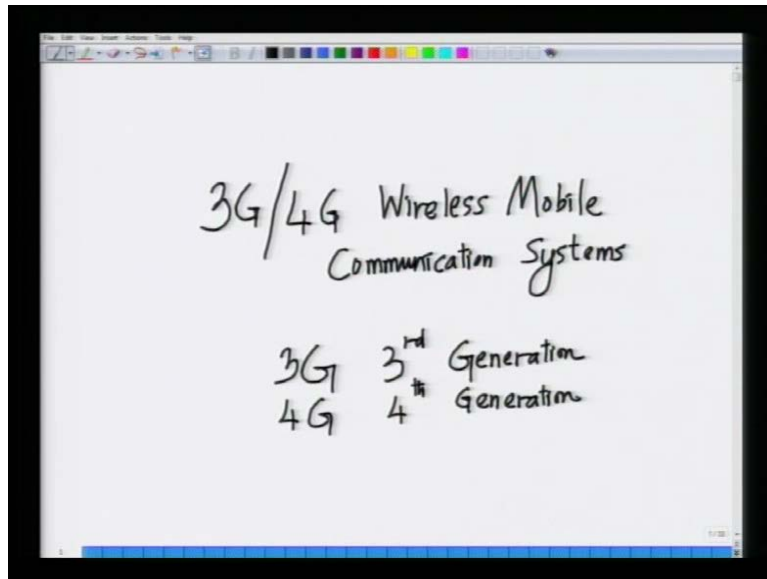


**Advanced 3G and 4G Wireless Communication**  
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**Indian Institute of Technology, Kanpur**

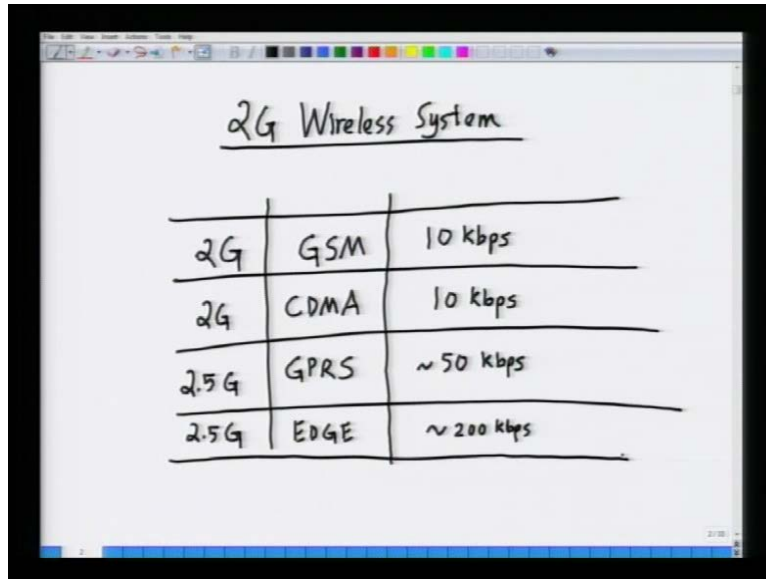
**Lecture - 1**  
**Introduction to 3G/4G Standards**

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Welcome to the course on 3 G and 4 G wireless mobile communications. So the title of the course that we are going to talking about, is 3 G and 4 G wireless mobile communication systems. Wireless communication systems have become an integral part of our lives, especially during the last decade. 3 G stands for third generation wireless communication systems, and 4 G similarly, stands for fourth generation wireless communication systems. So this course is about 3 G and 4 G wireless communication systems; that is third generation and fourth generation wireless communication systems. To get a better idea of what 2 G 3 G and 4 G systems are, let us start with a brief description of the current second generation systems, so that we understand, the nature of the current second generation systems that we are using, and the upcoming, and then we can proceed on to learn more about the, upcoming third generation wireless systems and fourth generation wireless systems.

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The image shows a handwritten table on a whiteboard titled "2G Wireless System". The table lists four wireless standards and their corresponding data rates. The first two rows represent 2G systems (GSM and CDMA) with a data rate of 10 kbps. The last two rows represent 2.5G systems (GPRS and EDGE) with data rates of approximately 50 kbps and 200 kbps, respectively.

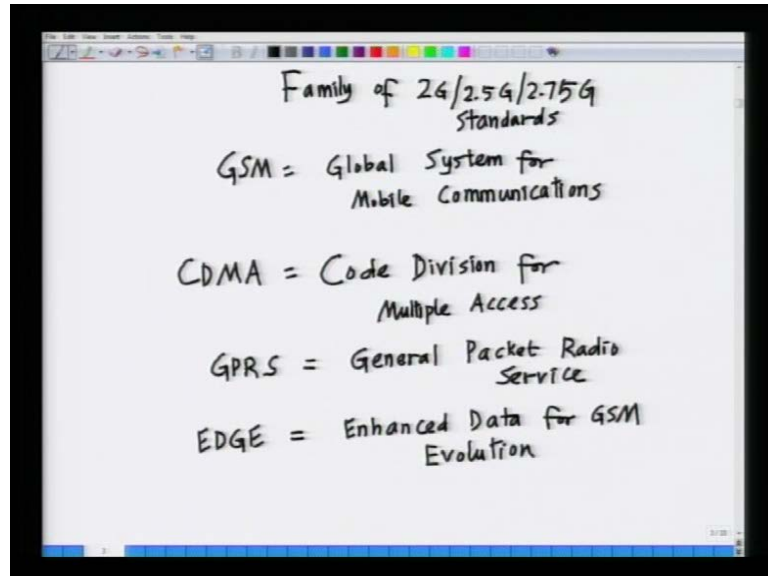
| Generation | Standard | Data Rate  |
|------------|----------|------------|
| 2G         | GSM      | 10 kbps    |
| 2G         | CDMA     | 10 kbps    |
| 2.5G       | GPRS     | ~ 50 kbps  |
| 2.5G       | EDGE     | ~ 200 kbps |

So let me start with a brief introduction, to different 2 G wireless systems and 2 G wireless standards that are currently being used. So let us start with 2 G wireless systems. Let me make a table here, and in this table I am going to write the different standards, and the data rates of the different standards. The first 2 G wireless standard, is currently the standard with most of you must be familiar with; that is the G S M standard, or the global system, for mobile communications this is the most popular 2 G wireless standard; that is currently in use. This has a basic voice data rate, digital voice data rate of 10 kilobits per second; that is, when I say about a voice data rate, I am talking about the voice call, that you place from one G S M mobile phone to another G S M mobile phone, that has a data rate of approximately 10 kilobits per second. This is not the only second generation wireless standard that exists, there is another competing second generation wireless standard, which is C D M A, it stands for code division for multiple access, and that also has a voice data rate of 10 kilobits per second.

Later there were intermediate 2.5 G or 2.5 generation standards, that were developed to enable internet access, or what is technically known as accessing best effort packet data, over cellular networks. These standard are the 2.5 G or 2.5 generation standards, the first is G P R S, which is general packet radio service, and that has a data rate of around approximately 50 kilobits per second, to access packet data or essentially to access internet over your G S M mobile phones, and another competing 2.5 G, or sometimes also known as a 2.75 G standard, is the edge standard or enhanced data for G S M evolution, I will write again this acronym separately so that to give you an idea of to explicit state, what each of these acronyms here

stands for, edge is essentially has a data rate approximately 200 kilobits per second. Alright these constitute, basically the broad family of 2 G; that is second generation and 2.5 G standards.

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Let me give you a list of this acronyms, for more clarity this is G S M, is the 2 G standard that stands for, global system for mobile communications, G S M stands for global system for mobile communications C D M A stands for code division for multiple access, G P R S stands for general packet radio service, G P R S stands for general packet radio service and edge which is the other 2.5 G or 2.75 G standard, that I briefly mentioned stands for enhanced data for G S M evolution; that is edge stands for enhanced data for G S M evolution, this is the family of 2 G slash 2.5 G slash, sometimes also known as 2.75 G wireless communication standards, I will simply call this as standards. So this is the family that is G S M C D M A G P R S edge, these are the family of 2.5 G 2.2 G 2.5 G wireless communication standards, enable to place voice calls from mobile to mobile, also some basic internet access packet data access over cellular networks.

As we are also know, that we have progressively moving towards third generation, and fourth generation wireless systems, essentially because of the rapid popularity of wireless systems, rapid popularity that has, the 2 G wireless systems have gained. There has been a tremendous demand for increase in the data rates to support not only voice calls, but also video related applications such as video calls video conferencing and so on, over future wireless systems.

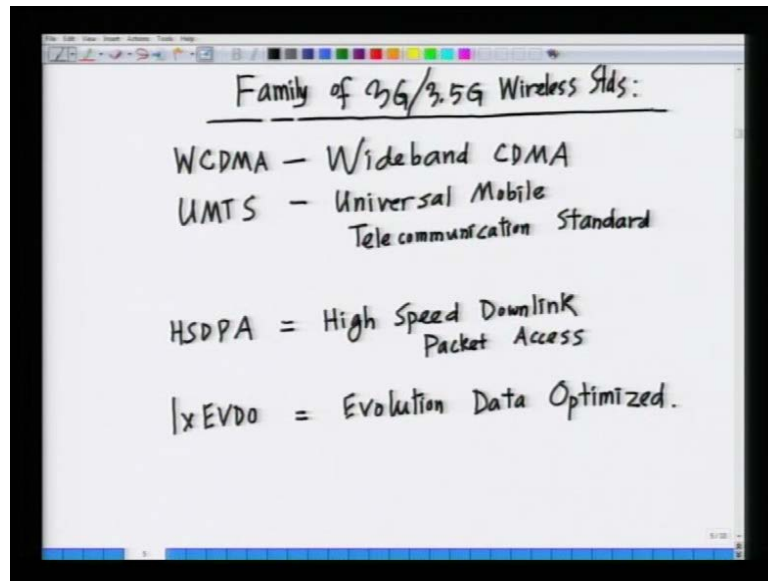
This has led to the development, this has led to the desire to have high band width, over existing cellular networks; that is to run applications of high band width over existing cellular networks, and that is led to the development of 3 G standards and also 4 G wireless standards. So let us start looking, let me just give you a brief basic idea of the third generation family of wireless standards.

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| 3G Wireless Standards: |                    |           |
|------------------------|--------------------|-----------|
| 3G                     | WCDMA/UMTS         | 384 kbps  |
| 3G                     | CDMA 2000          | 384 kbps  |
| 3.5                    | HSDPA/HSUPA        | 5-30 Mbps |
| 3.5                    | 1xEVDO Rev A, B, C | 5-30 Mbps |

So, let me describe the third generation wireless standards. I will again make a table to give you the name of the standard, and its data rate, so that it will give you a better idea. So let me make a table here. The first standard that I am talking about; 3 G standard is the very popular W C D M A, also known as U M T S. W C D M A stands for wide band C D M A, and U M T S stands for universal mobile telecommunication standard. I am going to give this acronyms again separately, let me just briefly talk about the data rates of this standard, W C D M A has a data rate around 384 kilobits per second. As you can see this has a higher data rate compared to G S M and G P R S, which are data rates around 10 kilobits per second for voice call, to fifty kilobits per second for packet or internet access. Another competing 3 G standard, is C D M A 2000, this also has a data rate of 384 kilobits per second. There are also a set of 3.5 G standards, which the first such standard is H S D P A, slash H S U P A, where H S D P A stands for high speed downlink packet access, H S U P A stands for high speed uplink packet access, and these have data rates that roughly of the order of 5 to 30 megabits per second.

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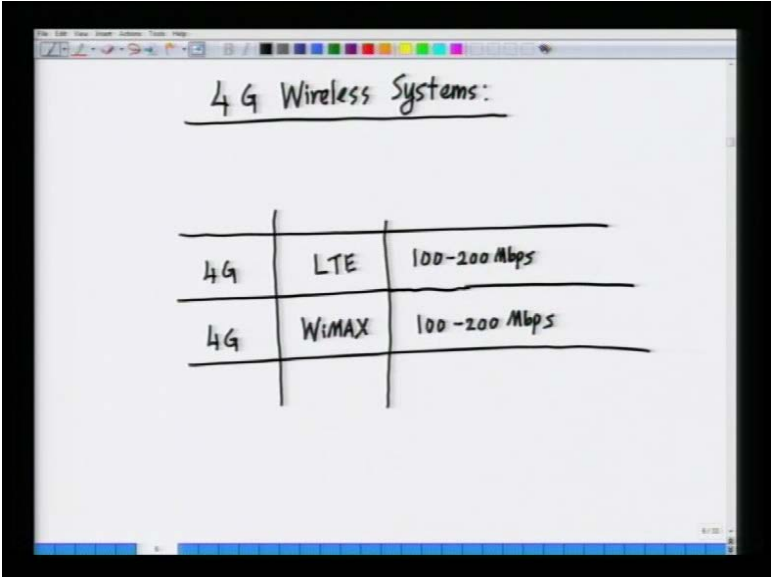


As you can see, this is a drastically high data rate, compared to previous 3 G and 2 G standards. Another family of competing 3 G standards, for high speed data access especially, are the 1 x E V D O group of standards, 1 x E V D O, 1 x E V D O Rev A B C. Rev stands for revision; that is 1 x E V D O, and then subsequent modifications denoted as, Rev A revision A revision B revision C, and these are also capable of data rates around 5 to 300 M b p s. So there are four, similar to what we had in 3G 2 G, we have a set of competing, four set four a set of four competing standard s, W D C M A, C D M A 2000, H S D P A and 1 x E V D O. This is the family, or this is the family of the most popular 3 G wireless standards. Let me give you again a list of acronyms for your reference; W C D M A, we have already seen that C D M A stands for code division for multiple access, W C D M A stands for wide band C D M A, or essentially wide band code division for multiple access.

U M T S stands for universal mobile telecommunication standard; that is U M T S stands for universal mobile telecommunication standard, and C D M A 2000, obviously stands for code division multiple access, 2000 is the year roughly in which it was introduced. H S D P A stands for high speed downlink packet access, H S D P A stands for high speed down link packet access similarly H S U P A stands for high speed uplink packet access, in any mobile communication system, or any wireless cellular network. There are two directions in which communication can take place; one is from the base station to the mobile; that is known as the downlink, the other is the mobile to the base station; that is known as the uplink.

So H S D P A is the high speed downlink packet access, H S U P A is corresponding standard for the uplink, which is the high speed uplink packet access, and also we talked about 1 x E V D O, where E V D O stands for evolution data optimized. So this is the set of 3 G, or third generation wireless standards. So this is the family of 3 G slash 3.5 G wireless standards. These are the four competing 3 G 3.5 G wireless standards. So, we wish to understand this systems in better throughout this course, or one of the aims of this course is understand the fundamentals that make the deployment, and design of such 3 G systems possible. And of course, this is also let the desire for more band width, has not stop there, this has led to desire for more band width, and that has led to the development of 4 G wireless communication systems, and 4 G wireless standards.

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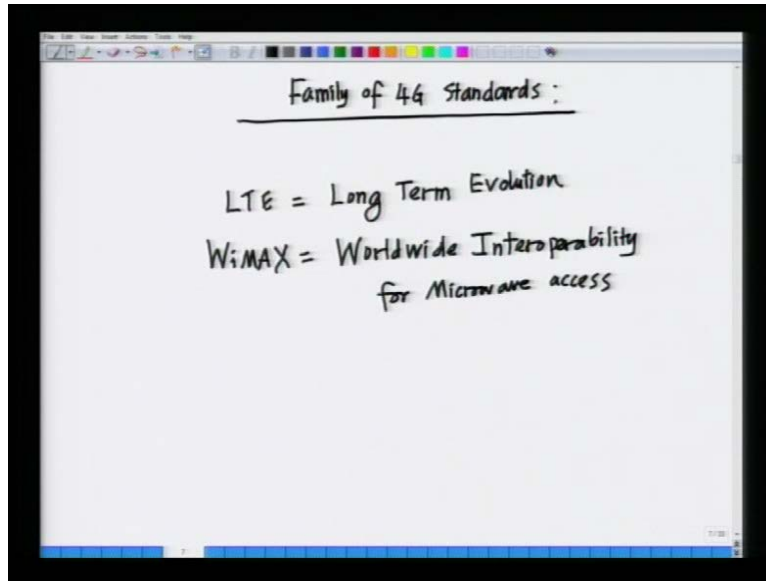


A handwritten table on a whiteboard titled "4G Wireless Systems:". The table has two rows and three columns. The first row lists "4G", "LTE", and "100-200 Mbps". The second row lists "4G", "WiMAX", and "100-200 Mbps".

| 4G | Standard | Speed        |
|----|----------|--------------|
| 4G | LTE      | 100-200 Mbps |
| 4G | WiMAX    | 100-200 Mbps |

Let me start with a brief description of those 4 G wireless systems, 4 G stands for fourth generation. Let me again make a table, and since many of them here are still in the development stage, this table here is not very big. There are essentially two dominant 4 G wireless or 4 Generation wireless communication standards. The first one is L T E, it stands for long term evolution, that has a data rate of 100 to 200 M b p s, and there is another competing 4 G standard, which is wimax, which stands for worldwide interoperability for micro wave access, also has a data rate of approximately 100 to 200 megabits per second. So these are the two most popular or dominant 4 G wireless standards, currently in development, and deployment in different countries in the world.

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So again similar to what we have done before, let me just briefly write down this acronyms for your reference; L T E stands for long term evolution, and wimax stands for worldwide interoperability, worldwide interoperability for microwave access. This is the family of 4 G standards, or fourth generation wireless standards. This is the family of fourth generation wireless standards.

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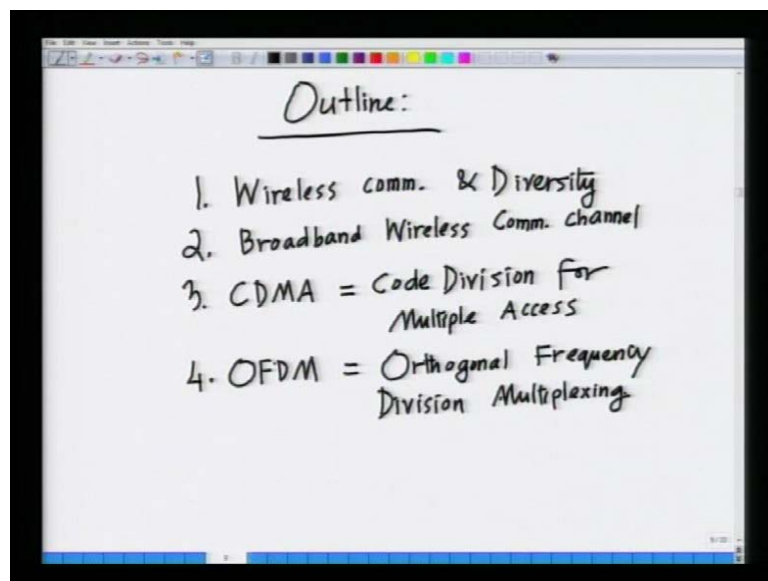
|      |                     |                                |
|------|---------------------|--------------------------------|
| 2G   | 10-100 kbps         | Voice + Data                   |
| 2.5G |                     |                                |
| 3G   | 300kbps - 30Mbps    | Voice<br>Data<br>Video calling |
| 3.5G |                     |                                |
| 4G   | 100 Mbps - 200 Mbps | online Gaming<br>HDTV          |

So to briefly recap, we have 2 G 2.5 G, 3 G, 3.5 G, and 4 G wireless systems. These are roughly around let say, 10 to 100 k b p s. These are around let say 300 k b p s to even 30 M b

ps; that is 300 kilobits per second to 30 megabits per second, and 4 G systems which are around 100 megabits per second to 200 megabits per second, and as you can see the data rate increases progressively, and while this can support, while 2 G are typically voice, plus some basic data. 3 G can support voice, data, and real time video; such as video calling, video conferencing etcetera.

Video calling video conferencing etcetera and 4 G can support a lot more applications such as voice, data. Inclusive of these applications it can support online gaming, real time tv, in fact H D T V, high definition tv and so on and so forth. So as you see the result, as the result of the increasing demand for higher band width applications has led to the progressive development, of 3 G 3.5 G and 4 G wireless communication systems, and in this course we are going to the main motivation of this course, is to understand the technologies, the underlying wireless technologies, that have made possible the development of such 3 G 3.5 G and 4 G systems. So let me start by describing a basic outline of the course, so that it will give you a road map, or where we intend to go to.

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We will first start with a description, so this is an outline of the course. We first start with our first chapter, which is basically wireless communications and diversity. The first chapter is wireless communications and diversity, the complete out line, including all the sub topics that we cover in each topic is given on the websites, so if you want to more details, please go the website. Here I will just describe the major sections, that we will cover in the course. The first

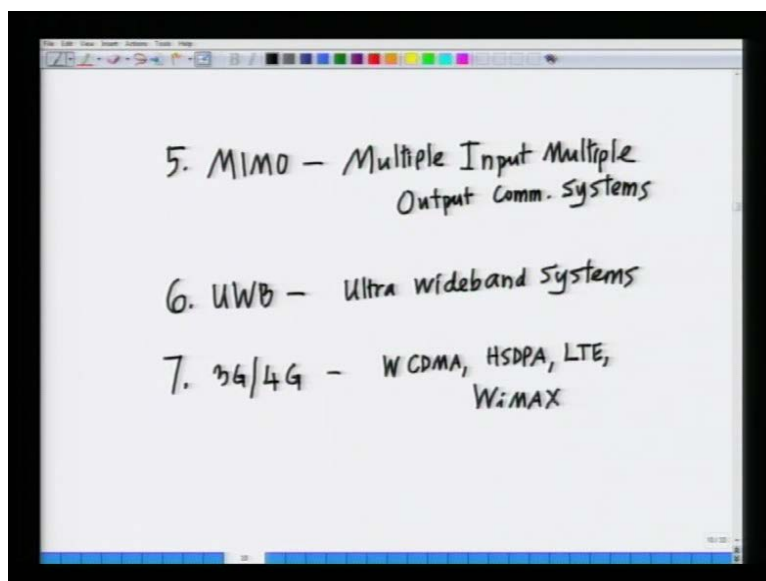


major section is wireless communications, a general introduction and diversity, which is a key feature of every 3 G and 4 G wireless communication system.

Then we are going to look in detail into modeling of a broadband wireless communication channel. Since we are talking about wireless communication systems, the wireless communication channel has a key effect, on the wireless communication systems, because the wireless communication channel represents a very adverse environment, as we are going to see in the future lectures, so we will devote sufficient amount of time to understand the nature, of the broadband wireless communication channel.

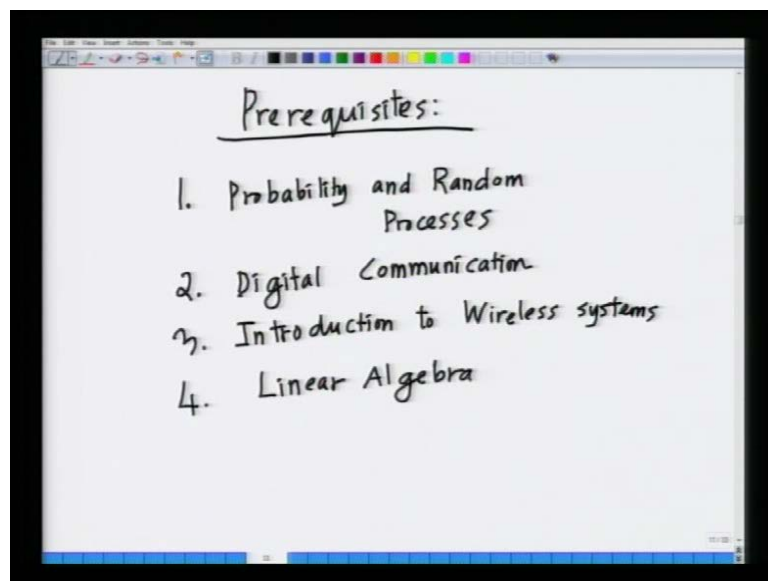
Then we will start discussing the key technologies, that make possible 3 G and 4 G wireless communication channel systems. Or in other words those technologies on which, or those principles on which third generation 3.5 G 3.5 fifth generation, and fourth generation wireless communication systems can be built. So the first technology is not surprisingly C D M A, which also stands for code division for multiple access, this is the first technology that we are going to look at. Another key technology which makes possible 3 G and 4 G wireless systems, is a very key technology known as O F D M. This is the basis for all fourth generation wireless communication systems, it stands for orthogonal frequency division multiplexing. So fourth topic that we are going to look at in detail is O F D M orthogonal frequency division multiplexing, is a key technology for all fourth generation wireless communication systems.

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And the fifth topic we are going to look at, is another very important technology for 3 G and 4 G wireless communication systems; that is MIMO or multiple input, multiple output communication systems. So MIMO stands for multiple input multiple output communication systems. These are an integral part of all 3 G 3.5 G and 4 G communication systems, so we are going to spend sufficient amount of time understanding, multiple input multiple output wireless communication systems. We are also going to talk about u W B which is a promising technology, which is ultra wideband systems u W B stands for ultra wideband systems. And finally, we are going to look at the 3 G and 4 G standards actually; that is going to talk about 3 G, 4 G standards; that is how do all these technologies come together, to define the 3 G 4 G standards that have been proposed, such as W C D M A, H S D P A, L T E, Wi-Max and so on. So in brief, this is the outline of the course, this is the part that we are going to follow as I said the detailed outline, including all the sub topics that we are going to look at, in each topic is available on the NPTEL course website, so if you need more details please go to the website, so that you can get a complete list of this topics.

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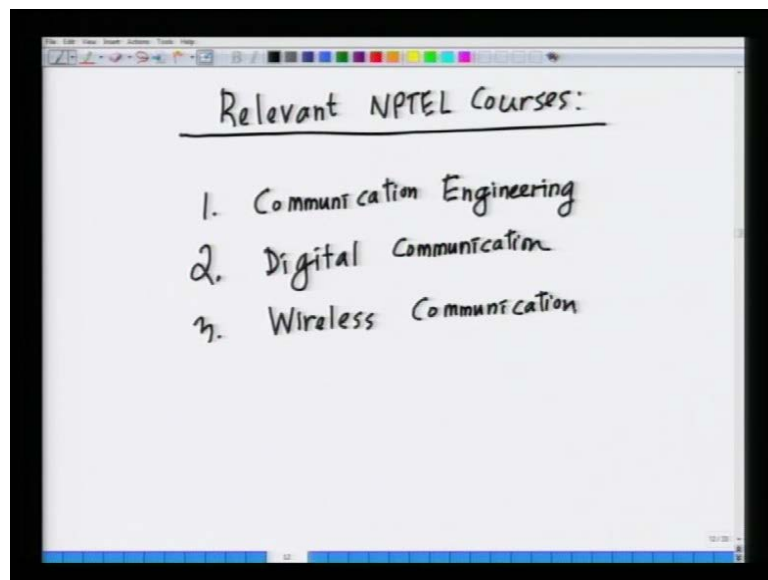


So let us now move on to some other aspects of the course, before I start the course formally, let me also give you a list of prerequisites, that you need to understand the material present in this course; a list of prerequisites that I recommend. The first one is a basic course on probability, and random processes. Another course that is, you need some basic information, or you need to know, in some detail aspects of probability, especially random processes. You also need to know some basics of digital communication systems. basics of digital

communication systems An introductory since this is an advanced course on 3 G or 4 G mobile communication systems, it would be good if the students are familiar at least at an introductory level, with some concepts of 2 G wireless systems, and the development of wireless communication systems so far. Some introductory course, so I will write here introduction, to wireless systems. And four, a basic course on linear algebra.

So I would strongly recommend the students have a background, basic background, or an undergraduate level background in these aspects; that is probability random processes, digital communication, introduction to wireless systems, and a linear algebra, because this is an advanced course, so we are going to a need a background of sufficient knowledge of these fundamentals, so we can understand the material presented in the rest of this course.

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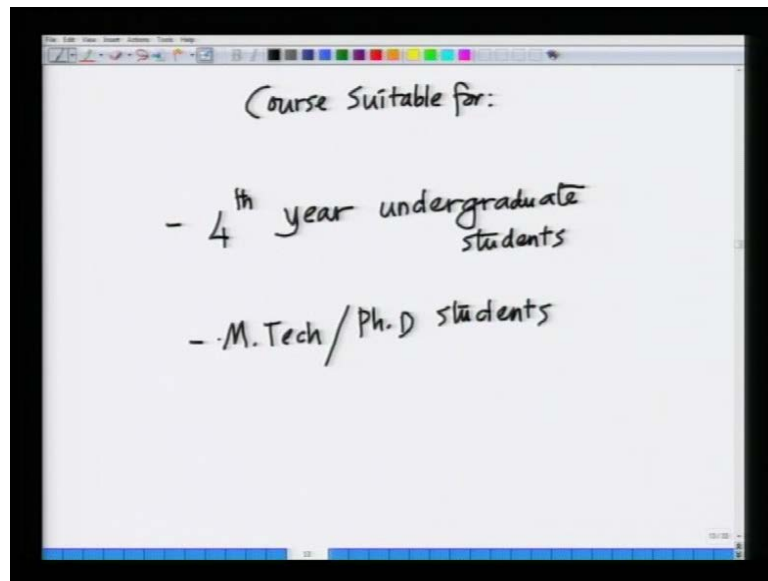


And however a lot of these prerequisites are already available, in the form of NPTEL courses. So let me refer you to the relevant NPTEL courses, that the students can look at, before coming to this course on 3 G and 4 G mobile communication. So the relevant NPTEL courses are; one, communication engineering, the course on. There is an NPTEL course on communication engineering. There is currently an NPTEL course on communication engineering, which will introduce you to aspects of probability and random process that we need for understanding communication systems, so please refer to that course. There is another course on digital communication, this describes basic principles of digital

communication systems. And there is another course, or an introductory course on wireless communication.

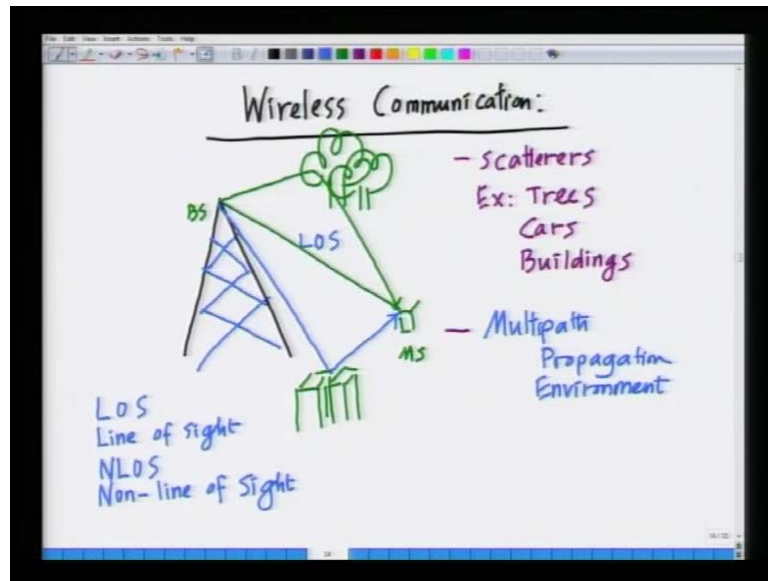
So these three courses are already available on NPTEL, so please go through these three courses, so that you gain an understand of the fundamentals that are required, to understand the concepts that are going to be present, in this course; that is advanced 3 G and 4 G wireless communication systems.

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And this course I would say is suitable for, fourth year, or basically fourth year undergraduate students. So let me write, this course is suitable for fourth year undergraduate students, or M Tech students of any year and PhD students; that is, let me write M-Tech and PhD. So this course is suitable, fourth year undergraduates, fourth year, because you need some prerequisites in terms of basics of communication systems, digital communication probability, and random processes and so on. So its suitable for fourth year undergraduate students, and PG students; namely M Tech and PhD students.

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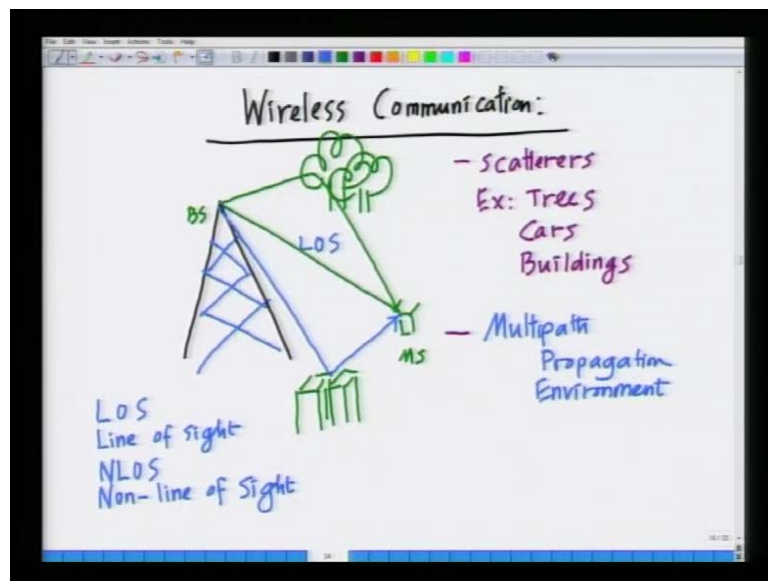
So with that, let me formally start with, actually going through the course content, which is the first chapter of the course, which is wireless communication. So let me start going through the first chapter, which is wireless communication. Let me first start with the brief description, let me start by drawing the picture, so it becomes clear, what the wireless communication environment looks like. A wireless communication system, typically contains, a base station. Let me use some color to represent this, it contains a base station; that is transmitting to a mobile terminal, your mobile phone, or that is technically also known as a mobile station.

So I have a base station; that is mounted typically at a very high, at a height on a tower, on the base station tower, and a mobile station, which I am going to denote as M S, and there is a signal that propagates from the base station to the mobile station; that is the electromagnetic wave, or the wireless signal, this information you should be familiar with, since you, I am assuming you have already gone through a basic introductory course, on wireless communication systems.

However, unlike traditional wire line communication systems, that is where the signal propagates on a wire. In a wireless communication systems, since the radio environment is open, in addition to the direct propagation; that is the direct line of sight, propagation between the base station and the mobile station. There are also several reflected components, that arise in the environment, namely let us look at some scatterer in the environment; such as trees,

what I am drawing here are essentially trees, and the scatter, the wireless signal. There might also be other buildings in the propagation environment, there are also other buildings, because most of these are employed in urban city environments, and in such environments, there are other scatter components, that are reflected of cities of buildings. And there might also be other scatterers; such as moving objects, such as cars so on, which are moving, and which also scatter.

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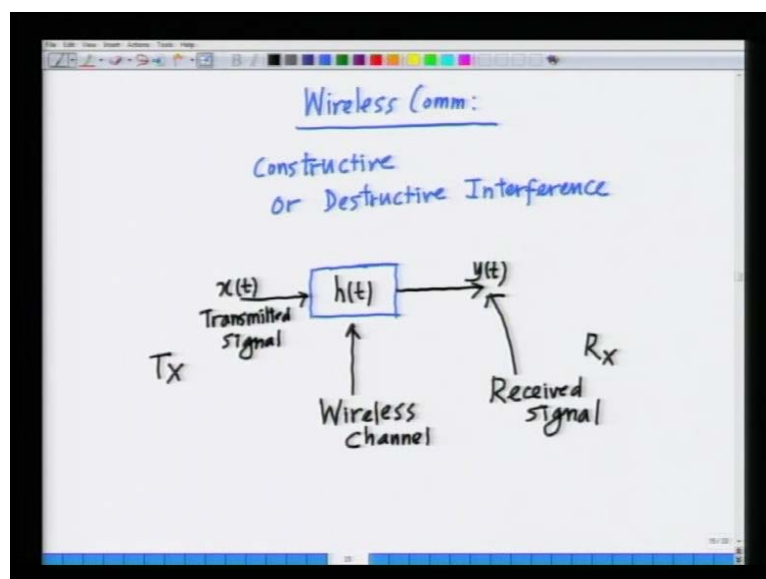


So in general, the wireless communication environment is very different from the wire line communication environment, because you might only have the direct one path, between the base station and mobile station, but you also have many scattered or reflected paths, and these objects which scatter the wireless signal, are known as scatterers. These are typically objects, large objects such as for instance; trees, cars, vehicles, large buildings. In a rural scenario it can also be objects, such as large mountains, hills, rocks and so on and so forth. So these are the scatterers, which implies at the receiver you not only have a single component, but you have multiple components, that you have multiple, that you have the signal, arriving at the mobile station, through not just a single path, but multiple paths, and hence this is known as a multi path propagation this is known as a multipath propagation environment, because unlike wire line channels in a wireless system, there is a direct path, and there are also many scatter paths, and there are multiple paths.

Hence, this is known as a multi path propagation environment. And there are technical names for this, the direct path is known as the L O S, or so the direct path is known as the L O S or line of sight component, and the scatter paths; that is, one that is the direct path is known as the non line of sight, or N L O S components. So the scatter paths, which are not do not arrive directly, but with arrive, because of the scatterers are known as N L O S or non line of sight, non line of sight components. So that is the characteristic of the wireless channel, where we have the signal coming to the mobile station, through multiple channels. Now obviously when you have such an environment, you must be familiar from a basic understanding of high school knowledge of electromagnetic waves, that each wave, that comes through a different distance, is subject to an attenuation.

Attenuation because of free space losses, and also because the distance is different, the delay is different, which means the phase that it arrives with at the mobile station is different. So we have this different signals, we have the same signal, arriving at the mobile station with different paths. It is adding up at the mobile station with different attenuations, and different delays. Hence we know from knowledge of high school physics, that these signals, depending on the different delays, have a phase factor, and depending on the delays, they can either add constructively to produce constructive interference; that is increase in the amplitude of the net signal, or at times they can also add destructively; that is they can cancel out each other, to produce destructive interference. So, an important idea of mobile communications an important.

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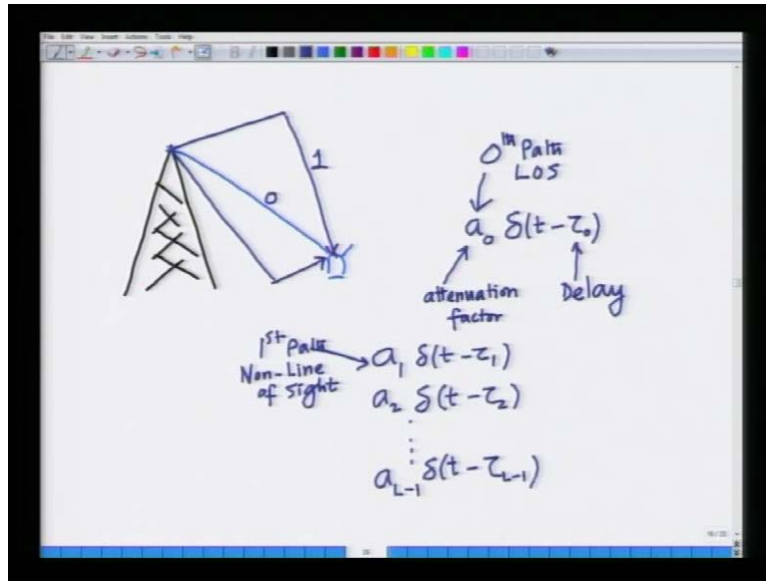
Let me just write the title again here, an important idea of wireless communications is, multipath components add with different phase factors, because of the delays and different attenuations arising, because of free space losses and scattering, and hence its results in constructive, or destructive, which means if it is constructive interference its good, because the signal level goes up, but if its destructive interference that is bad, because the signal level goes down, and hence we are not able to receive any signals. So that is why the mobile the wireless communication environment, is an adverse environment, because multipath propagation, or rather multipath interference results in a signal level; that is, if there is destructive interference then the signal level is low, in which implies that there is no reception of signals.

We want to model the wireless propagation environment, as a system, with some impulse response  $h$  of  $t$ , to which the base station inputs the signal  $x$  of  $t$ ; that is, this is the signal transmitted by the base station  $x$  of  $t$ . It propagates through the wireless environment, which can be characterized has having a response  $h$  of  $t$ , and the output is the signal that is received at the mobile station, which can be denoted as  $y$  of  $t$ . So this is the transmitted signal  $x$   $t$  is the transmitted signal alright.  $h$   $t$  is the wireless channel, and  $y$   $t$  is the received signal this is also often abbreviated, as  $T$   $x$  for the transmitter,  $R$   $x$  for the receiver. So  $T$   $x$  signal denotes transmitted signal  $R$   $x$  signal denotes received signal wireless channel is as an impulse response  $h$  of  $t$ .

So when I pass  $h$  of  $x$  of  $t$ , through  $h$  of  $t$ , the output is  $x$  of  $t$  convolved with  $x$   $h$  of  $t$ , this you should be familiar with, because you should be you should have done a basic course, being either fourth year undergraduate, or an m tech student you should have done a basic course, on signal and system analysis, which will introduce to the concepts of linear time in variant systems, where  $x$  of  $t$  if it is pass through a system with impulse response  $h$  of  $t$ . The output is  $y$  of  $t$  is  $x$  of  $t$  convolved with  $x$  of  $t$ .



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Now let me start with a model, let me again redraw the basic wireless system, that we had earlier, which is, there is a direct line of sight component, or a direct path between the base station and the mobile station, and an addition, there are several scatter paths, between the base station and the mobile station. Now let us look at one such path; that is the direct path. Let us say it we we already said, each path produce a signal copy, which is attenuated such as by the free space, or by the scatterers, and also is delayed. Now we know from the theory of linear systems that, an attenuation, is simply a scaling of the signal, which corresponds to multiplying the signal, by a scaling factor a naught, and a delay, is simply corresponds to an impulse function delta t minus t naught, where t naught is the delay. So a naught is the attenuation factor, tau naught is the corresponding delay.

So the signal x of t when it is passing, for the first path is attenuated by a 0 delayed by tau naught, as a system that can represented as a system ,with impulse response a naught times delta t minus tau naught. Now similarly, the first path here; that is, if I call this the zeroth path, and which is the direct line of sight path. The first path can be characterized as some attenuation a 1, and delay tau 1; that it has an impulse response a 1 delta t minus tau 1. So this is the zeroth path or the line of sight path. Remember we introduce this nomenclature L O S stands for line of sight, in the previous slide. a 1 is the first path, or the non line of sight path, with attenuation a 1 and delay tau 1. And similarly, we can have a second path, which has amplification a 2 or attenuation a 2 and delay tau 2 so on and so forth, we might have, we can have up to l paths, which is the zeroth path, line of sight, and l minus 1 scatter paths, denoted

by the  $l$ ,  $l$  minus one th path has an attenuation denoted by  $a_{l-1}$ , and delay denoted by  $\tau_{l-1}$ .

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The image shows a handwritten derivation on a whiteboard. At the top, it says "Multipath Component" with a bracket above it. Below that, the impulse response  $h(t)$  is written as a sum of terms:  $a_0 \delta(t - \tau_0) + a_1 \delta(t - \tau_1) + \dots + a_{L-1} \delta(t - \tau_{L-1})$ . To the left of this equation, it says "impulse Response of Wireless channel". Below the first equation, a box contains the compact summation form:  $\sum_{i=0}^{L-1} a_i \delta(t - \tau_i)$ .

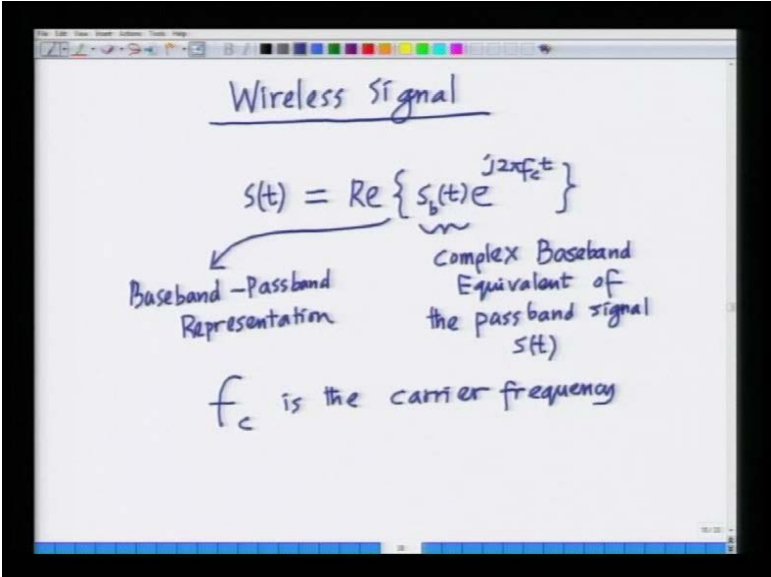
And now it is easy to see, what the model of the wireless channel can be, it is simply a combination of all these paths, which means the wireless channels impulse response  $h$  of  $t$ , which is the impulse response of the wireless channel, is simply the impulse response of the zeroth path; that is a  $0$  delta  $t$  minus  $\tau_0$  plus the impulse response of the first path, which is a  $1$  delta  $t$  minus  $\tau_1$  plus so on, plus so on until the impulse response of the  $l$  minus oneth path; that is a  $l$  minus  $1$  delta  $t$  minus  $\tau_{l-1}$ .

So, the net impulse response of the system, is the some of the impulse responses corresponded to each path, which is the attenuation corresponding to that path, and the delay corresponding to that path; that is for the  $i$  th path, it is  $a_i$ , the attenuation  $a_i$ , delay  $\tau_i$ , and I can represent this compactly as  $\sum_{i=0}^{L-1} a_i \delta(t - \tau_i)$ . So the time domain impulse response of the wireless channel, of this multipath wireless channel, is  $\sum_{i=0}^{L-1} a_i \delta(t - \tau_i)$ , where  $a_i$  is the attenuation  $\tau_i$  where  $\tau_i$  is the delay.

This is the impulse response of the wireless channel. Now look at this summation has  $L$  components; that is  $i$  equal zero to  $L-1$ , each component arises, because of one of the paths between the base station and the mobile station. Hence each of these is known as a multipath component. So each of these is known as a multipath component. So each

component will be corresponds to a path, is known as the multipath component. This channel that we have described here, has  $L$  multipath components; one of them is index zero, is the line of sight component, the other one, other ones, from index 1 to  $L$  minus 1, or the non line of sight or the scatter component. So this essentially is going to be for us. The impulse response, or the wireless channel. It is important to understand this, because this is going to be play key role, in the rest of the development; that is the wireless channel, can be represented as the sum of multipath components corresponding to the attenuation, and the delay.

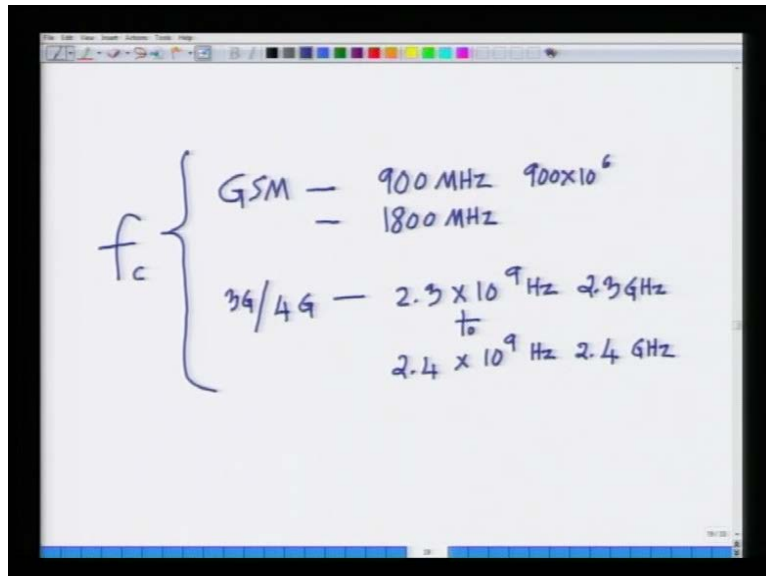
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Now let us model the wireless signal; that is transmitted by the base station. So the base station transmits a wireless signal, let us model that signal, let me call that signal  $s$  of  $t$ .  $S$  of  $t$  can be denoted,  $S$  of  $t$  is a pass band signal, that is its transmitted at a carrier frequency. I can model that, as the real part of  $s_b$  of  $t$  times  $e$  power  $j 2 \pi f_c$  of  $t$ . Now this is slightly sophisticated notion, that we are using here, and that is why I assume you have had the prerequisites, that are you gone to the prerequisites of communication engineering it is important, because this notation that we are using here, is. It has a name, it is a very standard notation in communication systems, this is known as the pass band base band representation, this is known as. So this is known as, this is pass band signal this is the complex base band representation of that. So this is built on baseband pass band representation. And in fact  $s_b$  of  $t$ , is known as the complex baseband, equivalent of the pass band signal  $S$  of  $t$ . This is the complex baseband equivalent of the pass band signal  $S$  of  $t$ , what is transmitted is  $S$  of  $t$ , which is the pass band signal,  $S_b$  of  $t$  is the complex baseband representation, corresponding to this pass

band signal  $S$  of  $t$ .  $f_c$  is the carrier frequency. This is the baseband signal,  $f_c$  is the carrier frequency, this is allocated to that that particular cellular network operator.

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As we know in India, there are couple of frequencies allotted, specific allotted carrier frequencies to current systems. For instance let me give you an idea, for current GSM systems, the allotted carrier frequency is either 900 mega hertz's. Each mega hertz is 10 to the power 6 hertz, so this is 900 into 10 to the power of 6 hertz's. Or there is also another carrier frequency which is, the 1800 mega hertz's carrier frequency, or it also be represented as 1.8 giga hertz's, where 1 giga hertz's is 10 to the power of 9 hertz's.

The allotted carrier frequencies for 3G and 4G systems, are two point 3 Giga hertz's to 2.4 Giga hertz's; that is 2.3 into 10 to the power of 9 hertz's, or 2.3 Giga hertz's to 2.4 into 10 to the power of 9 hertz's, or 2.4 Giga hertz's. So these are the values of  $f_c$ , that have been allocated, in a specifically for GSM and 3G 4G systems. And it is important to allocate different carrier frequencies, for different operators, especially because when you transmit over the air, each one needs a unique spectral band, so that these signals do not interfere over there. So a spectrum is an important part, so before you transmit the base station, up converts the baseband signal, to the allotted carrier frequency, and at the receiver at the mobile station, down converts the received signal, back to the baseband.

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$$s(t) = \text{Re} \left\{ s_b(t) e^{j2\pi f_c t} \right\}$$

$$h(t) = \sum_{i=0}^{L-1} a_i \delta(t - \tau_i)$$

$$y(t) = s(t) * h(t)$$

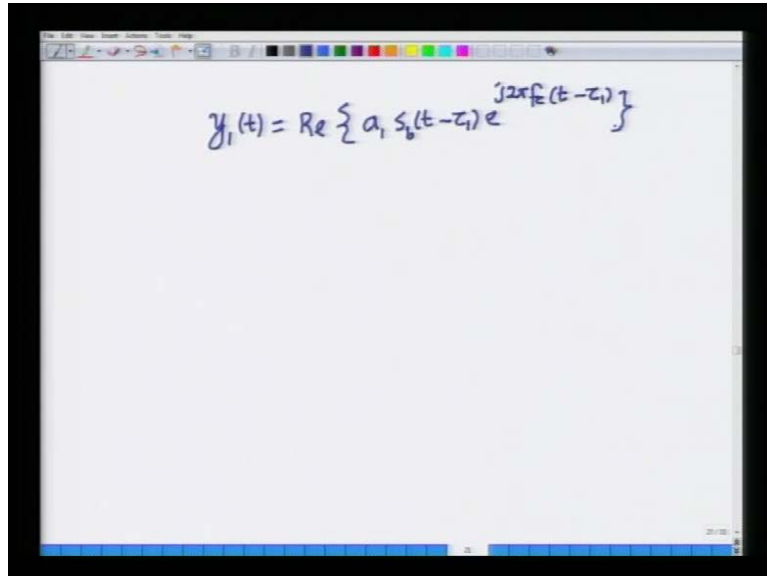
$$y_0(t) = \text{Re} \left\{ a_0 s_b(t - \tau_0) e^{j2\pi f_c (t - \tau_0)} \right\}$$

So as we have seen so far, the transmitted signal  $s$  of  $t$  can be represented, as the real part of  $s_b(t)$  times  $e$  to the power of  $j 2 \pi f_c t$ . And the channel, the wireless channel, can be represented as  $\sum_{i=0}^{L-1} a_i \delta(t - \tau_i)$  that is the attenuation corresponding to  $i$  th path, and  $\delta(t - \tau_i)$ , where  $\tau_i$  is the delay. Now what we have done is successfully, we have modeled the transmitted signal by the base, by the base station, and the multipath environment of the wireless channel, or the multipath propagation environment of the wireless channel. As we had said before, the received signal at the base station  $y$  of  $t$ , is now simply a convolution of the transmitted signal  $s$  of  $t$ , with the wireless channel  $h$  of  $t$ . Now let me do this component by component, let us first do it for the line of sight component; that is let me. So the line of sight component is characterized by attenuation  $a_0$ , and delay  $\tau_0$ .

If I pass my signal  $s$  through this component, as we can as we all know from an analysis of our understanding of the basic course on signals and systems. My received signal will be attenuated by  $a_0$ , and delayed by  $\tau_0$ . So corresponding to this path, the received signal is simply  $y_0(t)$ , which is signal  $s_b(t)$  transmitted through this component, which is real part of. Now the signal is multiplied by  $a_0$ ; that is  $a_0$ , and it is delayed by  $\tau_0$ ; that is the delay, so I have  $s_b(t - \tau_0)$ . Everyone knows if I delay a signal  $s_b(t)$  by  $\tau_0$  the output is  $s_b(t - \tau_0)$  into  $e$  power  $j 2 \pi f_c (t - \tau_0)$ . Let me repeat this argument again, because things are starting to get a little bit complex, we are building on these motions; that is the corresponding to the zeroth component, we have the received signal  $y_0(t)$ , which is the real part of  $a_0 s_b(t - \tau_0) e^{j 2 \pi f_c (t - \tau_0)}$ .

attenuation  $a_0$  and  $S_b(t)$  delayed by  $\tau_0$   $e^{j2\pi f_c t - \tau_0}$  that is the carrier delayed by  $\tau_0$ .

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$$y_1(t) = \text{Re} \left\{ a_1 s_b(t - \tau_1) e^{j2\pi f_c(t - \tau_1)} \right\}$$

Similarly, the signal corresponding to this path to the first path, can be written as real part of. Now  $a_1 t S_b(t - \tau_1) e^{j2\pi f_c t - \tau_1}$ , so this is the response or the output corresponding to the second path. We will stop this discussion here, this first lecture. And we have covered different aspects in this lecture; that is the family of 2G 3G 4G wireless communication standards. The nature of the wireless multipath propagation environment. The nature of the transmitted wireless signal, and we have started looking at the received signal at the mobile station, corresponding to the transmitted signal. So let us stop here, and let us take this discussion forward, in the next lecture.

Thank you.