Introduction to Wireless and Cellular Communication

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Lecture – 01
Overview of Cellular Evolution and Wireless Technologies
Overview of Cellular Systems – Part I

Good evening and welcome to EE5141 Introduction to Wireless and Cellular Communications. I am Professor David Koilpillai and very happy to have this opportunity to teach this course for this batch. I thought I would start off by just saying a few words about the course, but even before that maybe answer a question that is on your minds why in the studio. One of the feedback points that we have received at least I have received over many years is that students find it very hard to write was on the board and also listen at the same time, because you know information is coming at a very fast space.

So, the suggestion was you know at least can we have the notes after the lecture is over and unfortunately many times what is written on the board is very different from what I have in the sheet of paper because you know some things are changed as we progress. So, I thought the best way would be is to find a tool or a way by which we can capture whatever is happening in the classroom whatever is on the board as at the same time have the flexibility to introduce a power point or a MATLAB simulation or an animation, those things we could not do in a traditional classroom I am sure you know that in many of the use be classrooms we have projectors, but there off into one corner it is not easy to switch back and forth. So, this is a way hopefully by which we can use all the information in the different forms, and also at the end of the lecture you will have something that you can go back and refer and also look at in terms of the information.

So, as the screen is coming up I just wanted to mention a couple of points regarding the timing this is an f slot course, but it is a four credit course.

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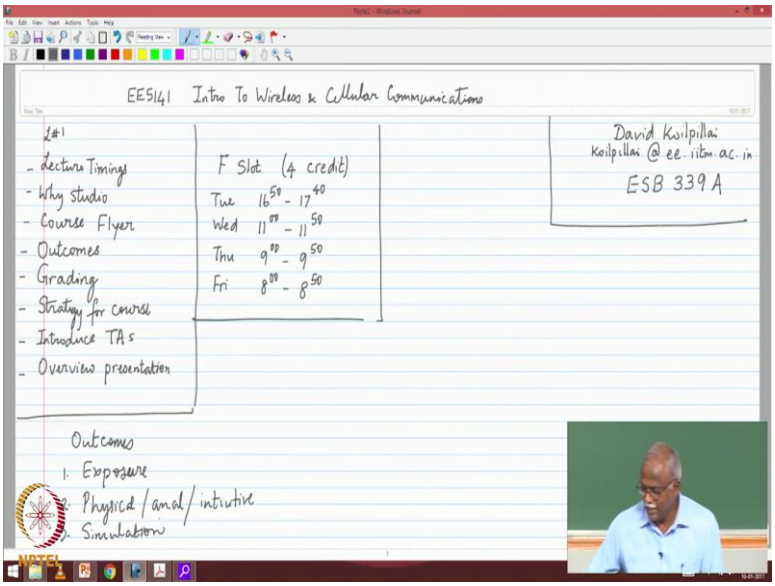

So, in addition to the morning slots we have one afternoon slot which is the Tuesdays at 452 to 540 and we will keep the slot at the present time let us see if we can shift it to an earlier slot in case this is there is an earlier time slot that is available to us. So, a one of the ways that I like to keep track of what is planned for the lecture is to have a quadrant where indicate what is going to be covered in the class. So, we already addressed the first two points why studio hopefully you will at the end of the course you will be able to affirm that this was a experiment worth doing, let me start with the course flyer maybe before that my room is in ESB 339 a welcome any time to stop by if you have something to discuss.

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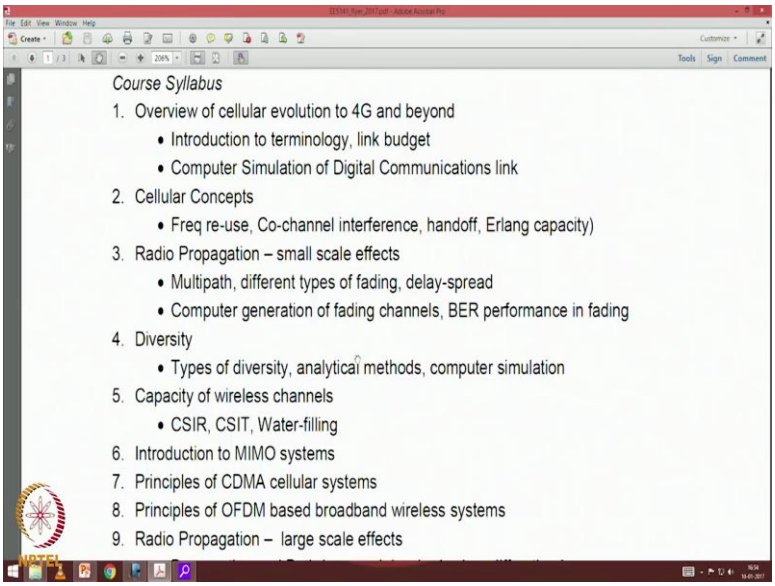

Let me look at the course information and let us just sort of highlight what we would be covering in the course because it is always good to know where we pick up and what we plan to cover in the course. The first week that is this week we are going to introduce give an overview of the cellular systems and introduction to wireless communications. So, you may know well you know this is familiar stuff, but just wait until the information is shared because there is a lot of activity happening in the arena of cellular and it is good for us to get a comprehensive view. The wireless course you are going a focus on one specific aspect and, but it is good for you to be very comfortable with the terminology with what is happening in 3G, 4G, 5G whatever may be the question.

Many of the things that we are going to be talking about pertains to the wireless channel very specifically to the wireless channel. So, one of the first things that I would like the students to be familiar with is to have a baseline digital communications link which ever you would have done in your digital communications course, we will then change the channel according to what the type that we are studying.

So, we will talk a little bit more about that in the course of we will one of the things that we do in first week is for everybody to have a baseline MATLAB or a C simulations that would be part of an assignment. We then move into understanding cellular the way it is deployed today you know how did the cell word whether the word cellular come from and what are some of the salient features probably the most important is the design of

cells, how these cells are deployed, what happens when you move from one cell to the other that is the aspect of handoff and then the notions of capacity what is a capacity of a cellular system.

Now, having understood cellular then we go into the heart of the course, which says that how do I understand the wireless channel. We call that as propagation and understanding the effects of propagation in the context of what we call a small scale effects and we will talk about it in today's presentation what are some of the distinctive features what makes it different from AWGN channel which you probably would have studied. So, here are some aspects that we will cover in a fair amount of detail and the computer simulations will now move from a basic digital communications link to a wireless channel with the impairments of a wireless channel, so that is the second step.

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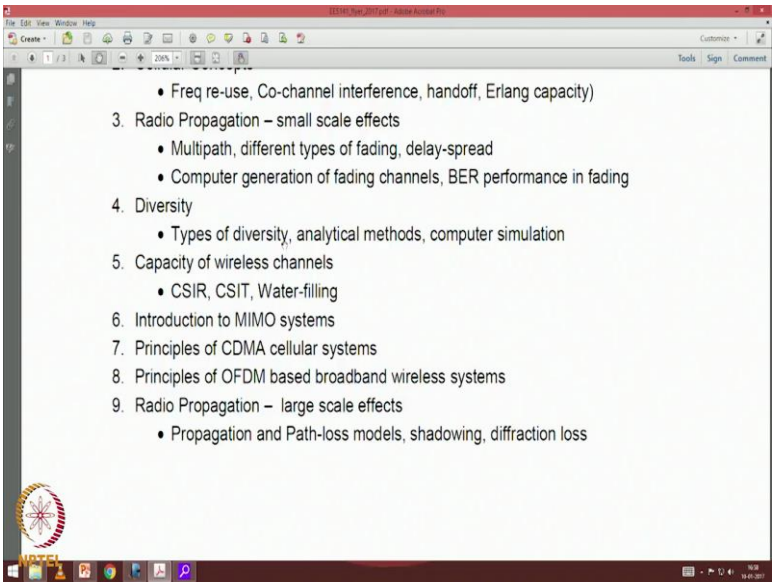

One of the things that we will find in the context of the wireless system is that having multiple antennas is a significant advantage. One it tells us that we can have the feature called diversity, it also helps us in terms of the capacity how we can improve the capacity of a system. So, diversity and capacity sort of go hand in hand, and along with the diversity what happens if both transmitter and receiver have multiple antennas those are called the MIMO systems. So, fading channel understanding it in full detail understanding what are the benefits of having multiple antennas at the receiver, what is the capacity of a system, what happens if you have multiple antennas at the transmitter

and receiver that would be the MIMO system and then we move into what are the cellular systems that you are looking at today, the basic concepts of CDMA which is the third generation system OFDM which is the fourth and fifth generation systems, and that is pretty much the span of the course.

But one very important element that is that you should know as a student were studied wireless communications is what happens when I set up a tower at one location and then try to receive it inside of a building, basically what happens due to walls, what happens due to buildings that is what we call as the large scale propagation and again those are well understood well studied we will touch upon that making sure that you know if somebody were to ask you to design a wireless system, you will know exactly how much power to use and what height of antenna to use and all of that will be well understood.

So, that is more or less the course when you get a chance you can go through in detail if you have any questions feel free to let me know, there is not a single book that would be complete for the entire course. So, what we are going to be using is a combination of books.

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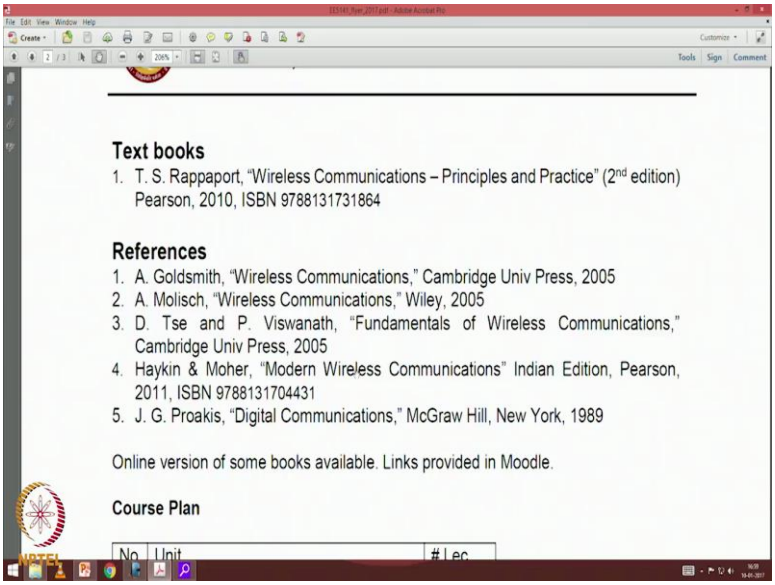

Rappaport has got a bulk of the information but Goldsmith say in Vishwanath and Molisch have quite a bit some parts on the CDMA side will be taken from Haykin of course, many times we will have to go back and refer to Proakis because a lot of what we talk about is digital communications applied to a wireless channel.

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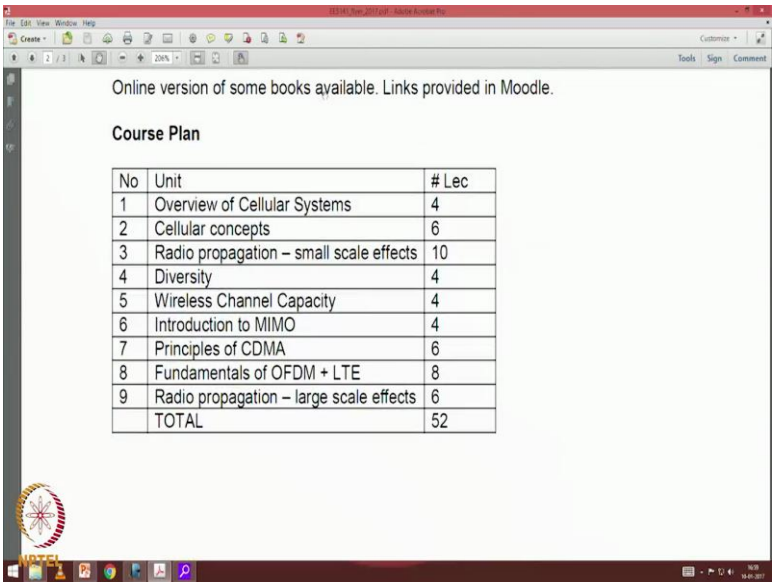

The course plan is given in the flyer you can take a look at it sort of tells you approximately how much time you will spend the total course is 56 lectures have a buffer of four in case we need to spend a little extra time on any of the unit.

So, that is quick run through of what the course outline is going to be. I thought I also give you a take a few minutes to share about the philosophy of the course, most students taking this course I assume have done digital communications either at IIT or at another institution. So, what we are going to be doing here is actually building on the digital communications foundation that you have. So, what you will find is the way we cover the material lot of times would be a quick review, applying it to the wireless channel expand the wireless portion of it and our understanding of it, and then develop the entire framework around that.

So, whatever you have done in digital communication. So, for example, you have studied information theory how to represent signals, how to compress signals, how to do channel coding modulation all of that we assume is a is understood, and we just sort of take it from there and then say how do we apply it in the context of wireless what is what are those things that are advantages, what are those things that are difficult. So, typically in a digital communications course you would have looked at an impairment of AWGN, apart from that I am sure you would have studied channels which have inter symbol interference. So, what we are going to be looking at is take those two impairments and

add to it the aspects of a wireless channel which we will refer to in terms of fading multipath, Doppler those are all elements that we will introduce. So, our as I said the approach is going to be pick up what is there in digital communications, assume that the students are comfortable with it wherever necessary you do a quick review and then focus on the wireless side.

On the receiver side again in digital communications we typically study how to build receivers talk about synchronization, how to do timing, how to do the demodulation decoding all of that again we assume is well understood we will build from there. So, our progression will be from digital communications part into the wireless communications and make sure that we are comfortable with all aspects of that. So, let me maybe share a few general thoughts on what I would consider as outcomes for our course. The outcomes that would be very good from a teacher's point of view would be that this course would give you an exposure. So, let me capture that outcomes would be an exposure to what is happening in the world of wireless the current cellular systems. Second element would be the analytical understanding of the wireless channel our understanding of that.

So, it would be the physical, the mathematical or the analytical aspects of that and also along with that intuition very very important, because a lot of wireless is about being intuitive understanding what is it that that works well in the context of a wireless system. Then the simulation aspects I think that is very key elements that I would like to capture in our course, and also talk about the problem solving aspects we will do assignments on the different topics that we are studying.

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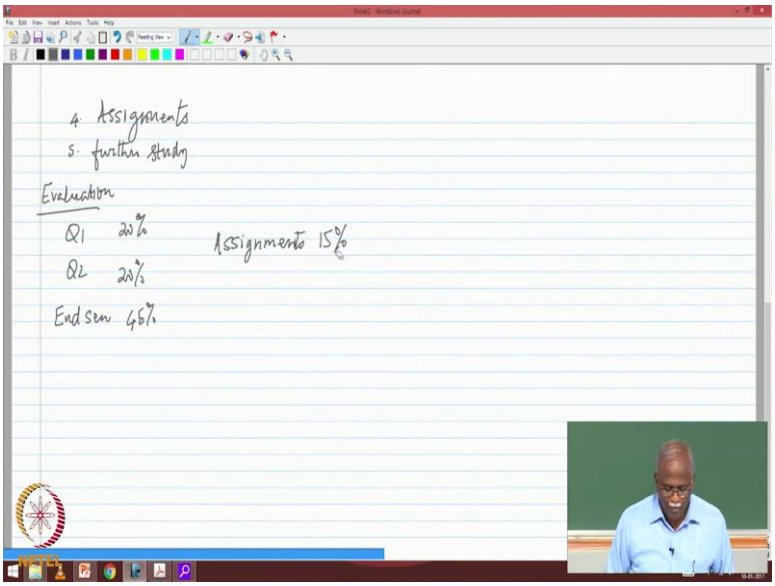

And finally, hopefully whatever we do in this is a preparation for a for further study, for further study or whether you are doing a project or research or you are going to be a practitioner I think all of them are equally we will prepare you for that.

Another element is what is it is a traditional course in the sense at the evaluation will be very much along the traditional aspects, we will have two quizzes quiz 1, quiz 2 in semester exam 20 percent for quiz 1, 20 percent for quiz 2, 45 percent for quiz for the in semester exam. Assignments our course is very much assignment based, so assignments will carry a fair amount of weight age 15 percent will give you a little bit more information about the assignments themselves, and how we will carried out a lot of it will be using for computer simulations it will be online submission for written assignments it will be evaluation will be done in the form of assignment test that is done in the class.

So, this is sort of a very traditional course in that sense, but I thought I would like to share with you a little bit about a strategy. As a student always wanted to know what the teacher thought was a good strategy for the course so maybe I should share that with you. Please stay abreast of the class because this is a course that actually does cover a lot of material covers it at a fast pace. So, please stay abreast you know reading up on the corresponding chapters in the books that we are currently following, but of course, having five books is an advantage because you can always cross refer and get a very rich

understanding of the wireless because each of the five books that we talked about I have been written with a very specific perspective. So, when you look at the outcomes you can almost map you know this book will give you a good exposure, this will give you analytical tools this will give you simulation.

So, I think you can almost understand. So, keeping it in perspective let me share with you a presentation which I have prepared very specially for the course and so that we can have an opportunity to dialogue a little bit. So, this is a way by which in a nutshell very very a briefly you can get a span a bird's eye view of the entire wireless domain and then we will zoom in and look at specific aspects of the topics that we are interested.

They say that it is always good when you want to look ahead always also look good to look back. So, let me take you on a few minutes journey to back in time.

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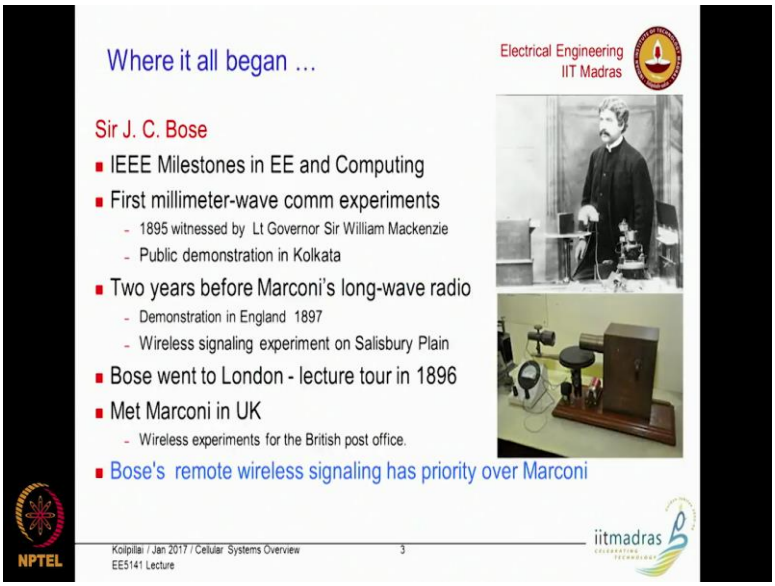

Lot of times when the question of who invented wireless comes about the answers seems to be it is Marconi. But if you go and look at IEEEs history site the credit has now been officially changed from Marconi to J.C Bose, because the experiment of Marconi was in 1897, several years before the transatlantic experiment but just the wireless demonstration, but almost two years prior J.C Bose had already demonstrated wireless in the city of Kolkata. And in fact, apparently J.C Bose and Marconi met in an inland in UK, but by that time J.C Bose had was on to other things he did not pursue wireless, but

Marconi did and that is that the rest of it was history but the first demonstration the credit goes to a Marconi.

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Today cellular is a common mans technology. So, if you were to ask for images that describe cellular probably you think of a towers in your neighborhood or you think of the sim cards or you know the Google maps or you know just people looking for information and a whole variety of handsets, today it has become very much a common man's technology.

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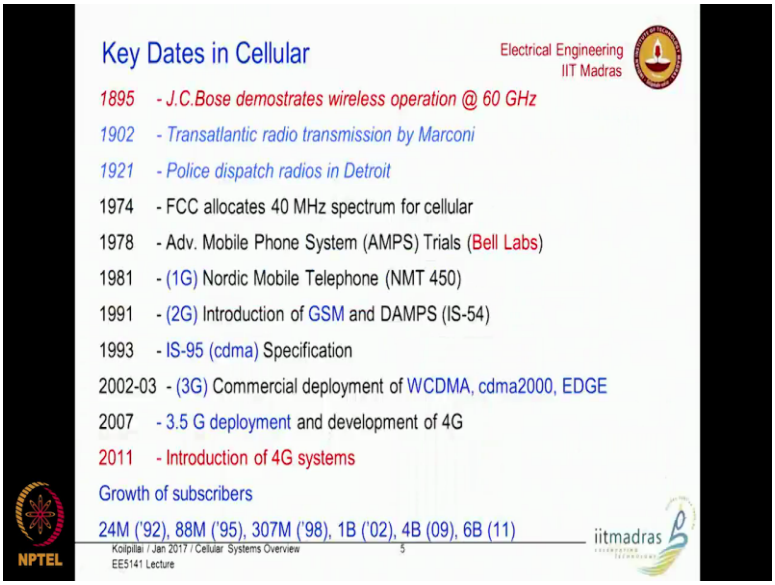

But when did it actually start and just a historical perspective a 1895 was J.C Bose first experiment, transatlantic experiment transmission by Marconi was 1902 the first users of a wireless communication where police and the arm forces during the world war with both world wars, but by and large the commercial use of cellular did not start much much until much much later.

The first analog systems what we referred to as the precursor to cellular as we know it today they what would be called as the 1G system that came into existence in 1981. Not very long ago in the context of the development of technology because wireless actually higher had happened in almost at the turn of the century; the original credit for inventing or the concept of cellular goes to Bell Lab laboratories, the famous laboratories of the AT and T company.

The first time digital cellular was introduced was 1991 and after that we saw the evolution of digital cellular the CDMA systems came in 2002 is 3G, now you may say well you know I thought 3G was not deployed until a few years ago in India, this is global perspective you know in India it happens to be one element of it we will look at India perspective, but this is what happened globally and why we had not yet even deployed 3G the world already went on to introduce 4G and now we have India's deploying 4G very aggressively, we are also participating in the 5G discussions. The last line tells you how steep the market of cellular systems have grown anyone who is interested in business always likes to ask you know what is the size of the market because that tells you what is your potential for revenues and what how attractive the market is. Even we back in 2011, we the total global market for cellular had already crossed 6 billion; so it is a huge market by any measure.

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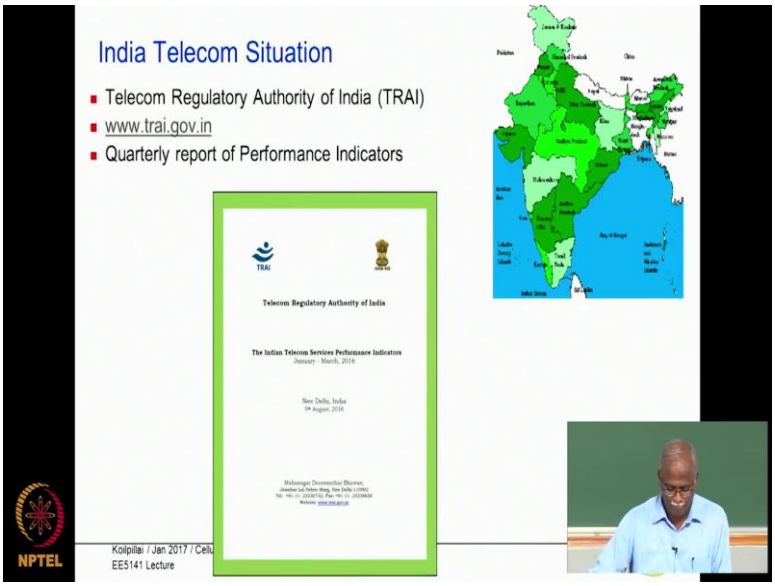

One very reliable source of a information for Indian scenario is from the telecom regulatory authority of India TRAI, they publish a quarterly report a we will upload the latest quarterly report in the module website, but I have to look at the size because these documents are slightly large in terms of size, but you can download it, it has a very very good information I have extracted the most important and relevant information hopefully just set we will get a good feel for what is happening.

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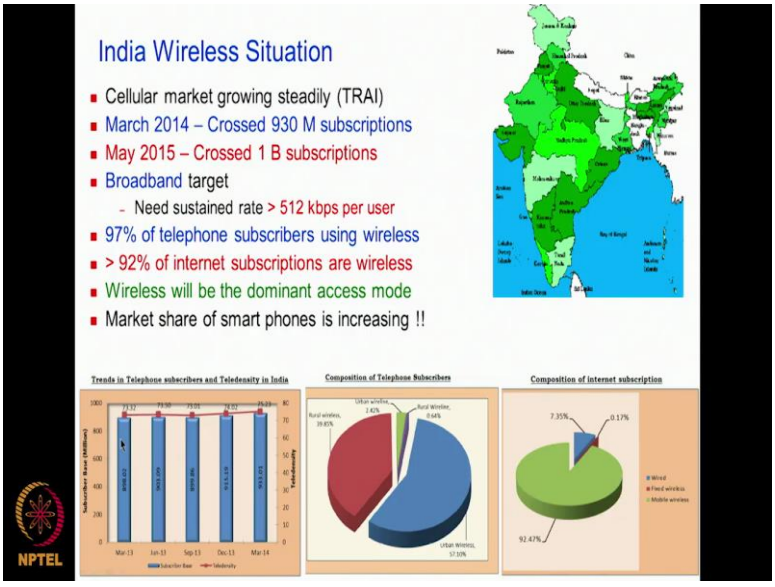

Now be the growth of a cellular in India, you may you may see well you know does not look like India is growing very very fast, but look at the numbers we had crossed 1930 million, and that was in 2014, May 2015 India cross one billion subscriptions, and what is what is interesting is the fact that the amount of wireless that is present in the country. The entire blue segment and the burgundy segment represent together represent wireless and the small slice is the wire line and it is actually decreasing our wire line deployments are actually going down while the cellular is going up. Another very interesting data which is good to keep in mind is that today when we talk about broadband and what people how people are accessing broadband in India, 93 percent of users are accessing broadband over wireless devices.

So, again here is a very very interesting or very compelling story why we as Indians should be very very interested in wireless, not only is it a big market globally that more or less defines how we use the technology as well as you know how broadband will be used in the future, so interesting perspective.

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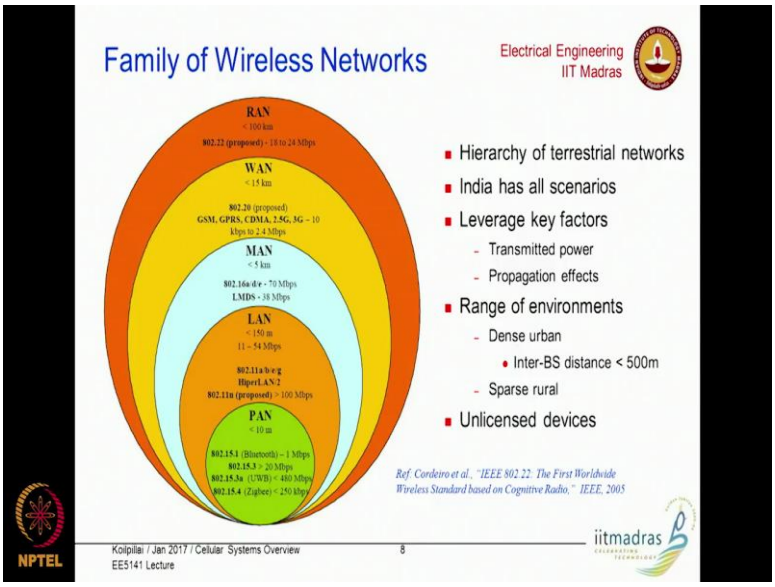

Now, just to get a feel for where cellular fiction in the big picture of wireless, wireless is not equal to cellular wireless is much bigger than cellular, but cellular happens to be the dominant technology that is there. So, if you look at the range or a hierarchy of a wireless systems starting all the way from Bluetooth, I am sure if everyone is familiar

with Bluetooth and Zigbee those are what you would refer to as postal networks, typically that could go in the range of 10 meters of the order of 10 meters.

The next in the hierarchy is local area networks of course, all our wireless technology. So, it is wireless personal area networks wireless local area networks, a technology such as Wi-Fi. So, that is the next hierarchy in terms of the distance then where the cellular come in, cellular says it is much more than a personal area or a local area it is something that can cover large geographical areas wide area network that is our cellular technology hierarchy. Now there is one which is bigger than cellular that is the regional area networks typically those are what you would refer to in the context of satellite, they cover continental coverage that is not our main focus and there are also some which are smaller than a city wide deployment called metropolitan area network. So, a little bit less limited in terms of their scope not as wide as cellular those are called metropolitan area. So, the three technologies that would be very important or interesting for us personal area, local area, wide area and cellular is in that range.

One very interesting fact about cellular in India is that the base stations are you know the infrastructure with which you connect. We started off putting them 4 to 5 kilometers apart, then they move to 3 kilometers, 2 kilometers, 1 kilometer. Now inter base station distance in urban areas is as less as less than 500 meters. So, every 500 meters on average you expect to see some sort of cellular infrastructure, and that then the driver for this has been the capacity. The only way we can increase capacity is by increasing the number of tower or cell sites and we will talk about that and a little bit a more, but it has it comes at a price and the price in invariably is the amount of interference you are generating. So, from a design perspective capacity is good interference is bad, but this unfortunately the only way we have to find a good balance between that.

Another interesting thing that you want to at least make a note of is that cellular is a license technology, you have you cannot transmit in the cellular bands without a official license whereas, the technology such as Bluetooth and Wireless LAN those are unlicensed technologies. So, again there is a difference between the two something to just keep in mind we are talking about license technologies for which an operator has to bid for and pay license fee before they begin operating.

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Many of you probably the first phone you owned was a smart phone. So, may not have seen what the phones where that preceded this, will spend just a couple of minutes just to tell you a little bit about what phones look like.

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And. So, that you can the phone on the left 1920 is a rotary phone and that actually lived for more than 60 years, even up to 1980 we had rotary phones. So, it is though that was the landline phone.

The first sort of wireless phones were the ones that were used by the military you can see old military phone up there you know they had to you know wind it up to generate enough charge. So, they could communicate, but it was a very rugged one very interesting. Motorola was the first company that made these devices and it used to be a company called Victrola, but because they made the devices that were mobile they said it is no longer Victrola we make it motorola because they are moving devices. So, again they are been a pioneer and over the years they have been the once one of the companies that have pushed the envelope of technology. So, the first handheld phone was almost a foot in height 1973 again came from Motorola, as you can see was being held here, but of course, this was a very power hungry device you know may last only a few minutes less than an hour in terms of the battery life.

So, you really needed to keep charging it and this was out the entry point. So, people actually wondered whether this will lever become a commercial technology, where it will become a mass market and there were predictions saying no really that is not it is not going to be a mass market you know nobody is going to be carrying around a big device like this what it is going to be, it is going to be a status symbol is going to be an elite symbol where the very rich will have phones like this in their car, that was the projection you know that you know if you had a phone in your car then you know you belong to a certain social status, never looked at you know that it would be a common mans technology. So, this was what it looked like the battery pack you know huge bag a battery pack and the device, and this would be installed the battery pack would be in the in the trunk of the car and then you would have the phone near the driver seat so that was how it started.

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So, occasionally if you are if you did not want your phone to be stolen I guess you had to carry the battery pack with you or if you wanted to communicate for an extended period of time, but fortunately the sizes became smaller and the phones became lasting a little bit longer in terms of battery life.

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The first sort of palm size phone palm size came from again from Motorola 1989; this was a device that was so small that you know when you held it to the year the microphone did not reach him out because it was so small. So, Motorola came up with a

very clever technology they called it the flip technology, the flip opened out and then the microphone was located here.

So, that is the only way they could make the distance between the year and the mouthpiece. So, again very interesting piece of history and this also served a very good purpose because once you closed it you could not accidentally press the keys, it sort of became in built keypad lock protection. Then came a series of what would by the way this one had a one line display, just only digits it could display the big jump came when they could get a three line display dock metrics display you know a few characters you could see the number of bars to get the cell, cell strength and your battery life, but that was the displace that we had in 1992.

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Then Motorola came up with another variation called star stack, in which case now previously the mouthpiece was opening out in this case the earpiece was opening out again very interesting designs.

But probably the most widely sold phone in the early generations was a Nokia phone, 1998 to 2000, they came up with this phone and then this was around the time that people started saying you know cell phones cause cancer right that I do not know it became a big concern, because you know it was starting to enter mass market and Nokia did a brilliant strategy they put the antenna inside, it was a built in antenna and I have heard some sales people say well that does not have an antenna. So, do not worry about

cancer everything it was very much there, but you know the antenna outside is actually a better design, because it gives you better link margin we will talk about it, but today it is by design put inside the phone, so that it sort of adds to the aesthetics to not have something sticking out.

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The first qwerty keypad came out in 2002 and of course, the minute the iPhone came around you know the whole smart phone phenomenon started 2007 and so this is on the right hand side you see the Ericsson family started out with the big phone went all the way is small and I guess now we are back into somewhere in the medium sized. So, that is been a very interesting evolution what happened in terms of the cellular handsets.

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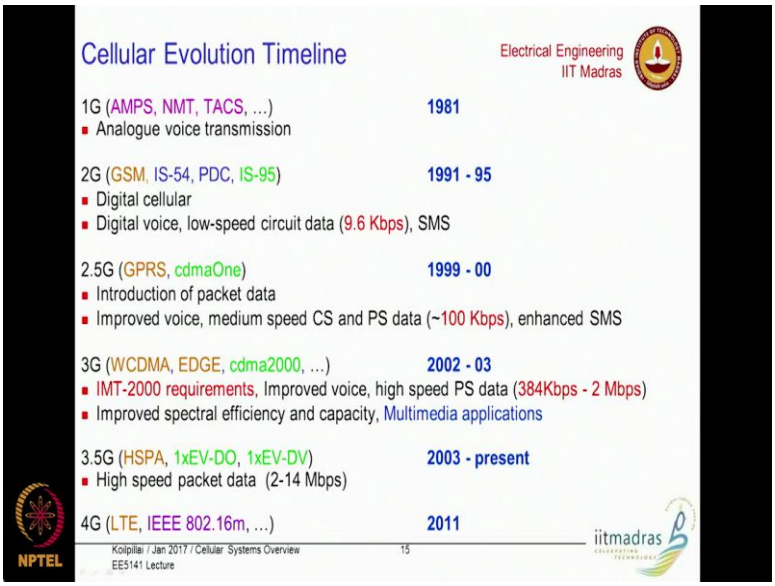

But we are a technology course again cell phones are one aspect, but what was the functionality that each of these devices gave. First generation was all about voice, voice was carried as an analog waveform basically f m type of transmission and therefore, the focus was on providing voice.

The minute digital came along the voice was no longer a waveform coding it was a vocoder, basically representation of speech using a speech coder which means that now you are doing the digital representation of voice. So, that is what we refer to as digital voice or in other words digitally compressed voice. And circuits which data at 9.6 kilobits per second there was a discussion you know should we have SMS or not because nobody could figure out what a SMS would be used for. So, eventually they decided let us keep it in there because somebody someday may find a way to use that. So, that is how SMS came in, but of course, today is a different story SMS is a key driver circuits which voice was replaced with packet switch voice in the 2.5G area many of you are familiar with the GPRS general packet radio service, that was the first time packet radio packet switch data was introduced. The data rates we were looking at 9.6 kilobits per second for circuit switched increased a little bit to 14.4, but packets which we could use could support higher data rates.

Third generation there was always an understanding that the growth is now going to be in packet switched. So, the data rates were packet switched went from 384 to two

megabits per second or the entire range was there voice was significantly improved, and then we started to see more and more data applications all of them using the packet switched data. 3.5G took the speeds up to 14 megabits per second; 4 g have taken it even higher, now in 5G we are talking about 100 megabits per second. So, now, the question that is often asked is well what application do you have that runs at 100 megabits per second or that requires 100 megabits per second. The answer is very simple remember wireless is a shared device shared medium. So, 100 megabits per second over the air does not mean that your device alone is getting the 100 megabits per second; there are several people who are contending for the 100 megabits per second.

So, what eventually gets down to you depends on the number of users and therefore, the individual data rates are still modest they not it is not a dedicated rate and that is why the push has always been let us see if we can push the data rates a little bit higher.

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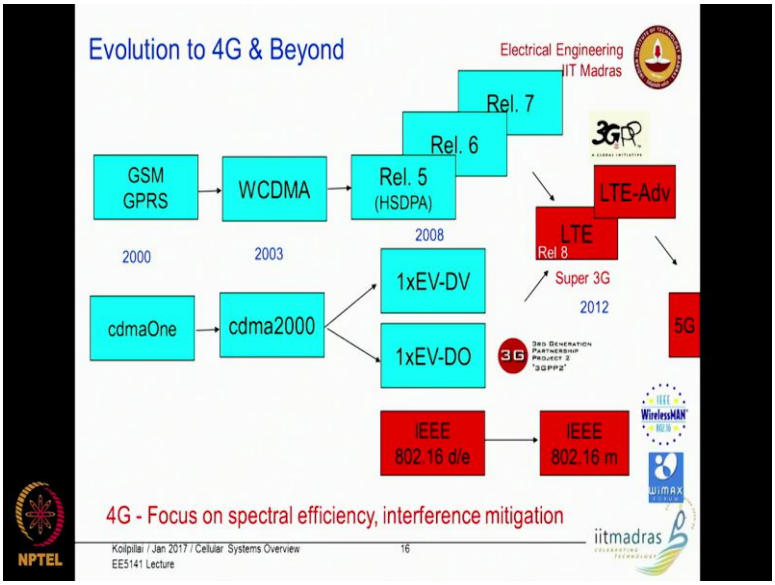

A very good way for you to sort of keep the cellular revolution in mind again maybe it is a good idea to when you get a chance create a acronyms sheet which you know all these different acronyms I just mentioned them, the second generation was GSM global system for mobile communications, GPRS general packet radio service that moved into a technology called wideband CDMA that was the third generation, then we started to see the 3.5 generation and then the fourth generation was a system called LTE, again the names may not be very logical it is called long term evolution. And a very interesting

phenomenon to observe GSM and CDMA were actually competing technologies, some of you may know that the operators also were competitors. Each of them was evolving on a path of their own, but when it came to the fourth generation they merged into a single system which is a long term evolution.

So, long term evolution went to 4.5G which is called long term evolution advanced or LTE advanced, and then let now talking about 5G which will be in the future the year is predicted as 20-20 as the target dates. So, the main aspects that we have been looking at in the evolution as you saw was the increase in the number of increase in the packet data speeds. As you are increasing the packet data speeds the number of users around the world increased several fold basically growing exponentially. So, how do you support increasing number of users each user asking for more and more data rate and your back your spectrum available is still very limited. So, the challenge has always been how do you support more users, higher data rates within the given bandwidth that is what we refer to as spectral efficiency and we will study this is going to be a very key element of our course as well.

A couple of conceptual pictures to keep in mind what is the trend of cellular versus other technologies.

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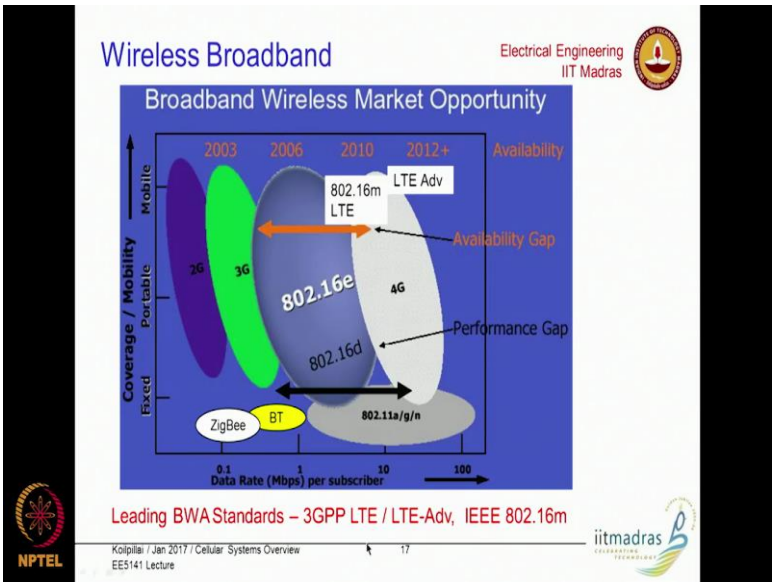

So, if you remember we talked about personal area networks; personal area networks like Zigbee and Bluetooth, how do you characterize them with respect to cellular one way to

characterize is on a chart which shows the data rate on the x axis, data rate in megabits per second if you can see the x axis it is data rate in megabits per second, on the y axis it is coverage or mobility how much can a user move and still be connected to the same system

So, Zigbee and Bluetooth are fundamentally systems that do not provide handoffs or mobility. So, more or less you are within a room or within a building, but the data rates can go for in the case of Bluetooth up to one megabit per second, and a little bit higher in the newer evolutions of a Bluetooth. Now compared to that GSM or a CDMA would give you coverage across the nation basically you can have nationwide footprint. So, you could have full mobility low speed all the way to high speed on a fast moving car or train. So, you could have mobility and the global national coverage, but the data rates would be very modest 9.6 kilobits per second would be the data rate. So, you can see that it will be very strong on the y dimension, not so strong on the x dimension. So, the cellular technologies basically said we need to fix this as the system evolves because people are going to ask for higher and higher data rates, but we do not want to lose the advantage that we have in the cellular system, that you have mobility and wide area coverage.

So, 2G to 3G to 4G you can see basically the curve is shifting to the right without compromising on mobility or coverage, but all the while increasing in terms of data rate. On the other hand wireless land technologies 802.11 will always assume to be one step ahead of cellular by the time cellular came to one megabit per second they were at 50 megabits per second. So, basically the wireless land technologies are stronger on the y axis, but again limited in terms of their mobility or overall coverage it will still be inside of building. So, interesting dynamics between how cellular systems are evolving, how the other wireless personal area networks and local, network's technologies are evolving. Good to anchor whatever we say in the context of what we already know. So, I think it is a good for us to now say, what are the components of a digital communication system.

So, this is review. So, hopefully all these pieces are going to refer to are things that you have already studied in one of the earlier courses.

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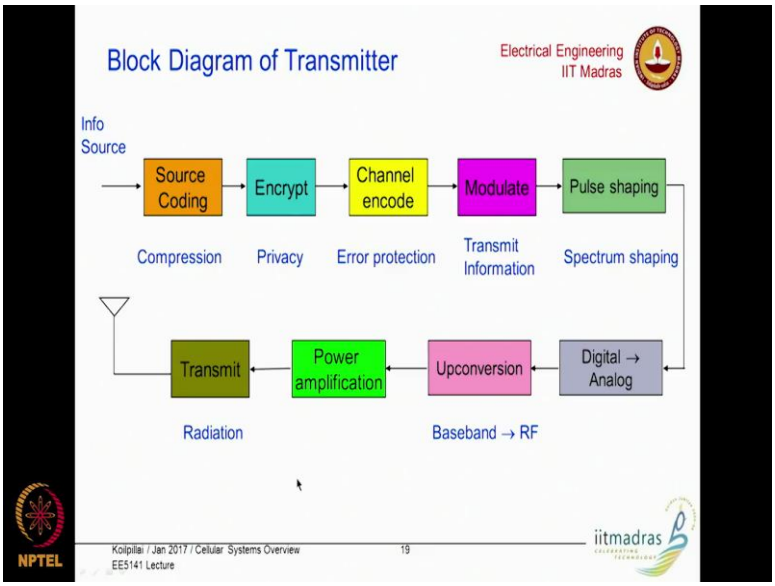

So, if I were to ask you to draw the block diagram of a transmitter, I am sure you would get most of it, but let me just sort of walk you through the flow you have an information source which you would up to which you would apply source coding or compression basically it trance if it could be an analog source like speech, you digitize it you compress it that is your first step. Second step would be privacy encrypt the information, then you are going to send it over a channel you want to do error protection we are doing carrier modulation so therefore, you have to put the information onto a carrier that would be the modulation aspect.

Why pulse shaping, what is pulse shaping? Pulse shaping you are introduced you are using to introduce ISI well I could use a rectangular pulse or without I do not do any pulse shaping that would still be just make it bandwidth efficient. So, the pulse shaping is our transmit filtering to make sure that our transmitted spectrum is as compact as possible. So, depending on how you implement your transmitter even the pulse shaping is probably done in a DSP, then after that you convert it into an analog waveform then you convert it up convert it into RF to the power amplification and then you connect it to an antenna for radiation. So, this would be the digital communications a block diagram.

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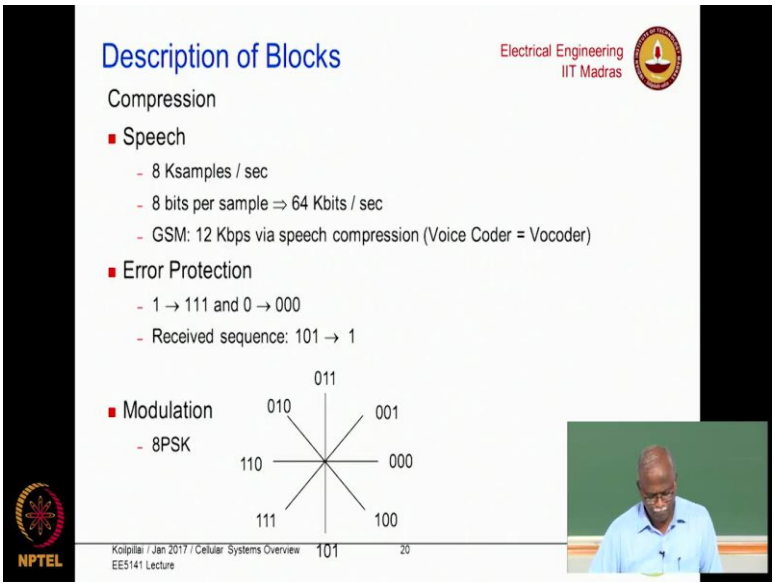

So, some representative numbers if you are talking about speech sampled at 8 kilo samples per second, 8 bits per sample you would have 64 kilobits per second that would be the transmission rate or your information rate.

The first step of doing the compression in the case of GSM reduces it from 64 kilobits per second to12 kilobits per second, and that is the voice coder or the vocoder that we use to transmit information. Error protection very sophisticated error protection codes are available, some error protection codes most recent ones turbo codes l d p c codes yeah several of them, but the earliest one that we know off or the easiest one to understand is repetition codes never used, but used for the illustration purposes. Basically you repeat information or protect your information so that at the receiver you can always recover the original information.

Modulation several forms of modulation most of the techniques that are used in wireless are input or modulation techniques that use both amplitude and phase, I have shown you an 8 PSK constellation 16QAM is another constellation, but you will find that a lot of wireless systems actually work with QPSK, and by the end of the course I hope you will give me an answer why not 64 QAM or 256 QAM.

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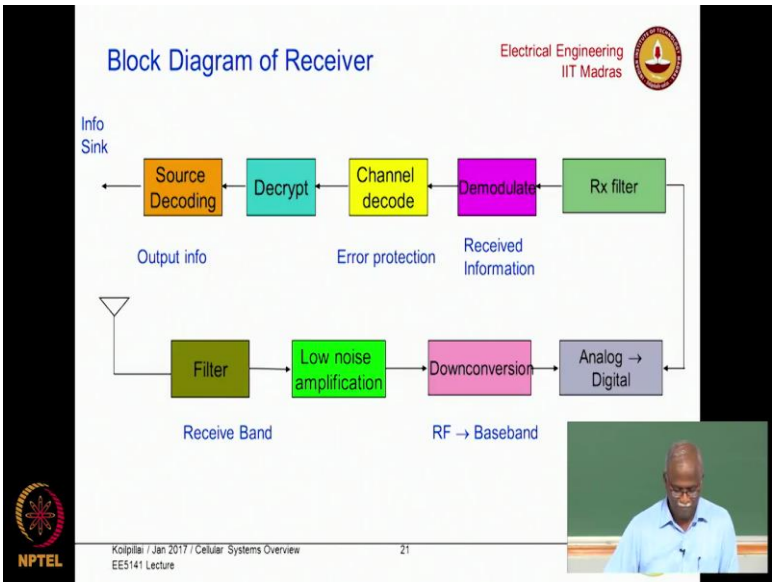

Now, the block diagram on the receiver by the way notice the flow of the arrows going from the information source all the way to the antenna. Receiver is basically going in the backward direction you take the signal you filter out that is your receive filter throughout all the unwanted information take only the signal of interest, amplify it or call it a low noise amplifier again a good question is why is should it be low noise. But I am sure you know the answer to that, convert it back from RF to baseband either in one step or in multiple steps heterodyne or homodyne receivers, converted into digital pass it through a matched filter match filter.

So, if you used a square root trace cosine at the transmitter a match filter will give you the best SNR and then you would do the demodulation, demodulate extract a information remove the channel coding get only the information that you are interested in undo the encryption and then do the re encode the information so that you can then play it back.

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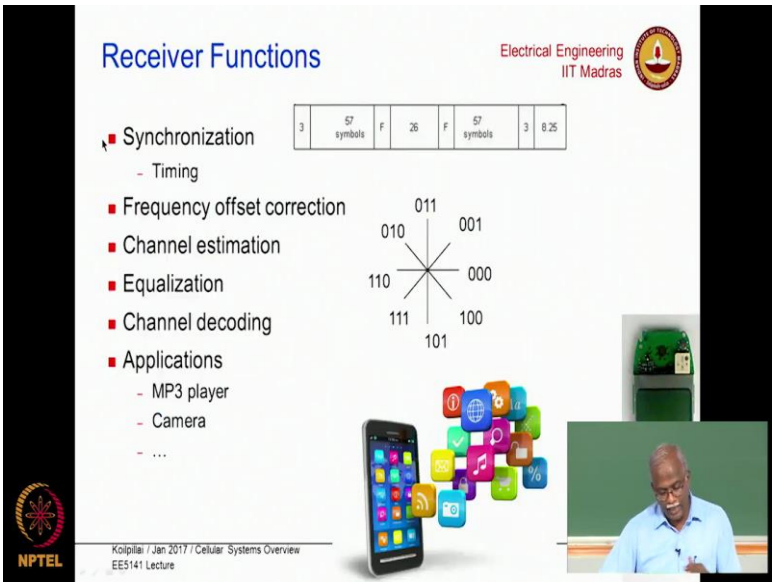

So, some of the techno some of the techniques that a receiver would need to do is synchronization both frequency and time synchronization, if you are a coherent receiver you would have to do channel estimation, if you have ISI in your channel you would have to do equalization and then of course, you have channel decoding, but at the end of the day you probably do not care what is happening inside you are interested in either the MP3 player or the camera whether the application is probably what is more interesting from an end user perspective, but from a communications engineer perspective our focus is on the transmitter and receiver.

So, now where is our course, all this is already studied where is our course. So, here it is the full transmit chain pick it up at the transmitter already radiated signal, at the other end the receiver it picks up the radiated information the receiver.

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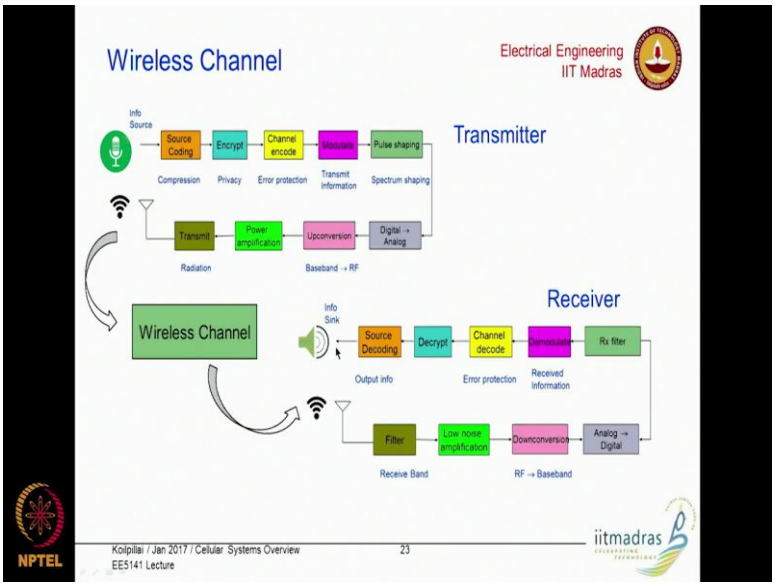

So, let us say it was an audio source you spoke into the microphone here then the speaker is playing what is sitting in between is the wireless channel that is the focus of this course and you may say well you know what can be. So, difficult in at the end of the day I transmit I receive what are some of the challenges there, but that is the crux of this of the course and that is what I would like to share with you in the next few slides what makes the wireless channel so different, what makes it so difficult to work with, why is it that we have to spend the whole course studying about the wireless channel alone, and still maybe not able to cover a lot of the things that we need to look at.

So, interesting our focus has go is going to be more or less around the wireless channel. Use everything that you have studied in digital communications, but apply it in the context of wireless adapted to the context of wireless. Wireless channel: so in the next few slides I hope to convince you that the wireless channel is sufficiently different and sufficiently challenging as well.

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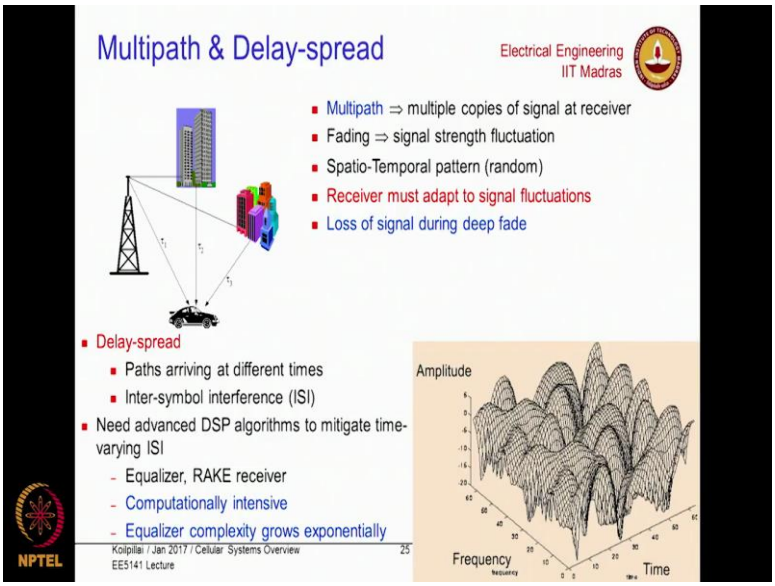

So, let us see if we can take a look at that. So, the first and foremost element that I want you to keep in mind is that the frequency the range of transmission that we are talking about wireless transmission particularly in cellular system is between 1 and 2 gigahertz one and two gigahertz. So, in that frequency range many objects which are very smooth like the surfaces of buildings can act as reflectors of the signal. So, which means that if I transmit a RF signal at 1 gigahertz or 1.5 gigahertz, what ends up at the receiver is not a single copy of the signal, but it could be an unknown number of reflected signals.

Now, this is what we refer to as multipath propagation, multipath propagation is one of the fundamental differences between other types of channels and the channels that we are talking about. Now when as you know that the phase of the received signal of the electromagnetic signal can be represented in terms of amplitude and an angle basically it is a phase a representation. So, each of these copies of the signal is coming with a different phaser weighting factor, when I add randomly phasers they may add constructively or they may add destructively. So, I have no control over when these phases are random.

So, when you study these sort of dense scattering environments this is what we observe that the signal is not always constant, if at one point it is signal with good amplitude I move by lambda by 2 lam half a wavelength, and then the signal becomes all of a sudden the signal amplitude becomes very poor, then I again I move by lambda by 2 in any

direction it becomes higher. Now lambda by 2 is not much because take a 1 1 gigahertz 900 gigahertz easy to can I 900 megahertz is easy to cancel calculate wavelength of 900 mega hertz c by f right. So, it is one-third of a meter one-third of a meter is approximately 30 centimeters, 30 35 centimeters, half of that is 15 centimeters. So, you do not have to move much for the signal to change.

Now, most people probably knew this without having to go through this explanation if you if you do not get good signal on your phone what do you do, you move your head what did you do you moved by lambda by 2 and you got a better channel. So, that is as simple as how the channel changes. So, now, I do not know this point where I am sitting may be extremely good, but where the first choice it could be a very poor signal. Now this is what we have to deal with that there is a spatio temporal pattern which is not known to the receiver, my receiver does not know it is in a good channel his receiver does not know it is in a bad channel basically it has to adapt.

Now, this is a very very important element because if you happen to be in a location that where the signal is bad, you must move in order to get a better signal otherwise you will not be able to communicate. So, there is a issue of loss of signal if you do not do something to remedy it. So, there is a challenge that we have to work with.

Now, there is no guarantee that all the copies of the signal came at the same time, they could come with delays in between them. So, then what happens if you have copies of the signal which are delayed in time that is called inter symbol interference you get into symbol, but now notice it is not fixed inter symbol interference it is time varying inter symbol interference, because the first path could become strong or weak the second path could become strong or weak the gap between them could change because if the car was moving you do not get reflection from this building, but now you get the reflection from another building.

So, it is time varying inter symbol interference which is very very difficult because this is this is something that we have to work with. So, as you know when I have inter symbol interference I have to design an equalizer, if it is a spread spectrum signal I use a technique called a rake receiver, but the rule of thumb is computation complexity is going to increase, on added to that it is a channel which is constantly changing so therefore, be ready for a very complex receiver this is one aspect of it.

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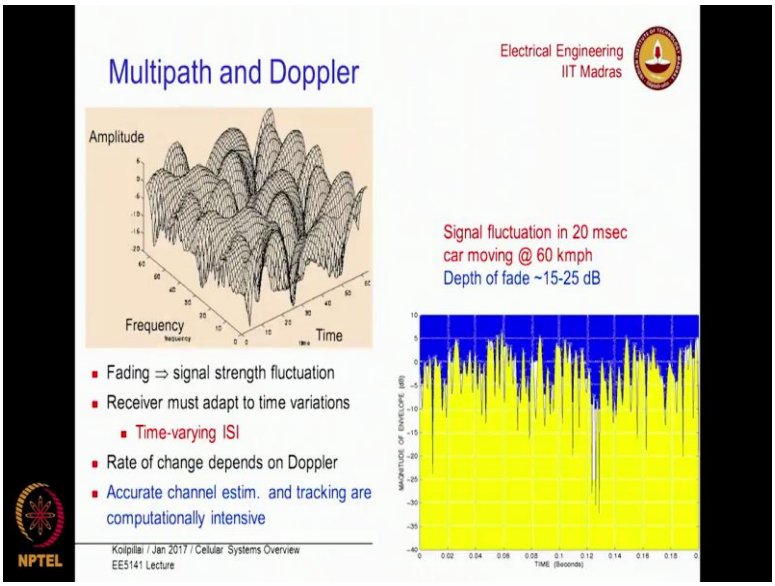

Now, the second element of it is when I start moving; now here is the element where multipath and Doppler start to interact. Now notice that this is the spatio temporal pattern now I am a user who is starting at this location I am going to walk across the room. So, which means lambda by 2 every time I cross lambda by 2 my signal is going to go up down up down up down. So, give you to give you just a flavor for how much the signal can fluctuate, take a handset that is in a car that is moving at 60 kilometers per hour in the duration of it should be 200 milliseconds; in the duration of 200 milliseconds this is the amount of fluctuation that you can see.

Several of them which have fluctuations of at least 25 d B or more. So, just so that keep that number in mind we will come back to addressing why this is a problem. So, if you are a user going across at 60 kilo meter per hour, your receiver receiving up down up down very very rapid fluctuations it could be having ISI and you have to build. So, you have to have a receiver first of all that must adapt to signal fluctuation it must adapt to ISI that is constantly changing and this very fast changing of the channel. So, basically the wireless channel is a channel that is very hostile, it is very complex to build a receiver and it is computationally complex.

But what user wants is a handset which will last for 2 days 3 days which means that you should not be drawing a whole lot of power, you cannot use a lot of signal processing or computational power on the handsets. So, how do you build a low power low complexity

receiver that will work in this type of an environment? So, that is the starting point of our understanding that there are significant challenges for us in the context of the wireless channel. Let me just indicate what are some of the other impairments that we have to do and then I will open up the floor for some questions. So, the idea of cellular systems is that we have many transmitters. So, you can think of these hexagons and the center of each hexagon as a transmitter being located.

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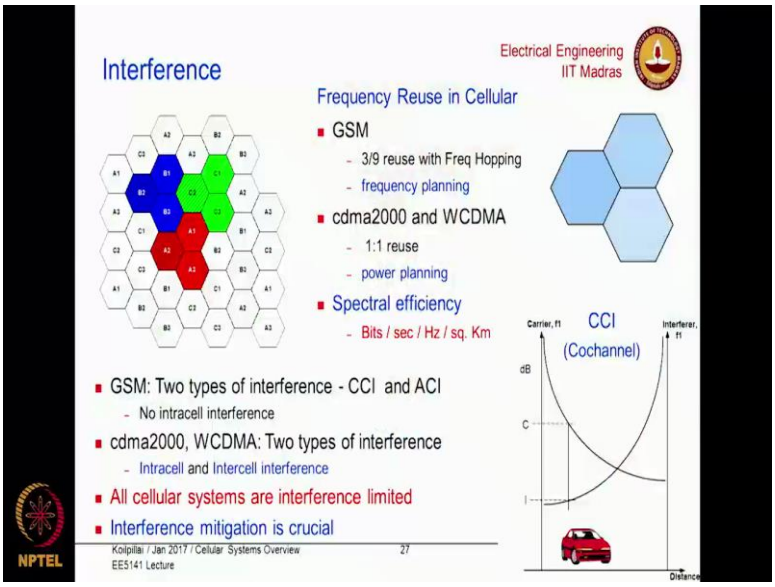

So, of course, I cannot have two adjacent sectors transmitting at the same frequencies to adjacent hexagons. So, what I do is I you let us say I use a frequency a one in this location I move some geographical distance away from it and then re use A 1. So, basically the only thing I am relying on is spatial separation to prevent these two signals from interfering with each other. So, this type of interference is called co channel interference, two users who are using the same frequency, but are separated between by geographical distance that is called co channel interference that is coming from different cells.

Now, in CDMA systems spread spectrum systems, I am sure you would have studied that all the users in there is in a particular location use the same frequency, and they have different signature sequences to separate them. So, which means that co channel interference for a CDMA system is very very high potentially, because everybody in the cell is also using the same frequency at least in the case of GSM you had geographical

separation, here there is no separation you are basically in the same cell. So, there are two types of interference one is inter cell that is coming from another cell, but using the same frequency the other one is intra cell, those people who are in your own cell who are causing interference steel. Bottom line all cellular systems are interference limited, ultimately when your call drops it is because the interference level went up to a certain beyond as beyond a acceptable point.

So, the key point that we need to understand in the context of cellular is how do you mitigate interference, whatever the multiple access method you want to use TDMA CDMA whatever it is at the end of the day it is going to come down to the question how do you mitigate interference that is going to be a very very important element. So, what we now want to do is you know what a link budget is, how much transmit power should I use to receive a signal at a certain level. I would now in the next class we will start by asking the question how is a wireless link budget different from just a link budget that you would have done for AWGN link or for a digital communications link. What would be the aspects that are different, and how is it going to impact the design of the systems that we will take up from that point.

So, this is sort of a entry point into the discussion on what cellular systems are doing, what is the wireless channel, why is it different and we start getting into the details starting in the next lecture. Let me take a few minutes to answer any questions any questions on what we had covered so far.

Student: Sir, recently I heard that Bluetooth 4.1 has came.

Yeah.

Student: But still the Bluetooth speed not up to the WLN speed.

So, the question is Bluetooth will it is it a direct competitor to two wireless LAN or not. So, the question is you know by design Bluetooth was targeting low range slightly lower rate than the wireless LAN systems that was how it was designed. Wireless LAN systems basically said we are starting at you know 50 megabits per second and are going to move higher. Now very interesting thing has happened I will just touch upon that in the third lecture, but there is a new era of wireless communication that is happening which is non cellular, that is called the internet of things basically devices that are

connected you want to have cars connected to their to the traffic system, you want to have your health monitoring devices connected to the hospital system, all of these systems are have not going to have to use wireless technologies.

So, given this scenario what did the Bluetooth people say, you know what if I can increase my data rate I will capture some of the market that is there for the internet of things, basically smart cities smart transportation all of that will require the use of wireless devices. Now wireless LAN people looked at it and said you know what why is Bluetooth very attractive because it is low power. So, what they said was you know if I bring a low power version of wireless LAN then I can compete. So, right now they were originally designed for very different, but now both are going to come and compete with the system.

So, when you say Bluetooth compared to wireless LAN you have to say which wireless LAN and it is probably a wireless LAN which is competing a Bluetooth where they both are very very comparable. So, we will touch upon it, but it is a very good topic to read because that that is happening even as we speak. The cellular and by the way cellular systems 5G 100 megabits per second, but there is a variation of 5G which says I want to go after the internet of things speeds which is low power low data rate. So, basically there is a low power low data rate mode in cellular which is called narrowband IoT, NB-IoT which is going to compete in the wireless. So, you will have Bluetooth you will have Zigbee and I will just mention it in the third lecture you will have at least ten other technologies which are competing wireless LAN and cellular, all want to be in the marketplace where we are talking about low power low data rate devices. Because that is going to be a very big challenge in the future, good question, any others?

Student: In the same channel like in these channel be a all our cell phone suppose their (Refer Time: 57:23) connected to the same (Refer Time: 57:25). So, they do like use the same frequency like (Refer Time: 57:31) are we all use the 4 G. So, there are like CDMA system. So, they are do use the same frequency in the (Refer Time: 57:34).

Ok, by the 4G actually is using a OFDM technology, but let me answer your question yeah. So, one of the most important elements in a cellular system, so that user a, user b two people who are in the same geographical location, do not interfere with each other is that they must be orthogonal in some dimension orthogonal in time means that you

transmit one time he transmits other time. So, basically your orthogonal in time or orthogonal in frequency you use f 1, you use f 2 orthogonal frequency or orthogonal in code, you use code c 1, use code c 2 which are orthogonal to each other you must have orthoganality the minute you loose orthoganality you start interfering with each other. So, that is the essence of cellular system design. So, even though let us say all these people in the room are connected to the same operator, the operator will design their system to ensure that all of you are orthogonal in some dimension frequency or time or code.

Student: As know as I maintain the orthoganality of the code I can like use the same frequency for as (Refer Time: 58:39).

Orthoganality has got dimensions at some point you will run out of dimensions of orthoganality. So, it when you run out of dimensions of orthoganality we go into something called quasi orthoganality, where we can maintain something that looks like orthoganality, but it is not perfect orthoganality and then eventually you run out of quasi orthoganality also and then you start interfering. So, I think the challenge is how do you extend the capacity using notions of orthoganality and quasi orthoganality, others will see you tomorrow at 11 o'clock.

Thank you.