Introduction to Wireless and Cellular Communication
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Lecture – 03
Overview of Cellular Evolution and Wireless Technologies
Overview of Cellular System - Part 3

We begin lecture three quick summary of the key points that we had discussed in the last lecture, we had talked about the aspects of multiple, the different forms of multiple access; time division multiple access, frequency division multiple access, code division, and orthogonal frequency division.

I would like to encourage you to think about not narrow band systems, but think about a broadband system which tries to achieve of the order of 10 megabits per second using a bandwidth of 10 megahertz, how would you handle the different types of users FDMA or CDMA or TDMA and what would be the tradeoffs that is something that will help us understand what are some of the advantages and disadvantages, and then get a perspective. Again the purpose of the first 3 4 lectures is to give you a bird's-eye view of all the different elements of the wireless systems, and then zero in on specific aspects of the wireless channel itself.

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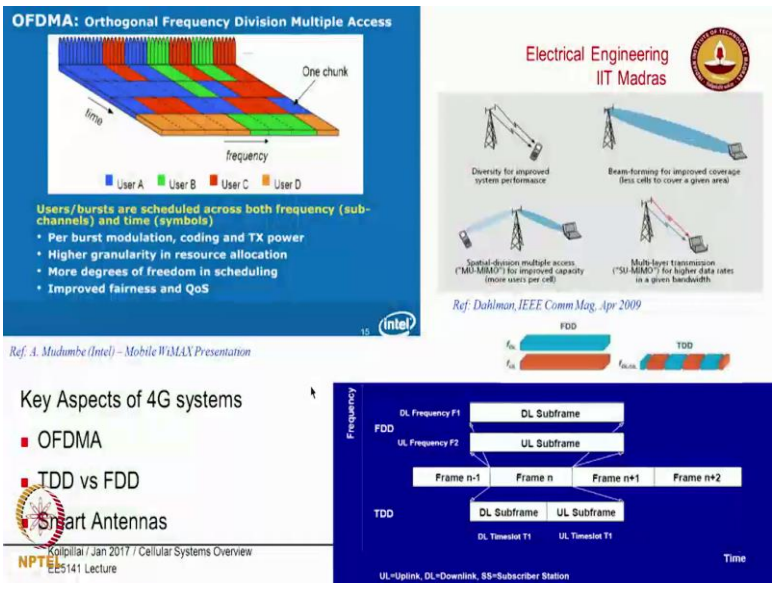

So, let us begin a quick element about the fourth generation systems, they are using orthogonal frequency division multiple access. As the multiple access mechanism we talked about yesterday the use of smart antennas and the possibility of using frequency division duplex or time division duplex those a couple of question were a couple of questions on what is TDD is one better than the other, they are there are the answer is TDD is an option when you do not have much spectrum. You can support both links both bi directional links on a single career, you share the career between the transmission from the base station to the mobile and then you switch to the other direction. So, basically frequency limited environments TDD is an option, but FDD is probably easier and more widely deployed around the world.

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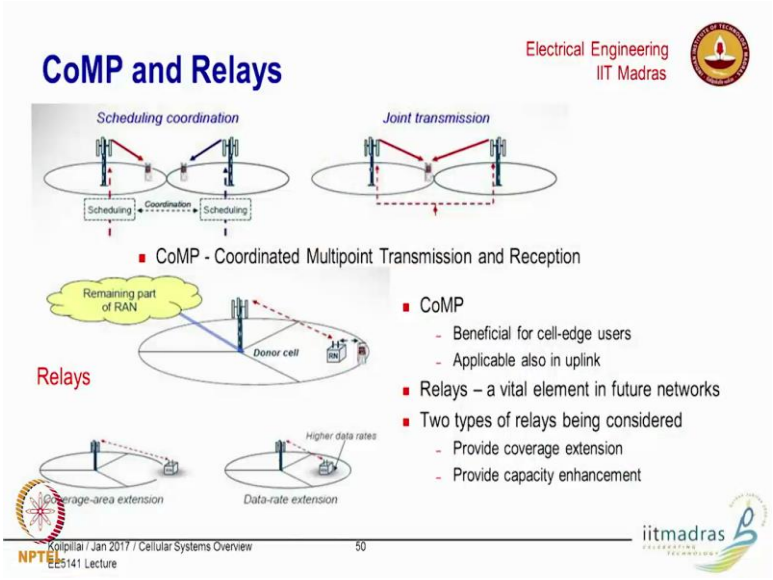

Some more elements of the fourth generation systems very important and just make a note of it because these are things that you will probably if you reading current literature you will find that these are referred to. One is called coordinated multipoint transmission CoMP. C o stands for coordinated, M P multipoint transmission and what it means is that we now have large number of small cells, and very likely there are users who are at the edge of the cell. So, you can see on the arrows that is pointing to is on the edge of the cell with the red arrow, the other one is the on the edge of the self or the neighboring one. Now both of these if the base station transmitter at the same time, your red base stations is transmitting to this mobile, but it will interfere with the other and vice versa. So, both mobiles at the boundary are likely to get affected in terms of their ability to

receive the signal; however, if the two base stations were able to talk to each other and say now you transmit to your mobile at the boundary then once you finish then I will transmit that basically coordination of transmission.

Now, how is that possible because today base stations many of them are on an optical fiber network and therefore, communications between base stations is very quick and we can easily do it well in time, so that the transmission to the mobiles can be done without any latency. So, this is a very powerful technique which reduces interference without reducing your capacity. So, basically you find out which are the mobiles that are at edge of the cell and then you do the transmission. Now you can do something even better, we know the using multiple antennas more antennas is beneficial for any form of wireless transmission. So, the two base stations can coordinate and transmit the same information to the mobile.

Because anyway when this one is transmitting the other one is not doing anything. So, therefore, they could transmit, but this will result in a reduction in capacity because a part of the time when you should be when this base station should be transmitting to its own users, it is taking part of its time to transmit to the mobiles in the other neighboring cell. So, with the reduction of capacity if possible you can get additional benefits, but in any case the important thing is the coordination between the base stations.

Now, another element which is very very prominent in the fourth generation is the notion of a relay. Now relay has got several definitions and meanings, the cellular definition of a relay; relay is a node which talks to the base station on one side and to a mobile on the other side basically it acts as a link as an agent which forwards receives and forward the information, it does not do any much processing itself it enables a connection the advantage. The mobile has to transfer to the only low power because it is transmitting to a node which is geographic very close.

The second advantage is that a relay node can typically be larger can have more antennas and therefore, we will have a better path to the base to the macro base station and therefore, there is an advantage there as well. So, two types of relays are possible one is a relay node to extend your coverage you want to extend your coverage that is basically the relay node is sitting on the boundary. So that it can extend beyond the current

boundary. The second one is to provide high data rates to some users. So, you are not going outside the boundary, but you want to give better signal to one or two mobile.

So, therefore, the relay node will provide high data rights in its vicinity, and that is a second advantage that you get. So, relay of two types the coordinated transmission of two types, and again there are several flavors of it very useful for us to know these are all part of the fourth generation systems.

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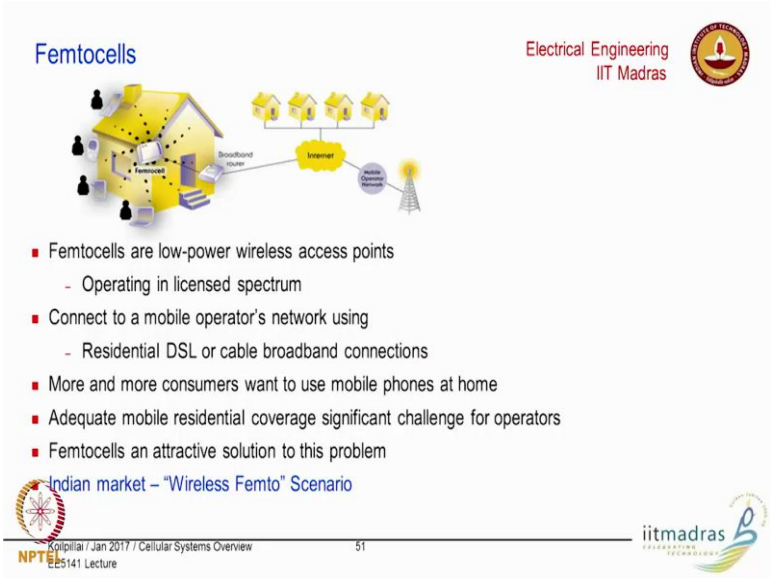

Another concept that has become very very popular in the fourth generation is the notion of a Femto cell. The Femto cell is basically a base station that you deploy inside your house for yourself. So, in other words you have to coordinated it with the operator, but this base station is sitting inside your home. So that means, all the devices connected to your home are will get very good signal; now how does the Femto cell connect to the cellular network, the assumption is that there is a broadband connection to your home. Now if you do not have broadband connection this concept does not work. So, you can see that this is a concept that came from the parts of the world where there was very good copper deployment and there was broadband to the home already available. So, this is a very attractive concept because then almost every home could have a Femto cell and the each of you each of once your inside your home you would get very high data rates.

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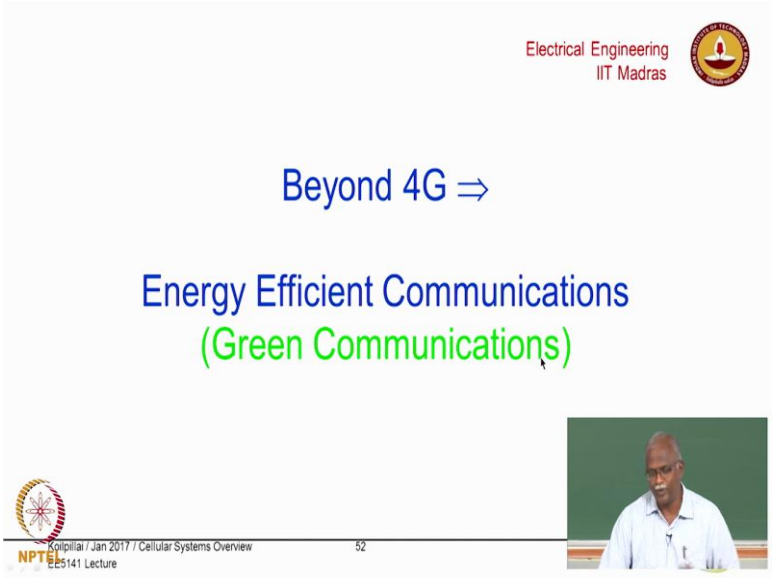

Now, what do we do for the Indian context since we do not have this we will answer that question.

Another aspect of the fourth generation is the recognition, that cellular systems are more or less the backbone of a communications of countries like India. And we also have to recognize that we do not have a very reliable power system electrical power grid system, which means that you have to have proper backup for your cellular towers. So, the way it works is the cellular tower is there you in order for the cellular tower to operate well very often they provide air conditioning. So, air conditioners are there, now if the air conditioner we should not fail, these tower should not fail. So, therefore, you have a diesel generator to backup for both of these.

So, basically the minute the grid goes down the diesel generator starts and this that is the site continue to operate like before. So, this essentially means that there is a large consumption of diesel, because anytime the power goes down the diesel generators have to turn on. And about 20 percent of the cell sites in the country do not have grid power; that means, they are running on diesel 24 hours a day. So, which also says that there is an huge amount diesel consumption after the Indian railways cell of the cell phone operators are the largest consumers of diesel. So, they basically are huge amount of diesel and they are not consuming and storing it they are actually burning it, which means that there is a concern about the emission.

So, therefore, the push in fourth generation says reduce power consumption, reduce wherever we can they call it green communications, but as a communication engineer we just asked the, we make a note that we have to reduce power wherever we can. So, here comes the aspects that we want to summarize.

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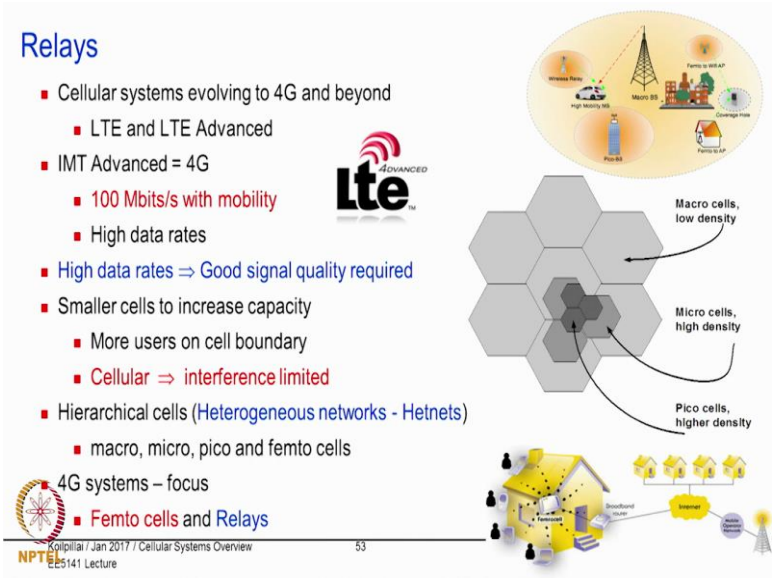

Relays are very important because especially if you want to achieve speeds like 100 megabits per second, it is good to have relay close to you, that you can get a good connectivity. Now how does the network create more capacity; the way the network creates more capacity is you initially take a deployment of cells, if you find that there are large number of users you create smaller cells within the large cells call it micro the bigger once are call the macro cells, then you create something which is smaller call micro then you if you still find that capacity more capacity is needed you create even smaller cells called micro cell Pico of cells, and then if you are still not satisfied you as a consumer would go and say I am going to create a Pico cell and I will connect to the network through my Pico cell.

So, since you have different size network or cells, heterogeneous networks macro, micro, Pico, Femto they are called heterogeneous networks different sizes and short form is hetnets, any archi literature that you see on 4G will refer to hetnets and very important to know immediately that you are talking about capacity achieving capacity using different size cells, and basically coordination is a very important element.

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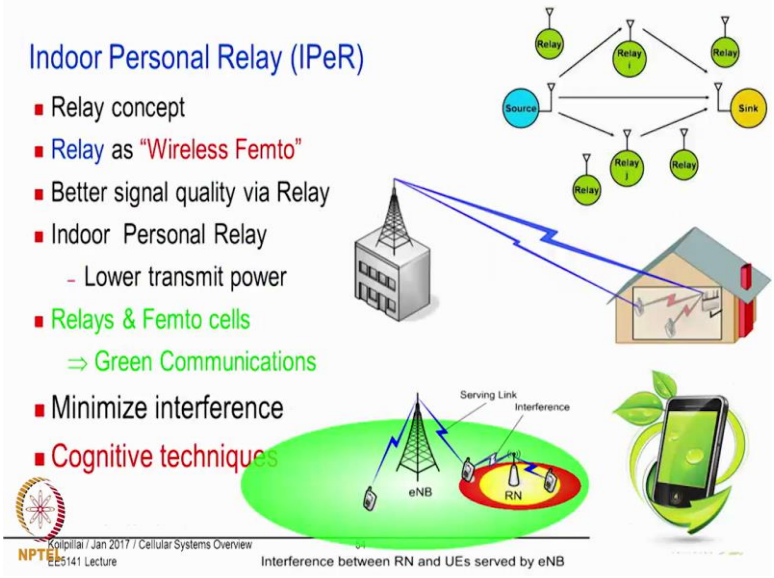

Now, how do we address this in the Indian context, we do not have broadband to the home, but I still would like the Femto concept. So, this is a concept develop at IIT madras, this is a concept with says yes I will deploy the Femto inside the home just like everybody else, but the Femto will not be connected on a wired broadband the Femto will actually talk to the base station over the wireless link like a relay. It is a Femto relay hybrid, it talks to the base station like the way relay does, but it is it is option is to only to serve the users within a network and it is deployed by the user. So, this is called a indoor personal relay, it is a Femto cell it is indoor it is wireless in transmission and it is for the use of that home again these are some methods and by which we can reduce the energy consumption and improve the coverage of the systems within the homes and that is an advantage to us.

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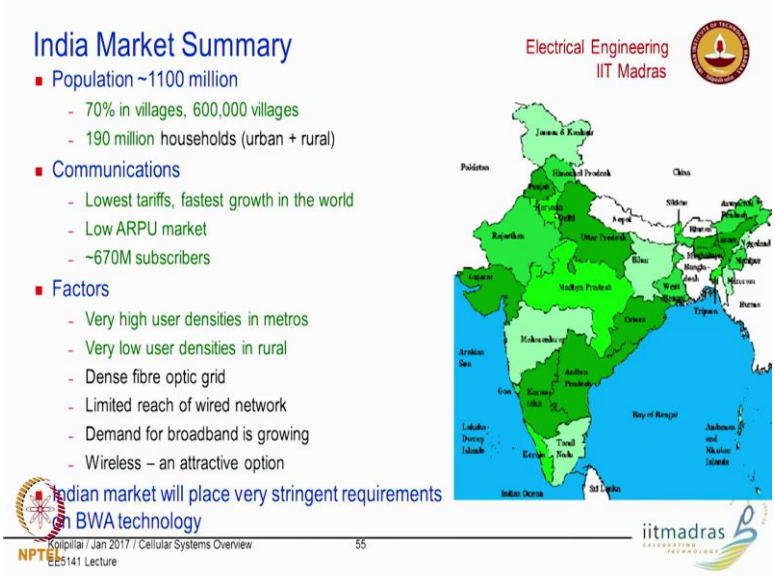

I would like to switch gears a little bit, we will talked a lot of technology may be for those interested in the business angle of it, here is a couple of slides which makes you think about the opportunity that is ahead of us. Indian market summary populations in the vicinity of 1.1 billion people about 70 percent are of the population still in villages spread across 6 lack villages in India. If you look at it in terms of household's number of houses units around 200 million you take an average of 5 house of 5 people per household. So, very large user base is there in India. The factors that affect Indian market we have very high user density is in the metros Mumbai, Delhi, Chennai. So, the densities are very very high that is why base stations have to be every 200 or 300 meters. But on the other hand on the rural side the densities a very sparse; the good thing is we will have an optical fiber grid running across the country called the Bharath net, and broadband for most people is going to be wireless broadband because there is no other form of broadband.

So, the Indian market places some unique requirements, but why would operators be interested given the fact that it is a low or poor market, average revenue per user it is not a market that will generate a lot of revenue there is a lot of competition. So, prices are low. So, why would the market why would operators be interested.

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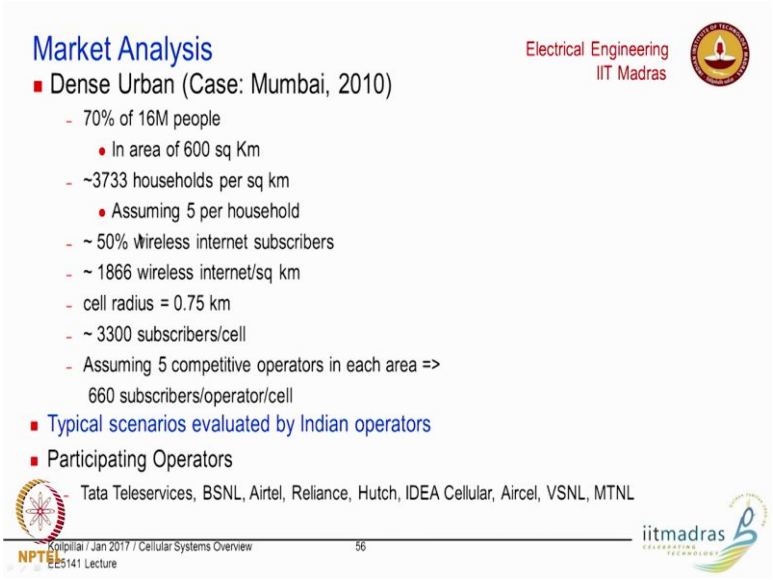

So, in 2010 IIT madras along with all the operators listed below we did a just a market analysis, and we let the study this was to focus on the city of Mumbai, it has about 16 million people and about 70 percent of the 16 million people live in the dense parts that is surround 600 square kilometers, and if you assume 5 people per household you will find that the a density of households comes out to 3733 households per square kilometer again this is simple calculations you can do that. At that time we said that may be wired broadband may come in at that time we did not see as far as 2016 or 17, we thought that may we will make a very modest assumption that of the people who are subscribing for broadband only 50 percent will be subscribing on wireless, the rest of it will have to do other forms.

So, which means that approximately half of that in these households mind you not individuals, you have to multiplied by 5 if you want to take individuals. So, from a household if you wanted to connect to broadband there about 1866 connections per square kilometer, and Mumbai we assume that approximately the cells would have become small enough that 0.5 75 kilometers would be the radius we know that it is now much less. So, we even with 0.75 kilometer cell radius there would be about 3300 subscribers per cell ok.

Now, if there are 5 operators competing equally they will have 660s of subscribers per operator per cell; and you multiply it across the number of cells which will be in the city

of Mumbai and you can start to see this is households, you have to multiply the number by 5 if people are starting to also have a broadband subscriptions on their phone. So, which means that this is a huge market posing some very unique challenges, and that is part of the ongoing discussion how does India leverage our strength as a big market. So, again the cellular market is a very very attractive market the way it is evolved; even in 2010 people said you know it is very very attractive now in 2017, it becomes you know several times more attractive.

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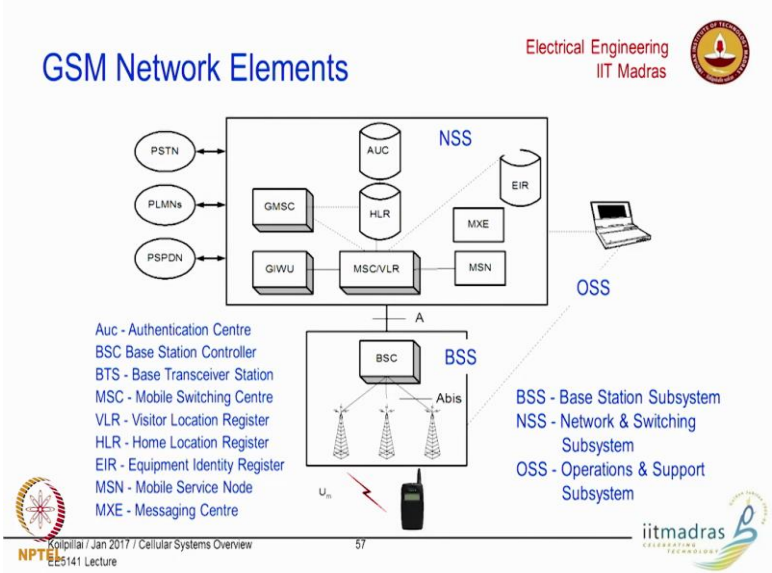

Now, I want you to take you back to understand how a call on a cell phone network is made. Again it is a conceptual discussion as long as you understand the overall flow I would be very happy. So, this is how GSM network is originally architected, and again the details are there for you in this slide, but the concept is what is important. You have the mobile the mobile talks to a tower we call that the base station, and behind the base station there is a controller based station controller. So, together they are called the base station sub system. So, that is what communicates with you over the wireless link. So, that is all the wireless there is in the entire network that everything else is wired. Behind the best station sits a switch, a switches something that will direct route your call; now supporting the switch are several entities which are needed for a wireless system or cellular system, the first the two most important things about a cellular system one is mobility the user is not in one location, but can move all over the place.

So, how do you keep track of the user? Mobility management is one of the elements that is needed in a cellular network, the second one is authentication. Now when you have a wired telephone and you pick up the phone the operator knows that it is you who is has calling, and they know who to send the bill to. So, there no doubt about verifying who is making the phone call, but that is not the case in the context of a mobile device because you may be in somebody network far away from home and you want to make a call. Now how does that network know that you are a valid user of your own home network? So, basically authentication to know whether this is a valid user what is the subscription can I go ahead and give him an STD call a privilege and all of those list. So, that is part of it and calls which you make may go to another user who is within your own network then you do not need to go outside the network the switch will route you back into the network.

Occasionally you may go to the network of another operator. So, which means that you go through a gateway call PLMN gateway, public lane mobile network gateway that will connect you to another operator mobile operator; now occasionally you will call to a landline network then there is a gateway to the PSTN public switched telephone network. So, basically there is a base station subsystem which talks to the mobile behind the base station subsystem there is an entire network of devices that are there to give you mobility to give your authentication to give you the connectivity. It is all seamless they signal very very fast between each other and what signaling happens is good for you to know because occasionally people get very impatient you know it is like oh why call taking. So, long let me explain to you, what are some of the reasons why the call is taking so long.

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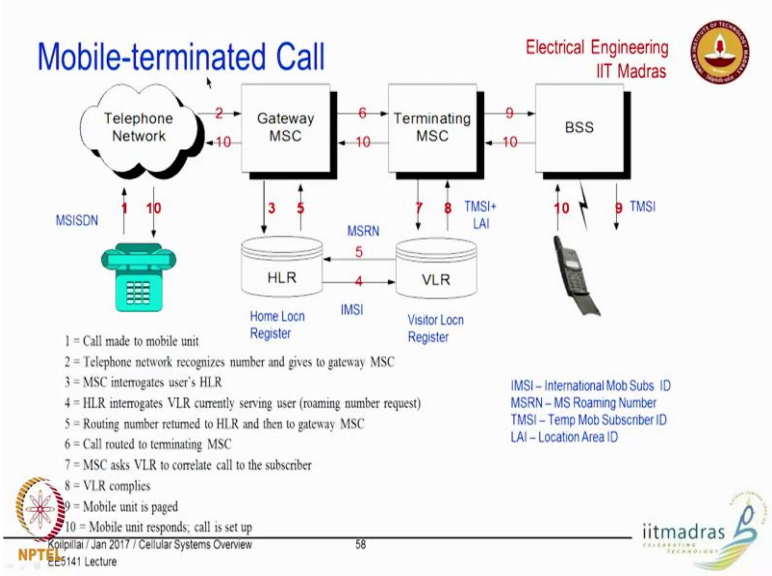

So, again concept how does a mobile terminated call happen; let us say just for example, a landline network a landline telephone wants to call a mobile that is and you can take mobile to mobile all of those are good for us. The assumption is that this is a user who is not in his home network, basically somebody who is registered in Chennai, but may be has gone to Bangalore, but the landline net subscribers does not know that does not does not dial anything differently dials the same 10 digit number. So, the first step is step one the landline subscriber dials a 10 digit number the PSTN network looks at the number that is being dialed and its recognizes this is a mobile number. So, I need to forward it to the nearest mobile gateway.

Step two the signaling goes to the mobile gateway saying there is an incoming call for this number. Now the local mobile let us say you are a Vodafone subscriber, the gateway then checks with the Vodafone home register that basically your home network let us say from your number they can figure out that you are a Chennai subscribers.

So, it comes to the Chennai database and says validate this there is an incoming call for this particular subscriber, the database checks the record and says wait a minute this user is not here in the Chennai network he is actually in the Bangalore network. So, the database then sends the information to the Bangalore database and says oh by the way is this user currently active the net. Bangalore database replies back to the Chennai database saying yes this is his current roaming number roaming number is like a

temporary number that the network has given you if you use this number he will this user will respond. So, then the Chennai database informs the gateway saying look we cannot terminate the call in Chennai you need to terminate it in Bangalore.

So, the call now through signaling goes to the Bangalore switch, the Bangalore switch once again checks with the databases I am have incoming call for this mobile with this roaming number, do you have the details. It checks his database and says yes I know where to find this user and sense him back something call a temporary mobile subscriber identity, and reason the roaming number is roaming number is not to a temporary identity is a smaller number and it is something that can be changed for privacy reasons and. So, by the way there is this is the area in which I last heard from the subscriber that is location area identity, this was the last time I connected with this. So, the switch then forwards it to the base station subsystem, which is operating in that location area and says page the subscriber.

The paging goes out to a large number of cells, whichever cell the user is in he will respond the paging stops and then the information can you see goes back to the Bangalore MSC, back to the Chennai MSC, back to the telephone network and back to connected things all of them before three beeps happen. So, all of this has happened.

Occasionally may be there is a problem with you did not register or you did not you moved away from the network or you switched off your mobile or put it in airplane mode or something for whatever reason or ran out of charge. So, at that time the network may not know. So, actually is tries to page you for some time and then comes back saying no response, but it is quite fascinating how the system has been architected, and all of it to enable mobility and authentication. Why so many handshakes between different registers is because they need to know that that you are a valid user. So, the home Regis, home database is very important, the visited database is the only one that can provide you the service and at the end of the day the base station systems and the switch all of them have to work in harmony.

So, it is actually the more you look at it is a fascinating system very very well designed, and it is actually very credible that they know they have designed a network that today you cannot tell the difference between the calling a landline user and the mobile user

really takes no difference in time because the signaling is so fast and our ability to track the users has also become very very good.

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Before we move on to some other interesting aspects of 4G, I thought I should at least show you what the old phones look like on the inside. Old phones had a display so that was the display as you can see it was one which probably had 3 or 4 lines would have a few images to show battery level and network, the keypad basically was on the body of the of the phone there was a circuitry behind it. So, when you pressed it the certain connections would get energized, and then the device would know what keys were pressed.

Now, if you remove the keypad then the insides of the phone, always good to start with antenna; antenna at one end microphone at the other. So, basically you know which end is which. So, your audio signal goes in here gets process by the DSP then gets converted to the intermediate frequency to the RF frequency and rights here you see some metal shielding that is the power amplifier know why should the power amplifier be at the top.

Student: (Refer Time: 24:00).

That is been the antenna right because that is that is the logical place, but where is your ear near the near the top. So, that is why if you talk for very long your ear gets hurt because you are very close to the power amplifier. So, where should you put the antenna

somewhere here right put it far way put it near, but people do not like something sticking out you know near their mouth. So, they said leave it when the original design. So, that is that is how it was and of course, that you have the more than more than 70 percent or 80 percent of the weight of the phone comes from the battery and rest of it is very light because the components today is actually highly integrated, this is a earlier generation phone today you probably you see just one chip which operate this plus some analog components.

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Very very quickly antennas different types of antennas this is the what is call this stub antenna, they used to be a telescopic antenna basically you could pull it out and then you could communicate and then close it so that you can keep it safe others it. So, this was the best antenna that in terms of performance why because it comes out and whenever it communicates it communicates clears of your head. So, basically your head does not act as a obstruction to the signal so, but this was very quickly discontinued anybody know why anybody can guess why.

Student: they break of

They break of and why do they break up.

Student: (Refer Time: 25:36).

People keep pulling it (Refer Time: 25:37) not people do not know what to do the antenna they keep playing with it breaks and then come back for warranty. So, in Ericsson they said change that antenna we do not want it because it breaks all the time. So, today what do they do they put the antenna inside. So, basically if you ignore the antenna that is outside you see the antenna that is inside this is basically a patch antenna. Now unfortunately when you hold it and you keep it against your face is either your hand is absorbing or part of it is absorbing on your face, but that is how the antennas are today, but again the important thing is knows how the antenna is and how it works so good thing.

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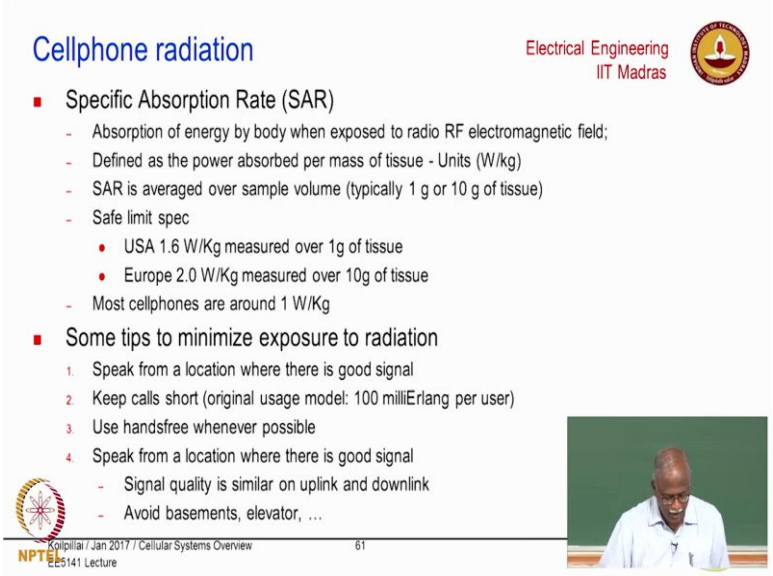

Now, one of the question that is commonly asked is will I get cancer let me answer that question it is a important question because we are all users of a wireless technology maybe a little bit of ethics is also tie to it one of the requirements in Ericsson used to work for Ericsson, and we made cell phones was that phone cannot go into the market which you will not give to your wife or child. So, you cannot send a phone out into the market. So, issue of sending a unsafe phone into the market is out of the question from a ethical point of you, but there is also a legal requirement and let me just mention that.

So, a the effect of electromagnetic radiation on human tissue is measured by something called specific absorption rate SAR, and there are units of SAR which either watts per kilogram or you know there are different ways of measuring it and typically these

measuring methods are specified by the different regulatory agencies. The safe limit that means, there is absolutely nothing to worry about radiation if the SAR value is written as 1.6 in the US, and it is 2.0 in the in Europe. Now keep in mind that this already has a significant of factor of safety factor of 10 safety from the safe limit. So, basically they took the safe limit applied a factor of 10 and say there is no way this device is going to cause any damage or radiation hazard. So, and of course, if you take and look at your SAR values it will be sometime mostly less than one.

So in fact, that when we designed the phones we make sure even lower than what is allowed, but as good communication engineering here are some good points to keep in mind; when does your phone transmit with maximum power.

Student: (Refer Time: 28:17).

When you are in bad signal, how will you know where the I do not know where the cell tower is I do not have any idea by the base station received my signal strong or weak how do I know that?

Student: Voice got (Refer Time: 28:33) quality of the (Refer Time: 28:35).

Well voice quality is somewhat of an indicator, but you may be may not notice it as easily.

Students: There are tower also (Refer Time: 28:42).

Good indicator is if you see only one bar on your phone you are not in very good condition. So, is a good there is fair amount of reciprocity in the channel condition. So, move to a different location if you are inside an elevator in a basement you can assume that your cell phone is transmitting with maximum power. So, again the good suggestion would be is go to some hands free mode if you are going to be on a long call, and try to take your call from a place where the signal strength is as good as you can see on your phone and that is going to be in that your phone will transmit with the least amount of power that it needs to.

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So again some common sense steps, but at the end of the day it is a safe device. Batteries have been one of the main stay of the phones, we started of nickel cadmium batteries then went to nickel metal hydride, today most of your battery is look like this lithium ion batteries and in the future we are talking about some in further enhancements maybe it is going to be some fuel cell or something based on solar, but as of now with lithium ion and how do we characterize a battery?

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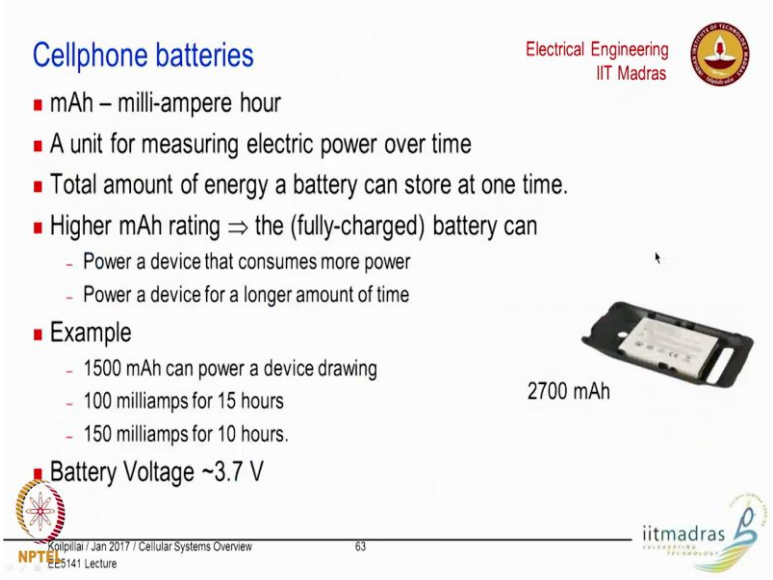

Batteries are characterized by means of a parameter called milli ampere hour, and it is not by coulombs or by the charge it hold that is because the battery voltage is standardized.

So, 3.7 volts is standard. So, if you can do whatever amperes you can draw at 3.7 volts in for the number of hours that gives you the charge that your battery holds. So, most of the time batteries are rated as 2700 milli ampere hours or 3000 milli ampere hour is good to see that. And that the understanding of it is 1500 milli ampere hour battery, if you are going to draw 100 milli amperes it will last you 15 hours very simple, because it has to deliver power at 3.7 volts. So, that is the that is the norm if you change if you draw more current it is going to last the less very very simple method, but it is good to know how much power your phone actually consumes.

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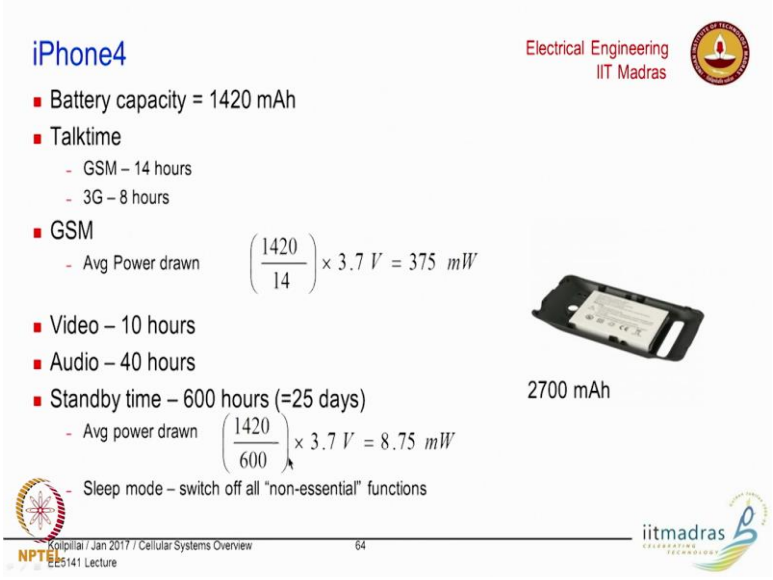

So, if you look at your battery you are what is the mill ampere hours and then look at your phone specification. So, maybe it says for three say for GSM your talk time is 14 hours. So, what does that mean? You take your battery capacity divide by the number of hours that is specified for talk time that is the current that you are drawing during talk time. Mill ampere hours divided by hours is the million amperes that you are drawing multiplied by 3.7 that is the power your phone is consuming when it is in talk time; that means, it is actively transmitting on the other hand if you are in standby; that means, you are just connected to the network, but not making or receiving phone calls, which means

that the standby time would have been specified also even some 10 years back the talk time was the standby time was already 25 days, 25 days 600 hours which means only 8.75 mill watts of power are being consumed by a phone because it has turned off all the non essential functions.

But good to know how your phone is rated, how much is your talk time if you are watching videos what is your the battery life you can as basically cons calculate approximately how much power is being consumed. Now when we were designing phones and somebody dropped the phone it was considered oh why did you do that you know cannot you be more careful because what will happen you know the battery will come off the, but the biggest thing that we were worried about was the display will stop working; and what was there in the display it was the 4 line display with nothing much you know few dot matrix elements. Now move the clock forward 20 years you have this fancy touch screens and people drop the phone like that and pick up and say oh its working no problem.

Student: (Refer Time: 32:47).

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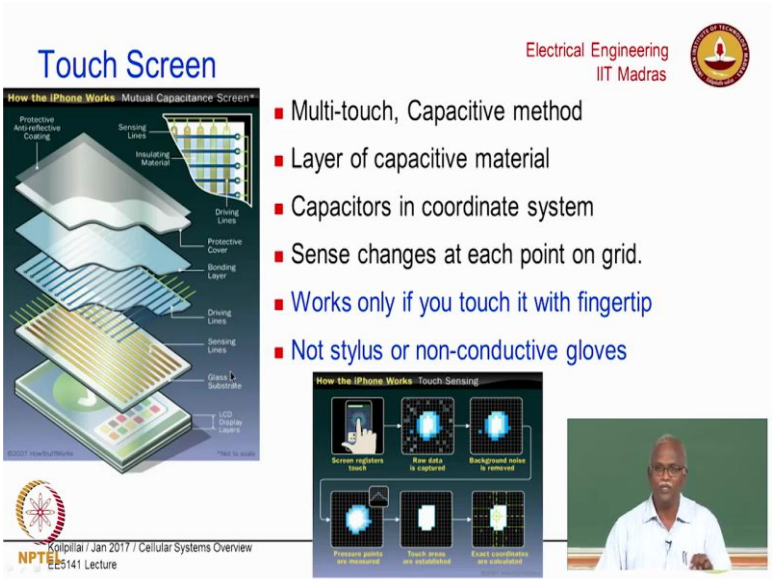

And it is like wait a minute do you know what is behind that touch screen phone it is not just oh it is working. So, here is your display, on top of that there are two layers which actually form a matrix of connections and then after that there are several layers of

bonding and then finally, a protective layer. So, now, when you touch the point what it generates using this grid is it is region of locations where the contact gets made.

So, this is this is approximately where the person touched and then it is given to some signal processing device which then narrows it down and says here is the max centre of gravity or centre of the of the location where the person has touched and finally, figures out exactly the coordinates of the point that you touch. And you know just being able to touch shrink, and it its extent it is amazing amount of signal processing that is going on with an amazing amount of electronic that is sitting behind it and you just threw the phone on the ground and you has and it is like you know show more respect to the phone, because you know it is it is one of those amazing device. So, l c this is a the fact that you can drop a phone pick it up and expected to work is actually one of the amazing feets of cellular engineering, because in the olden days you dropped the phone is falling going back for repair because the device the display would stop working ok.

Any questions hopefully some something you would you heard which was not something may be something that was new.

Student: Eelescopic antenna.

Ok.

Student: How they receive the call (Refer Time: 34:24) will antenna will (Refer Time: 34:25).

That is the very very good question how did the telescopic antennas receive the call? Because you do not know when a call when you are making a call you extend that; now between an extend antenna that is extended and an antenna that is in its compact position there is a difference of gain. So, that let us just say is 4 dB is a difference in gain between what you would if you had a telescopic antenna. So, the signaling channel the channel that tells you that a call is coming in has got 4 dB more link margin than the than the voice channel. So, even though the antenna is down the signaling channel will still get through because it has got 4 dB additional link margin. So, that your phone even without with antenna being down will still know that a call is coming in, but the minute you are alerted by means of the ring the first thing that you will do is extend the telescopic

antenna. So, that you can then speak on the phone, but good question good it is a system level question, it is good to know how the system works any other question.

Student: You said this (Refer Time: 35:28) you are given the example said madras data base and manual data base. So, this communication is wireless or wired.

Wired, all signaling other than the communication between the mobile and the base station everything else is wired. So, it is basically complete telecommunication wired telecommunication network with wireless access, the only the access part is wireless everything else wired and it is mostly optical it is very very high speed communication links.

Student: Sir (Refer Time: 36:01) there has to be a (Refer Time: 36:03) communication (Refer Time: 36:04) two different operators.

Yes

Student: Instead of Vodafone from Chennai based Vodafone to Bangalore base.

Yes.

Student: So, is there any other module in the middle (Refer Time: 36:12).

No the basically there is a signaling scheme which because the Vodafone gateway will talk to the Airtel gateway. So, the gateways have a protocol by which they can communicate different gateways of different, you can you cannot talk directly to the switch off another operator you can only talk through the gateways. So, basically the gateways have the protocol; the question was can you how do they different operators networks talk each other.

Student: What is the take place if we add a zero before the 10 digit number sir (Refer Time: 36:48) Bangalore.

Yeah.

Student: (Refer Time: 36:48) Chennai.

Yeah.

Student: What is the difference between (Refer Time: 36:49).

So basically it is how you are landline network or mobile network recognizes and interprets the zero. So, in most cases zero maybe just ignored or just be told that this is an ISD or STD call and, but at the end of the day it will still look for the number that has been dialed because the that number basically has to be clarified with the local database because they need to know where to route your call. So, though they are they assumed the a local network assumes that is it is this person is trying to dial an ISD call STD call, but they will still look for parsing the number and trying to understand. So, that is why even if you dial plus 91, it will still take the mobile number and then that is what is processed.

Student: Is the protocol same over voice over LTE.

No, voice over LTE is a packet system. So, the entire mechanism by which you connect to another user is completely different because it is like the internet. So, both users are already connected to the network the assumption is that, all you are triggering is an application that will connect the two of you are not signaling to the as user and saying where are you how to find out this is for a circuit switch come.

Student: (Refer Time: 38:11) two 4G standards (Refer Time: 38:12) and l t.

Ok.

Student: What happened to (Refer Time: 38:12).

Very good question the at one point it seem like there were two very very strong contenders for the 4G space, the contenders were coming from one was coming from the cellular dimension that was the LTE, the other contender was coming from fixed wireless basically wimax was a fixed point to point or point to multipoint communication link to which they added mobility. So, the question is which one is you know more adapted to the requirements of 4G, you take a cellular network and migrated it or you take a system that is primarily designed as a fixed system and give it mobility. Both had similar features, but because the cellular system already had may be 4 billion plus operator subscribers more people went on to the cellular side and market forces more or less where in favor of LTE, but there was a fundamental difference one was a cellular

migration the other one was adding mobility to a fixed system which was difficult, but it was done very nicely excellent keep asking those questions.

Now, question is I do not even have 4G on my phone I am actually using 2G why are you talking about 5G. So, I think it is very valid question let us see if we can give a reasonable answer to this question next slide is actually quite an interesting slide very important one.

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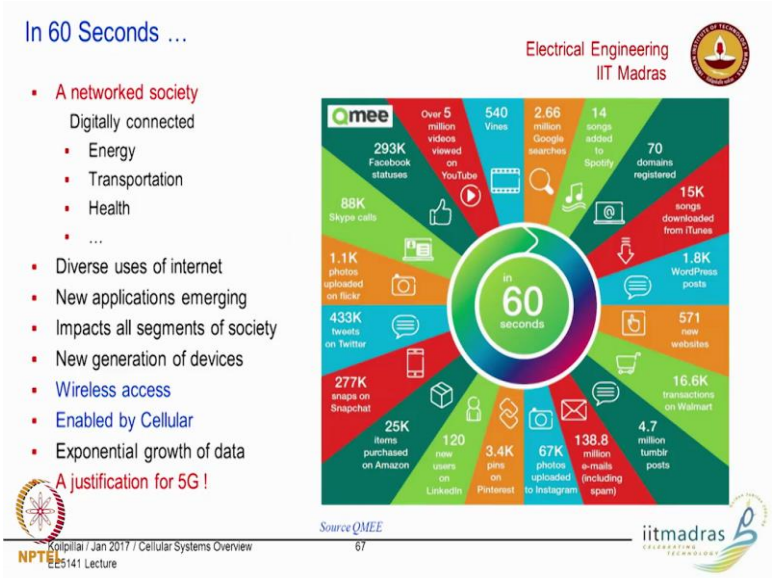

Sixty seconds look at your clock 60 seconds; in 60 seconds this is how much information has flowed across the internet. 5 million videos viewed on YouTube by different people of course, and about 293, 1000 face book status updates 138 million emails, 67000 photos uploaded on Instagram and the list goes on you can see this list and this is the sum of all this all of these are happening within 60 seconds.

Now, if you assumed that countries like India will have a significant portion of it of this as the internet traffic that we are generating, and for us the only device that we only way we can access the internet or broadband will be through wireless, then you already have the answer because today is 4G and do all the voice it can do quite a good number of a dead applications, but nowhere near the type of capacity that you will need for this type of this level of information flow. Now this is flowing on a wired internet, but for countries like India our portion of this data will have to go on a wireless network which

is why we are looking at even talking about 5G. 5G is very very important for India because this is this is the reality of the situation.

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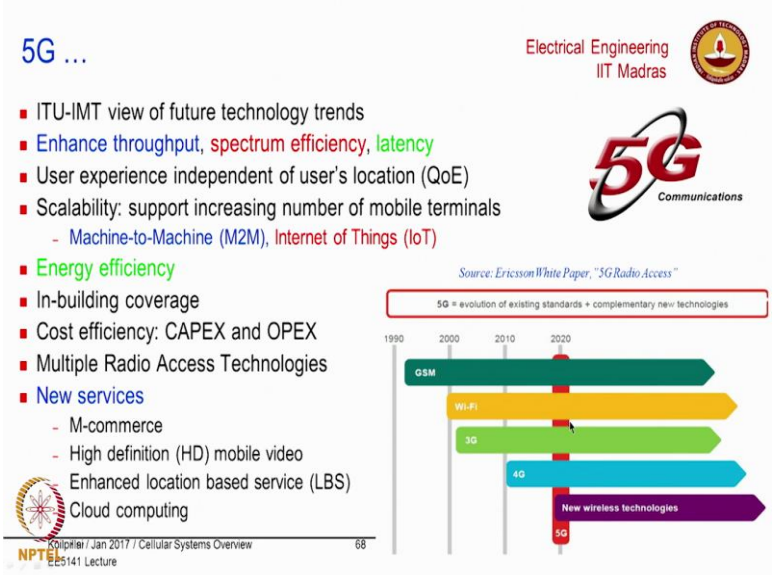

So, now the question is I throw it 2G, 3G, 4G and I bring in a new system 5G now the answer is not that. 5G is probably going to be super set or an integration of all the features because we know that market like India GSM is not going to go away, there will be pockets were GSM is there 3G will be there 4G and of course, we know that Wi-Fi is an important technology why not integrate that also into 5G. So, in terms of these technologies it is not necessarily a brand new technologies though there could be a new system called 5G, but it is by and large going to be integration of old ones possibly some new technologies coming in as well. Why new technologies because we already talked about the number of applications that will require broadband and a lot of these applications are machine to machine.

So, therefore, when we talk about connectivity of things called internet of things connectivity of devices, does lot more machines that need to be connected to each other connected to humans this is going to require additional types of communications, and all of this has to be done with energy efficiency remember green communication. We also recognize that a lot of the applications will be inside of buildings. So, therefore, our wireless coverage inside buildings must be improved very very significantly. M-

commerce is going to be very significant in the future and location based services and of course, new applications like people watching high definition videos on their hand set.

So, again there is a whole spectrum of a potential applications and also recognition that the way the only way we can do this is something very very efficient that is why 5G is being talked about.

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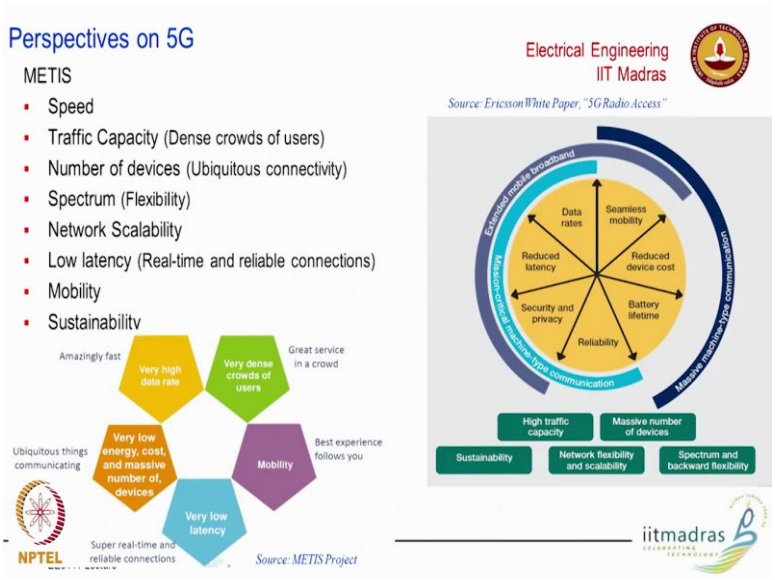

So, this is one of the slide that you may have to tell me whether is readable, but let me just highlight the fact that there are applications that require very high speed like high definition television. There are scenarios where you would have to connect thousands of devices let us say you want to do meter reading across city of Chennai, electricity meter reading. So, there are thousands of these devices that need to be connected and, but the data rates are very small may be hundred bits per second.

But the numbers are very large spectrum we do not have a single spectrum, but we have got some spectrum in 900, some in 1800, some in 2.3 gigahertz. So, basically is the spectrum is fragmented. So, it must be very flexible. The latency if you want to have control of a traffic signal using wireless mechanism basically smart transport, citywide transport which means that your ability to control the traffic signal must be very precise. So, that is low latency you cannot send a command and then you know it responds after 5 seconds. So, basically there are scenarios where you must have very very reliable very low latency communications and of course, you know whole issue of mobility.

So, here are the different dimensions cost is important, if you are putting up meter reading or some like you know all the vending machines have a device to report back their current stock, those will require long battery life you do not want to keep having to go and change the battery some applications demand very high reliability and then there are of course, issues of security. So, how do you meet these requirements across with this with the singles with a solution? So, you can see that flavors of 5G will be such that you may have the dark blue communications which is geared towards machine type communications, low latency low data rate then there are this light blue which is what we call mission critical, police communications, traffic signal control, the automated factory those are mission critical you have to be very very low latency, then of course, the medium blue which is talking about the very high data rates. So, again different flavors there will be options for us to solve these problems, these requirements using the different systems that we have.

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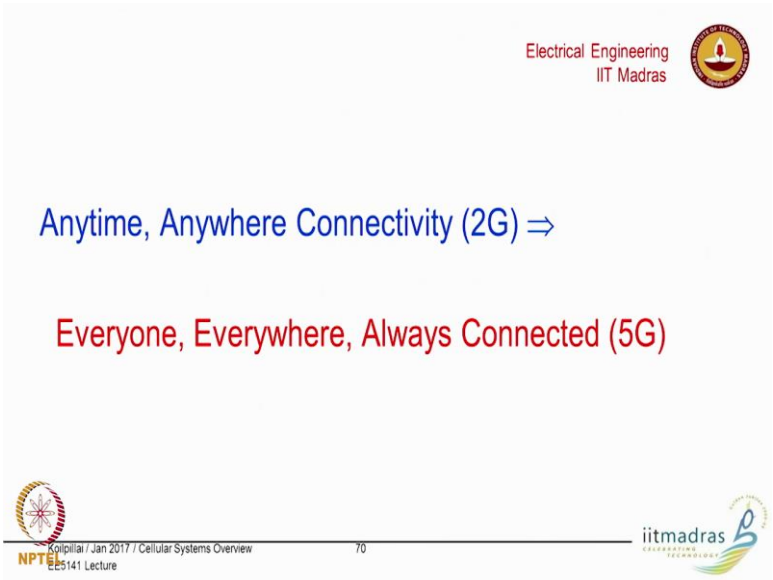

Let me leave you with the slogan of 5G, and it is thought of tells you how to think about 5G. 2G when cellular systems came in 2G they said anywhere anytime you can connect to anyone; anywhere any time any one that is what 2G promised you pick up the phone and you call. 5G says everyone everywhere everything devices also always connected you are not to connect they are already connected that is 5G.

So, how do you maintain the connectivity, how do you manage the mobility, that is part of the challenge that we see.

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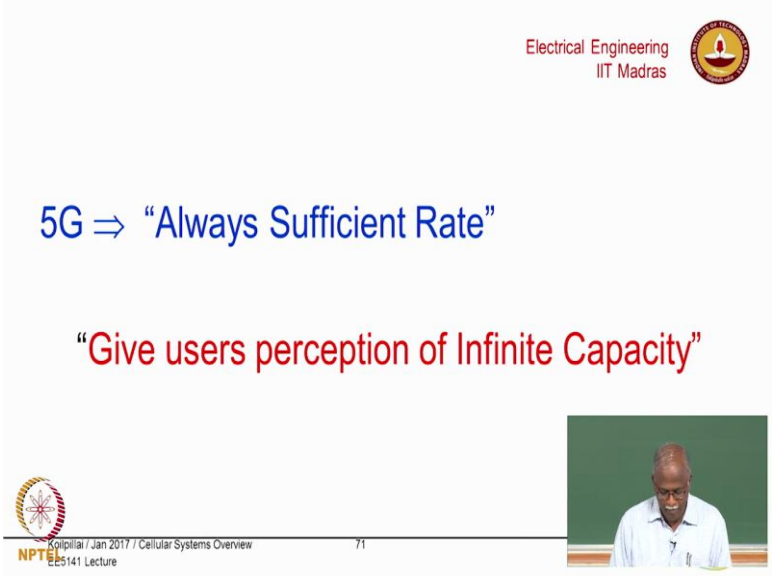

5G they also say that you must give the user perception of infinite capacity. So, they should not worry about am I ordering a pizza or am I going to watch a movie that does not matter, your, the data rate will be sufficient for the application that you are looking at. So, this is how 5G will be viewed and it more or less tells us how we should look at the evolution of cellular system. Is not just that you know few people who are very fascinated the technology think that we should now come up with 5G or just a buzz word, no it is not a buzz word the market forces are driving such that 4G may soon run out of the ability to support the market opportunity. So, that is why new systems will come and that will be called as 5G any questions.

Student: So, 5G will basically view in the same (Refer Time: 47:00) 2G.

Well the question regarding spectrum is coming up in a later slide that will be addressed tomorrow, the answer is it can use existing spectrum, but most slightly it will be deployed in new spectrum and the reasons 2G system and 5G system may be difficult to coexist in the same spectrum. So, what you would have to do is something call spectral reframing; that means, you today you have GSM you have to clear it just like a farmer says. So, I am going to plant a new crop you know reforming, now is no longer groundnut I am going to grow rice. So, basically you clear out all the GSM and you have

to deploy 5G or 4 G. So, reforming is difficult because already operators have got a equipment. So, they prefer to use newer spectrum, but somebody like reliance jio who does not have 2G, 3G comes in they can deploy where ever there has spectrum they can deploy it ok let, yeah.

Student: For i o d why cannot we use Wi-Fi instead of going for 5G.

Yes very good question and answer comes from the business people, if you tell the cellular industry saying you know what you already got 6 billion subscribers why do not you be satisfied with that why do you want to go after one more market which is got only 20 billion subscriptions, there is no 6 billion is good another 20 billion even better. So, its market forces right. So, of course, you know if there were. So, cooperative there is you take voice I will take data no they do not do that everybody wants because it is a large market. Everybody says Bluetooth your job has to connect headsets and you know music player why do you want to go into i o t space well there says it a big market let me go there is there a market forces.

So, basically the markets are huge and each one is leveraging their own strengths. Cellular says yeah you the minute you give me your traffic everything is taken care of mobility authentication billing everything is taken care of if you go to Bluetooth yes no way of billing the system, you have Wi-Fi there is no mobility whereas, Bluetooth says I can last 10 times longer than the cellular phone why not you give me the business. So, there is there are market forces that are in play ok.

What I want to do in the couple of minutes that are remaining is to spend show you the computer assignment and encourage you to start thinking about it that t s and I will be happy to help you basically the goal is to verify the theoretical bit error rate performance of a QPSK system ok.

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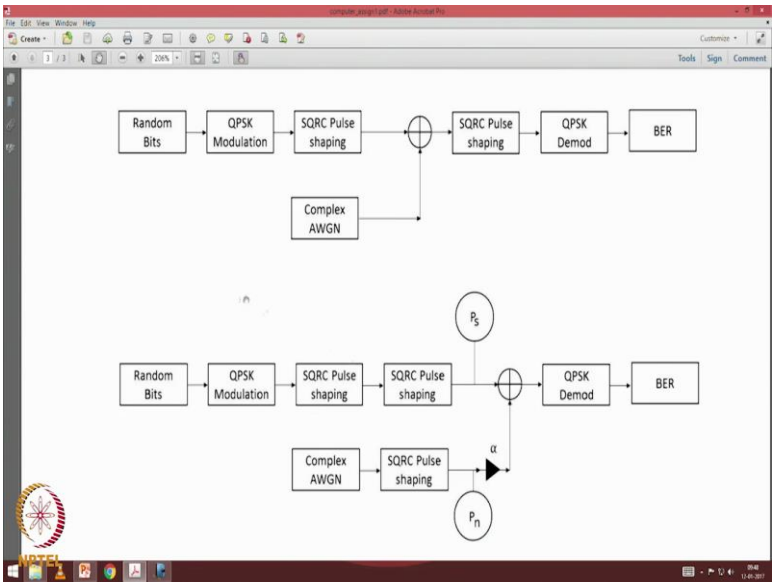

So, the way you would do it in a conventional sense is you would generate bits, modulated using QPSK add some pulse shaping noise and then you would pass it through a matched filter and d mod and then compute the bit error rate that is what is supposed to be, but if I tell you 10 t b E b by n naught get me the bit error rate, it is actually very very difficult why because where do I measure a b by n naught. I do not know because n naught is what noise spectral density watts per hertz and do I measure it before the filter or after the filter have to measure it before the filter because it is not a b n naught is not constrained by whether you use the square root raised cosine or a Gaussian filter does not matter. So, actually if you see E b by n naught is not a quantity that is easy for us to understand as a and work with as a practical engineer, what you can do is what is called carrier to noise ratio the power.

So, basically you put a power meter on the signal side you put a power on the noise side and then you say this ratio is carrier to noise ratio, that I can measure that I can control; but now how is this link to the E b by n naught that is a very important question, that is one of the things that this assignment will help us understand. Now where do I measure signal to noise ratio not in the event not in air, after I have passed through my receive filter. So, after I have passed through my receive filter is at this point right you can see the maker there. So, can you see the marker there that is where you, but by the time signal and noise have already mixed there is no way I can measure signal alone and noise alone.

How do you do signal to noise ratio. Some very very interesting questions think about it in the next class we will spend a few minutes to explain how it can be done in a very systematic way 10 dB Eb by n naught will give you 10 dB E b by n naught, and the bit error rate will be exactly what Proakis and other books will prescribe you can verify it. So, that is part of the task it also tell this what is the role of pulse shaping how do I do up sampling and down sampling all of that is also need it because if you want to talk about synchronization and others. But it is a very it is a basic experiment, but it will probably teaches a lot of things on which we can build take out this channel and then add a fading channel that is what we want to do, but we need to have this baseline that is what we will do thank you will pick it up tomorrow at 8 o'clock.

Thank you.