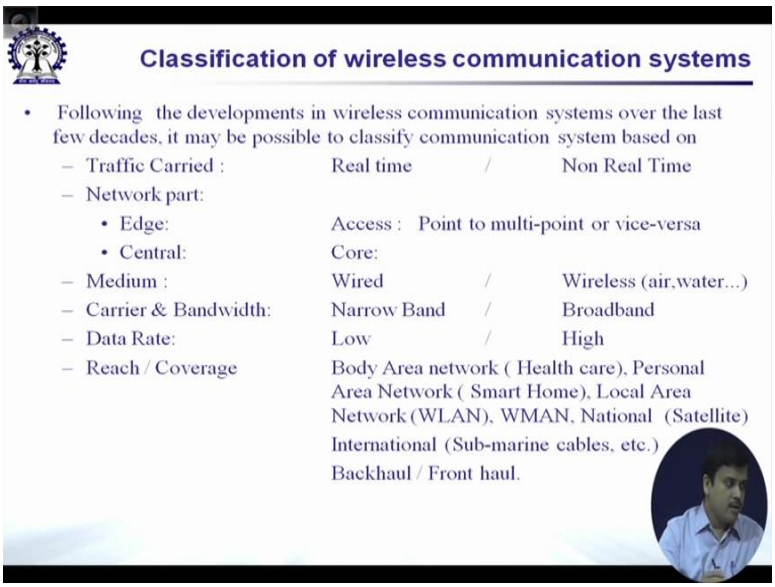

We move on further to see some of the classifications of wireless communication systems. Wireless communication systems have been classified in many ways. We take one look at it, so going ahead we can say that wireless communication systems can be classified according to the traffic that is carried, it could real time or non real time. Examples of real time traffic can be telecommunication networks, which are primarily designed to carry voice. The new trial communication networks are also been designed to carry video traffic. If you look at data services like the local area network or Ethernet

they are been primarily designed to carry data. With new demands of real time traffic that the nodes which connect the links are required to support quality of service.

The next important way of classifying networks is whether there is the edge or whether there are the central part. Edge in the sense there at the edge of the network, that means it is a access network. If it is central part we would usually call it the core network. For example, if we take LTE the 3.9 g and 4G system the part that is air interface between the e node b that is the base station and the user equipments would be the edge of the network, whereas the SAE which forms the evolved core network is part of the central part of the network. The networks as we know can be classified whether they are wired, according to the medium that is connecting the devices or whether it is wireless. Even in wireless the medium could be air, could be water, and could be anything else.

The next important classification matrix would be the kind of carrier. One could be using low frequencies could be using high frequencies, could be going to gigahertz or even going to millimeter waves, terahertz, visible light and even beyond that. So, carrier frequency is a very important parameter which identifies the kind of network, because whole ranges of network stack the physical layer would be change according to the carrier of operation. The bandwidth is also important way of classifying networks, whether they are narrow brand or broad brand systems. Data rate is also usually one of the typical considerations whether it is low data rate or high data rate.

For instance, generally speaking if we talk of sensor networks we talk of low data rate, whereas if we talk of broadband wireless communications we will typically talk about very high rate data communications. The other way of classifying networks would be the reach or the coverage. One example of networks could be body area network which is within a small period within a small range of communication limits where sensor nodes are placed all over human body. And it connects to one access node which could typically be a phone and that phone would connect this particular access network to core network.

Then there is example of personal area network with examples of smart home or smart office. Going beyond you are already experiencing wireless local area network which is

part of little bit wider region that is local area network. Then there is metropolitan area network, there is national great which is usually covered by satellite links. International links which have covered by sub marine cables or even satellite links. Further, there could be also classification on whether a particular type of the link is a back haul or it is a front haul.

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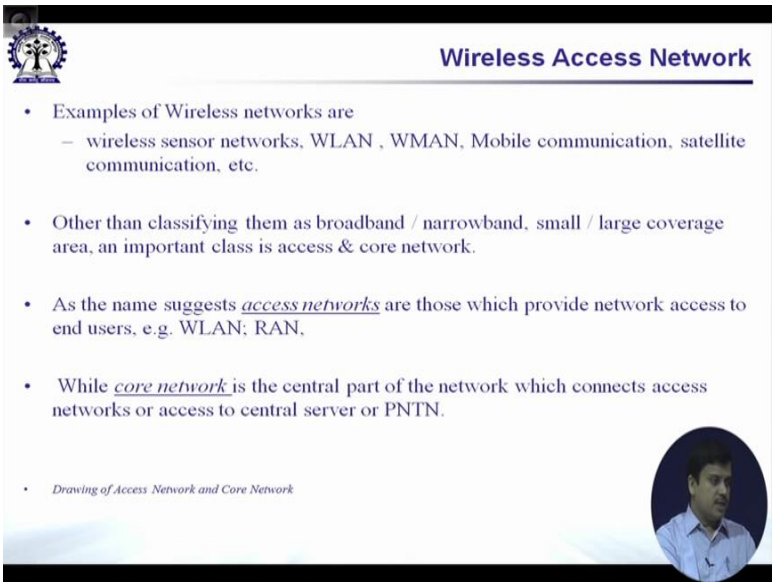

Going beyond all of these different types of classifications, if we typically take examples of networks as mention below; sensor networks, WLAN, WMAN, mobile communications and satellite networks; if we look at them one of the most important ways of classifying them would be the edge as presented in the previous slide, the network part the edge or the central. What we are mainly interested in this course is the access part of the network. The access part of the network is that part which provides connectivity to a network; it provides access to the network. Examples are; WLAN, that means wireless local area network or the radio access network. When we talk about the core network it is the central part of the network which connects the access networks or different access networks to a central server or PSTN.

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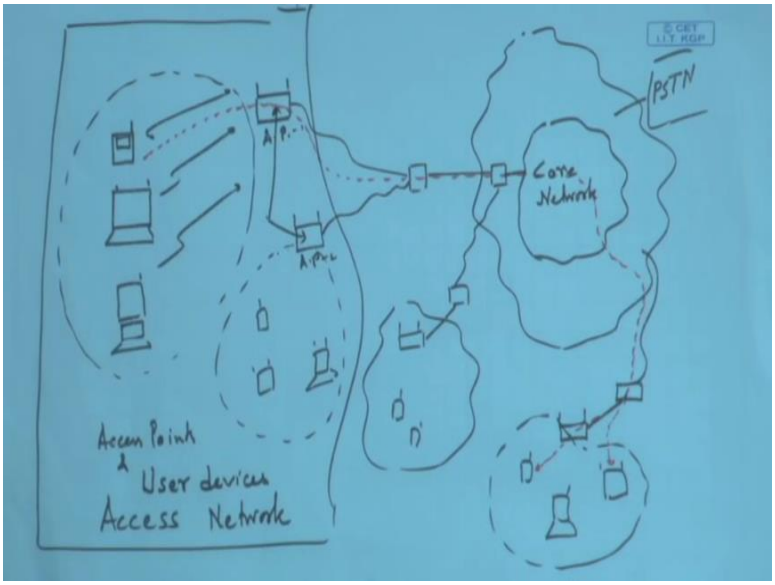

If you would like to take a look at one such example you might be able to imagine a situation where there are smart phones or any other phones, there could be laptops, even there could be PCs with connectivity to wireless access point. Similarly there could be other access points in the vicinity and they would be covering another region, this is the coverage region of access point one let us say, there could be coverage region for access point two and so on. These could be connected to some router for the network nodes. In this way you could cover quite a large area. This in turn connects to the core network.

On the other side of the core network similarly one could find another access network. Typically we are concerned with data signals going from one device through the access point into the core network via another access network to another device or it could be connected to a central server or there could be PSTN link and so on. This part of the network which is the network of the access points and user devices is known as the access network. Most of our studies will be concentrated in this part of the network, where a group of access points two or more connect to large number of user devices.

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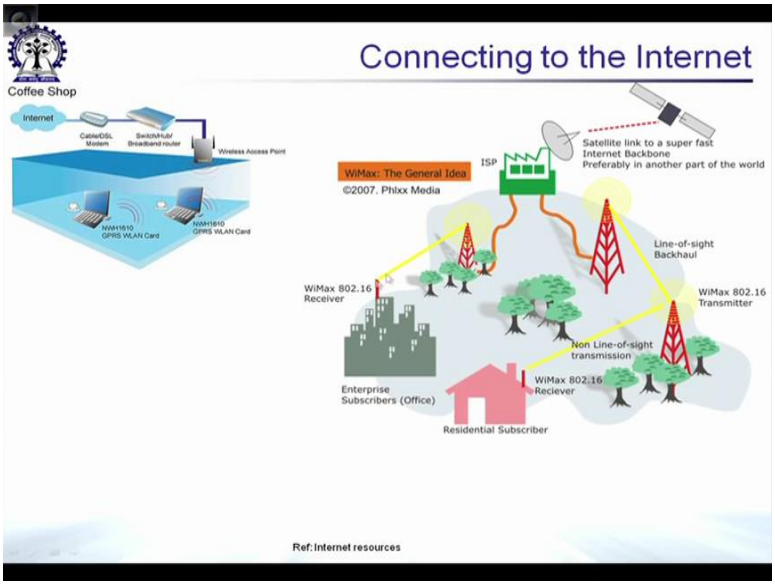

Typical examples would be one as shown in this particular slide where we have access to the internet through a wifi, we have already drawn such a picture. This particular picture represents a typical WiMax scenario where you can see the house is having a receiver where inside the house there could be wireless Lan providing access from the house to the network there could be back haul link and finally this could be connected to the internet service provider who could be connected to the core network via satellite back bone connectivity.

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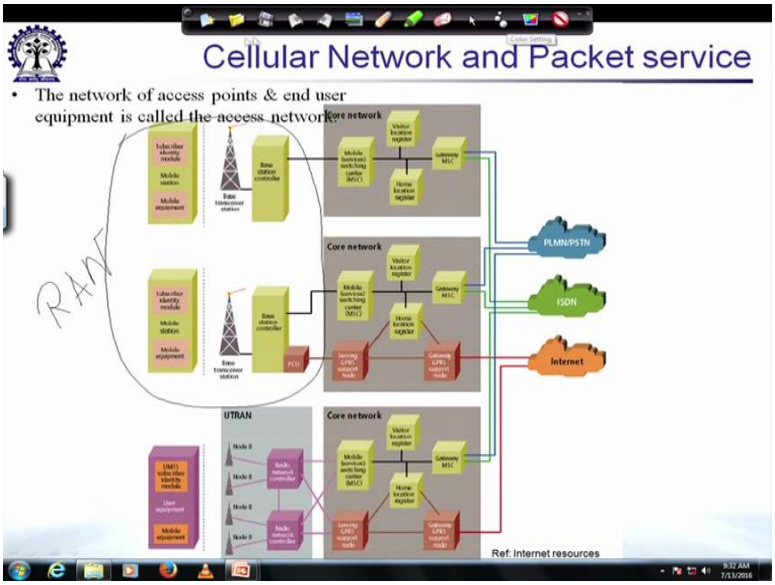

Moving on further if we take a look at the typical cellular network there is a base station there are subscriber modules. So, this part of the network which is having the mobile phones and the (Refer Time: 10:43) station is typically part of the access network. In case of mobile telephoning it is also known as the radio access network.

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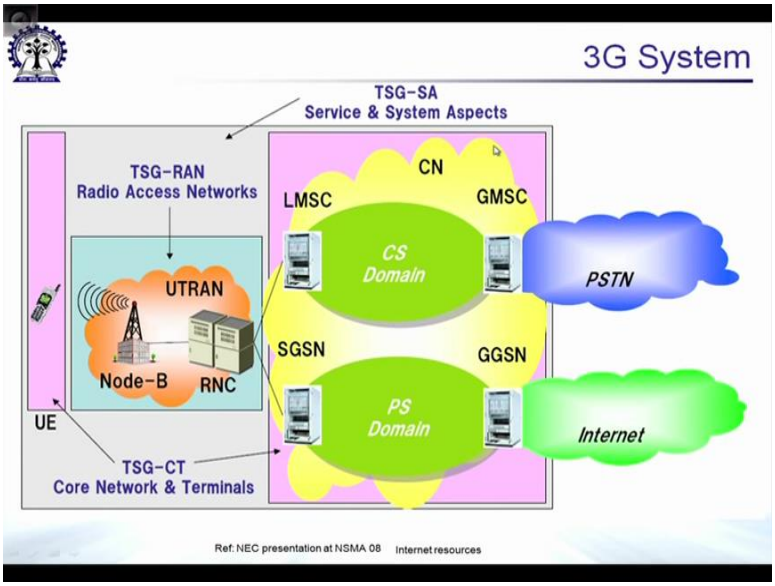

This is the typical picture of a 3G system where again we have this radio network controller the utran and clearly written radio access network which is contained of several such e node-B's or base stations and several such user equipments.

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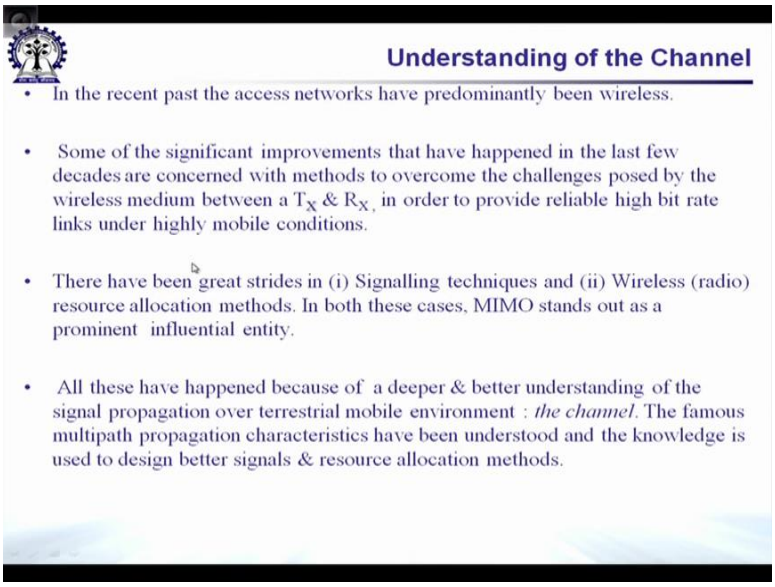

So, in the recent past what we can see is that these networks have predominantly been having a wireless in the access part. And some the important significant improvements that have happened in the last few decades are concerned with methods to overcome the challenges posed by the wireless medium between a transmitter and the receiver. The modification or the new technologies that you have been hearing about 3G 4G or even what is going to come about 5G is fundamentally about understanding the wireless channels and design better and better signaling techniques as well as resource allocation methods so that the challenges posed by the channel can be overcome and better service provided.

In all of these MIMO stands out as prominent influential entity. We will see how MIMO has been effected these things. And all these improvements have happened as mentioned because the understanding of the channel has improved, people have moved to newer channels and improved signal processing techniques are also come up. So, with

improved channel knowledge and with improved signal processing techniques we have enable to greater and greatest heights in the domain of wireless communications.

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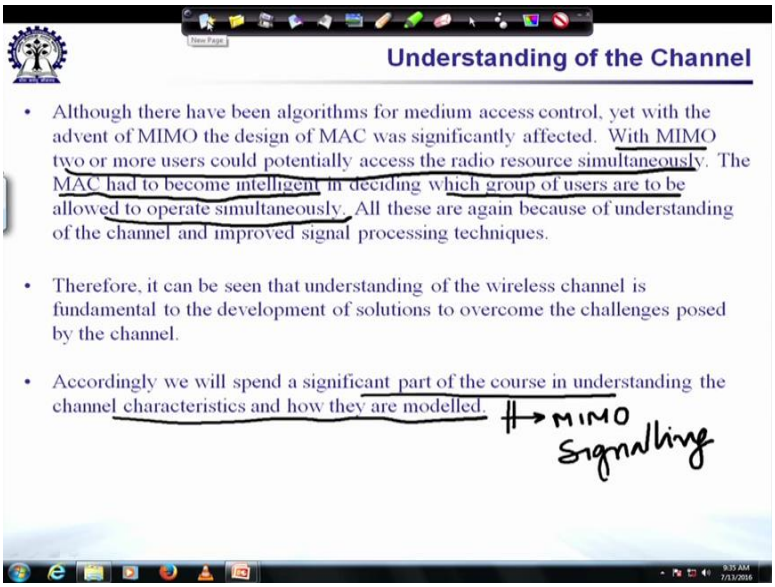

For example, if we take the example of MAC, the medium access controller is usually one of the most important entities which control access to the medium the physical medium. When MIMO was introduced MIMO allows two or more users to be connected simultaneously. This is one of the important things that we will see in the course.

With MIMO two or more users could potentially access the radio resource simultaneously. Now, this was not happening before, with this the medium access controller had to become intelligent in order to decide which groups of user are to be allowed to operate simultaneously. With the new change in the physical layer the medium access controller which controls access to the medium also required to be improved and these changes are reflected in 3G as well as 4G technologies.

Therefore, we can say that understanding of the wireless channel is fundamental to developing good solutions. Accordingly we will spent a significant part of the course in understanding the channel characteristics and how there modules, because base on this

understanding we would be able to proceed to understand MIMO signaling techniques. In fact, MIMO is born out of detail understanding of the channel propagation affects.

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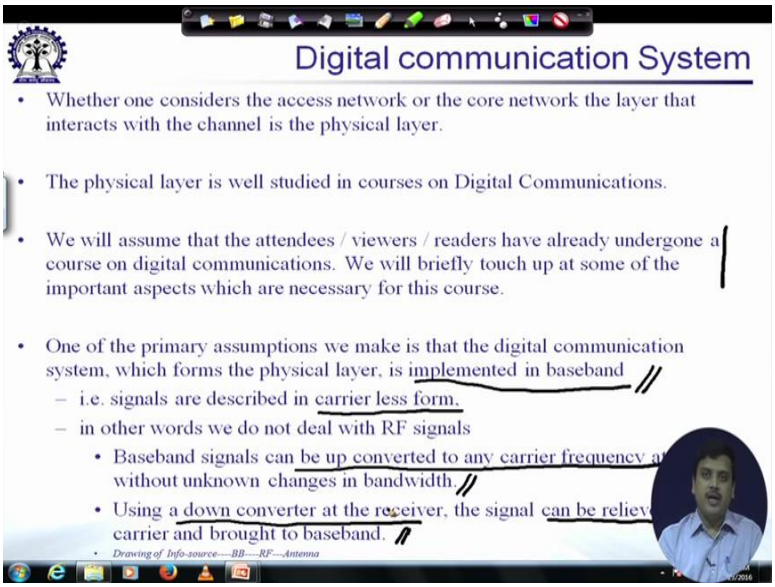

Now, let us look at the next important part which connects the channel.

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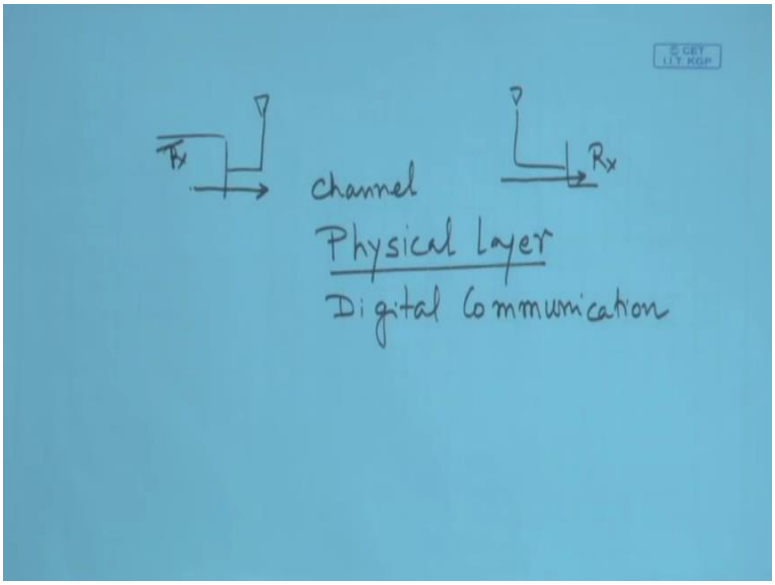

If we see a typical transmitter the receiver, the immediate part the transmitter which talks to the channel and the immediate part at the receiver which listens to the channel is a physical layer. Typically physical layer is discussed in courses on digital communication techniques. We will assume that the students or the attendees of this particular lecture this particular course have already under gone a course on digital communications without which it might be difficult to understand the details of the subject. One of the primary assumptions we make in digital communications is that the signals which forms the part of the physical layer is implemented in baseband.

Now this is very important thing which we usually study in digital communications. That means, the signals are in carrier less form; that means, there is no carrier representation in the signal. This is achieved because we can assume that the baseband signals can be up converted to any carrier frequency at the transmitter without unknown changes in the bandwidth. That means, when we do conversion from baseband to RF or the past band we know what kind of changes in bandwidth occur and we can easily translate from baseband to past band without surprises.

Similarly, using a down converter at the receiver the signal can be relived from it is carrier and brought to baseband. That means, at the transmitter we have baseband signal at the receiver we again have baseband signal in between what we have is the past band signal which propagates through the channel and comes to receiver. Once it comes to the receiver it is again down converted, now this up conversion and down conversion if they cancel each other what we have left with is the baseband signal.

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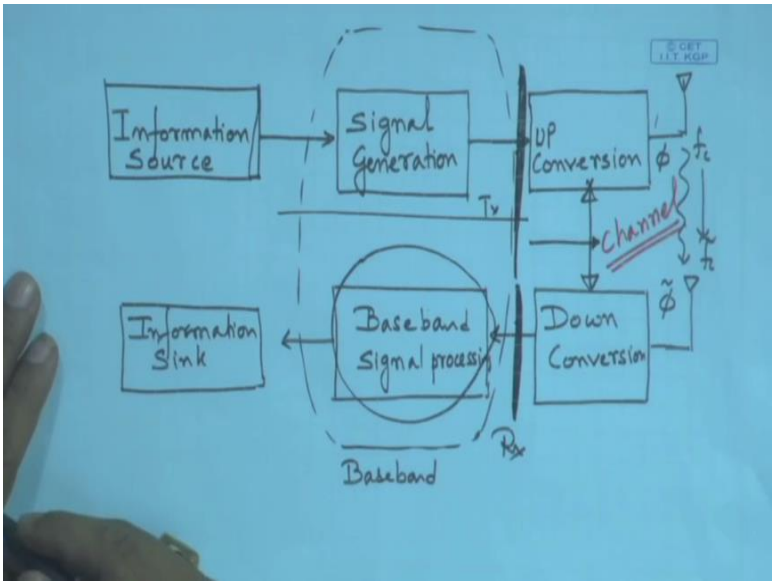

What we mean is suppose we have an information source. This could be analog or this could be digital, if it is analog we will assume analog to digital conversion. It goes on to the section of signal generation followed by RF section or up conversion and then finally into the medium. At the receiver we have the reversing happening; we have the down conversion followed by baseband signal processing. Once the signal has been process it can be given back to the information sink.

What we will be concerned with this particular course will be this part of the communication link which is the baseband section. So, our entire discussion would be limited to the signal generation in baseband at the transmitter and the same thing at the receiver.

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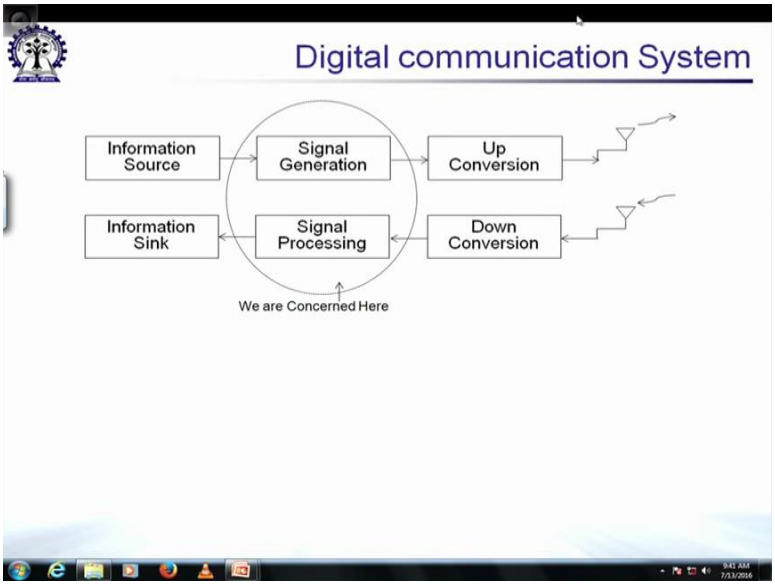

The picture is summarized over here. So, as just mentioned we will be concerned in this part signal generation and baseband signal processing.

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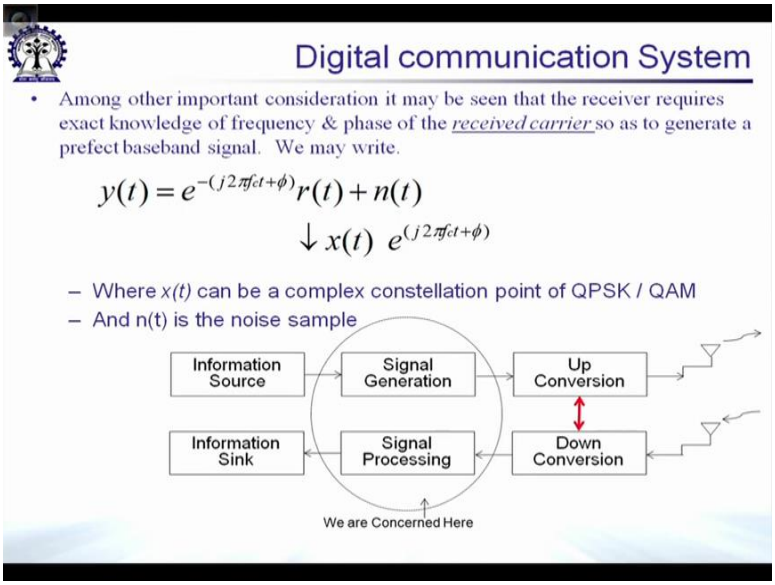

In digital communication system we have another very important assumption that is the up conversion and the down conversion; they are in perfect sink which each other.

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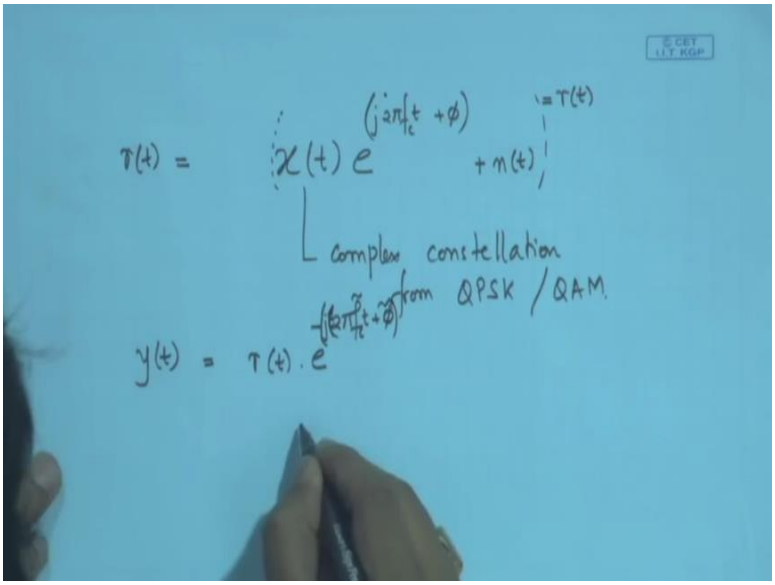

Or rather to be define very precisely if we say that the transmitted signal is x of t which contains the complex constellation point from QPSK or QAM signal, at the transmitter we would usually up convert it to e to the power of j 2 pi f c t plus there could be a face component involved this. And at the receiver they could be addition of noise. So, when we collect it at the receiver we get r of t, this whole thing could be written as r of t. So, when we deconstruct the signal at the receiver we could say y of t is equal to r of t multiplied by e to the power of minus j 2 pi f c t plus phi.

So, here although we have said that phi are same technically speaking we should have a phi tilde and we should have a fc tilde because dividing the transmission of signal from the transmitter to the receiver they could be mobility and the frequency of operation which is fc could get modified to fc tilde due to Doppler effect. Additionally because of other situations instead of phi which is these which is the phase of the transmitted carrier it could be phi tilde at the receiver. So, what we essentially mean is that the receiver requires exact knowledge of frequency and phase of the received carrier face so as to generate the perfect baseband system.

As we have written the received signal will be down converted phase matched with the transmitted signal. In other words as we just mentioned the up conversion and down

conversion should be in as perfect sink as possible. This is one of the important assumptions that we will make while continuing on different derivations in this course. We should remember this and we will not referring back to these kinds of primary assumptions. Although when we studied digital communications we are greatly involved in studying synchronization techniques at the receiver.

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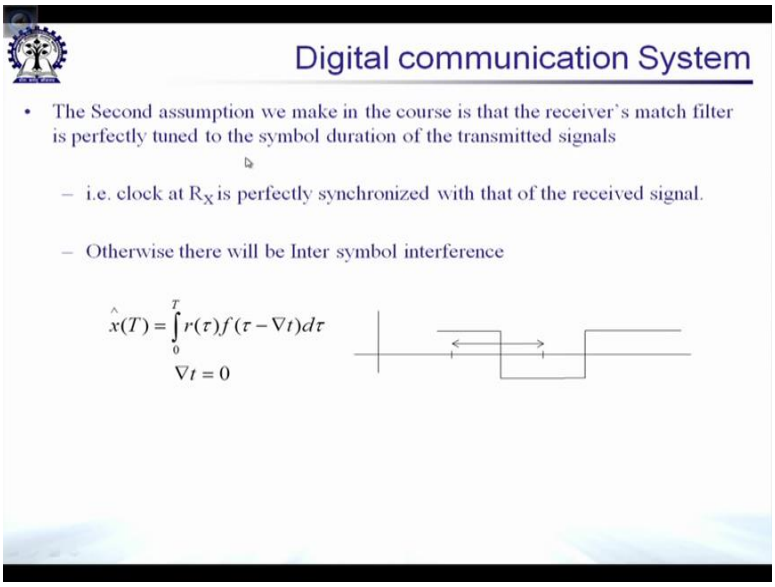

Moving on further, the second assumption that we make is about the matched filter. That means, there is perfect match filtering at the receiver.

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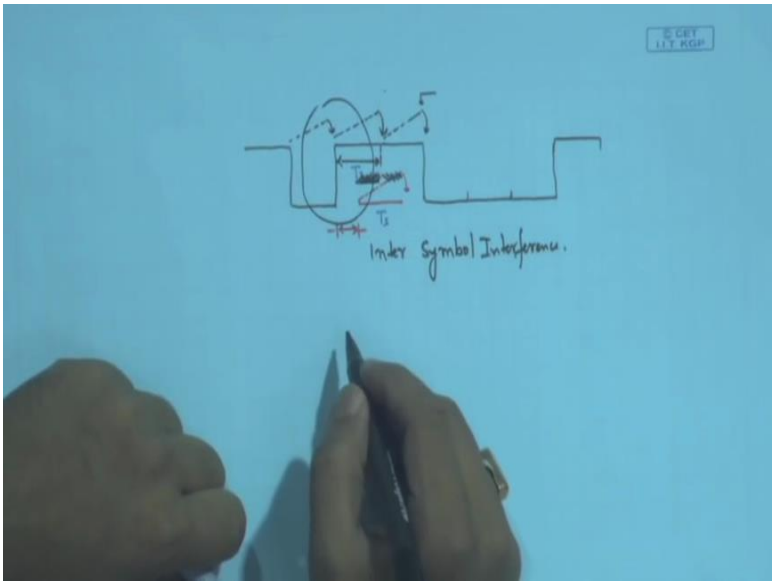

In other words if we considered the symbols in baseband to occupy a certain symbol duration and so on, so we take match filtering for rectangular pluses typically we will be having the integrate and (Refer Time: 23:47) circuit which can be graphically represented through an integration followed by a dump operation which goes on happening for every symbol duration and the values are read off at the peak where the symbol duration ends.

Now instead of having perfect synchronization, suppose the receiver starts the integration at this point. So, if it does integration at this point and dumps at this point, that means it is ensuring that there is exact timing between the transmitter and receiver, so let us say this is T S; T S is exactly the same. However, there is a phase mismatch this could result in inter symbol interference, because one would be taking part of the symbol and part of this symbol. If the first symbol and second symbol are up out of phase for instance we take this particular example the result of the integration would be zero and we will not be able to recover the signal. So, the second important assumption that make is that the receiver is perfectly synchronized with the symbol duration of the received signals.

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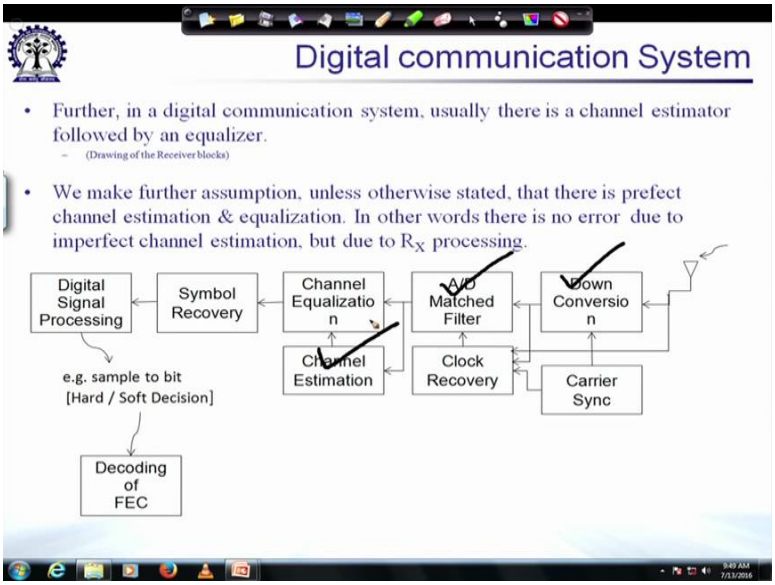

We move on to the next important assumption about digital communication systems that we make. Typically in a digital communication system we have the channel estimator, because between the transmitter and the receiver there lies the channel. So, as we have just drawn in this figure between the transmitter and the receiver there lies the channel which is for us to workout.

Typically the channel estimator which is followed by the equalizer, but if you look at this diagram the signal comes in through the antenna goes to the down conversion process which we assumed to be perfectly synchronize; to do that there is a carrier synchronization module which estimates the carrier if it is to the down conversion. After down conversion it is goes through the matched filter where again different signal coming and clock recover clock is generated.

This signal is fed back is fed forward to the channel equalization where channel estimation received channel equalization and channel estimated signals are fed into channel equalization. This channel equalization effectively removes all distortion that is brought by the channel. The channel which is filtered and all enamel it is removed is sent or symbol recovery, this could be through ml or any another technique followed by

digital signal processing example hard decision or soft decision of (Refer Time: 27:25) followed by decoding of the forward error correction code.

Important assumption that we make in this particular course is that the channel estimation is perfect. What is meant by this is that channel estimation gets perfect estimate of the channel and channel equalization operates using these channel estimates. That means, there is no error due to imperfect channel estimation, but due to receiver signal processing which could mean different algorithms of channel equalization. Or there could be different algorithms of symbol recovery or any other operation.

So, essentially what we have made assumptions in this particular a lecture today is that we will assume perfect frequency synchronization, perfect timing synchronization and perfect channel estimation, so that we can concentrate on the link between the transmitter and the receiver. In other words we would be concerned with the baseband signals where we assume the signal at this part at this interface whatever is generated there and whatever is received over here is having only the channel effects. So, with these we will concentrate on all kinds of baseband signal processing and what is the maximum limit of throughput that can be achieved between the transmitter and the receiver for different kinds of channels.

With this we would like to conclude today's lecture. And as discussed today that channel is a very important part of the wireless communication systems. And of the communication system is fundamental towards designing better and better systems. So, is the understanding of MIMO systems we will start to take a look at the channel modules that a required to understand MIMO communications from the next lecture on words.

Thank you.