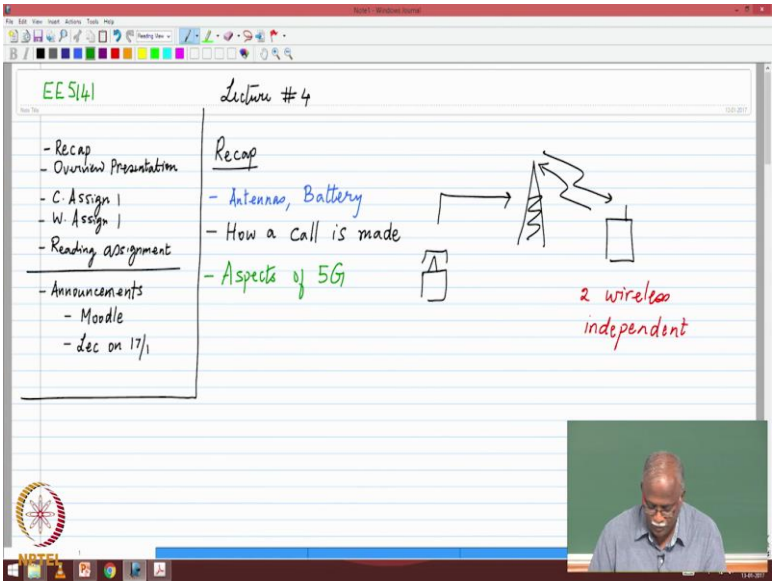
Introduction to Wireless and Cellular Communication
Prof. David Koilpillai
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 04
Overview of Cellular Evolution and Wireless Technologies
5G and other Wireless Technologies

Good morning and welcome to lecture number 4, as customary let us start with a quick summary of what are the some of the key points that we mentioned in the last lecture. Mostly it was due to in the form of presentations and also an opportunity to ask any questions to clarify.

(Refer Slide Time: 00:31)



So, the general information that was covered was some context with respect to antennas and batteries, hopefully that was something that was helpful for the students and hope you had a chance to think about some of the points that were mentioned what are the a assumptions in the design of the cell phone and of the antennas, and how that it becomes a safe device to use. Probably an interesting element that helps us understand the system was how the how a how a call is made to a mobile phone, basically how a call is made and I thought I would ask you a question that is connected to this, just to sort of understand the whole process.

So, we talked about a landline phone connecting to a cell phone. So, basically there was a landline phone and it went through a certain process and eventually came up to the cell phone. So, this is the last segment of the call being made just wanted to ask how many wireless links are active when one call is made. This is an FDD system, so there is one link through which the cell phone tower talks to the mobile, and then there is a second link on which the mobile talks to the cell phone.

So, there are two wireless links. So, again keep in mind these are some elements that are that makes us understand. Now the question is are these two wireless links independent of each other; what I mean by independent is one can be good the other can be bad is that possible in this in the framework that we have assumed what do you think? There are different frequencies that that assumption is correct that is because it is an FDD system, and again our basic understanding of propagation is that it can be very different for different frequencies. So, these two channels can be assumed to be independent in terms of quality, one may be good the other may be bad and even if one of them is bad your call will not be satisfactory and eventually the system will drop your call. So, the applied question, if a mobile were calling on mobile how many wireless links are?

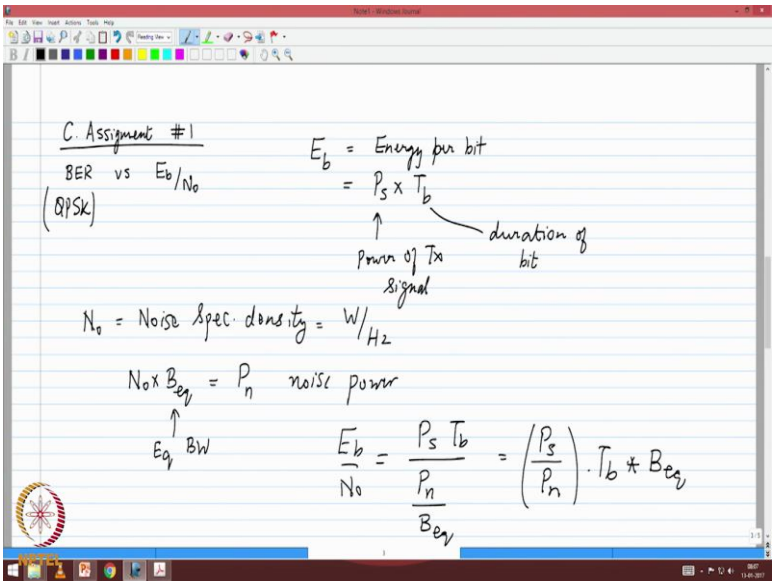
Student: 4

4, so there is a higher probability that if we are calling from a mobile to a mobile one of the links could go back and therefore, it is a vulnerable channel. The other question which is when you I am sure you probably have seen a landline phones and if you cannot hear you tend to talk louder like you talk you shout you hear (Refer Time: 03:44) people shouting on the landline phone. In a cell phone system you can hear the other person, but they cannot hear you will shouting help why? So, you can hear them. So, which means that one side is fine they cannot hear you it means the reverse channel is bad in which case shouting is probably not going to help. So, you know or being surprising you know how come I can hear you how come you cannot hear me do not be surprise, sometimes the links can be independent and therefore, the quality is no is something that you know it is a way the system has been designed. So, that of especially a mobile to mobile 4 links are there even if one of them is affected then we see the effect of that.

So, then the rest of the a discussion was on aspects of 5G, again these are a concepts that I am sure post the course as you look at material I am sure you will be able to appreciate.

One of the elements that I thought I should mentions point of few minutes is regarding the computer assignment, and some of the terms which are there which I hope you had a chance to look at and we will discuss it if there are any doubts we will we will clarify that as we go along.

(Refer Slide Time: 05:02)



So, the computer assignment was to enable us to simulate in a or using mat lab or C, C++ whatever you are comfortable with the bit error rate of a digital communication system we are looking at bit error rate of QPSK as a modulation scheme that we have used versus E b by N naught, and as I was mentioning to you E b by N naught is something as very difficult to specify and implement precisely in a communication system, and maybe a few minutes of explanation will be interesting and helpful; this is information from digital communications, the E b is energy per bit energy per bit.

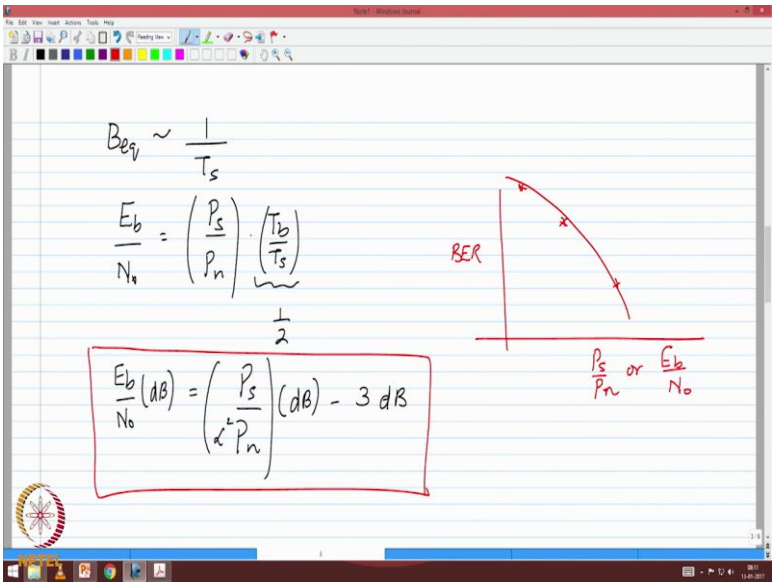
So, this is something that you would be able to understand in many different ways probably the easiest way is to look at the power of the transmitted signal P s. So, that is the power of the transmitted signal times the duration of a bit, power into time gives us energy T b is the duration of a bit. Given that it is QPSK the duration of bit, duration of a symbol a symbol is two bits long. So, are the bit duration is half of a symbol duration, duration of a bit. So, this is the basic definition of energy per bit. Now the tricky one comes when we start looking at N naught. So, let me ask you to tell me what N naught is, give me a definition of N naught.

Student: (Refer Time: 06:44).

It is the power spectral noise power spectral density, and the units are, now watts per hertz? Noise spectral density, thank you that is that is good. Now comes the intuition part. So, this is in watts per hertz that is our unit watts per hertz. Now how do I, if I have a certain noise power that I measure in my receiver, how is that related to N naught and that is a very important element because N naught noise spectral density a times the equivalent bandwidth or the amount of noise that comes in that is the equivalent bandwidth refers to the property of the received filter, this will correspond to my noise power, this is noise power and equivalent bandwidth and again the definition of equivalent bandwidth there is a notion of it, but basically think of it as the bandwidth of the received filter equivalent bandwidth.

So, with this basic understanding we now are ready to define our E b by N naught that is given by P s times T b divided by P n divided by equivalent bandwidth; that is a very good equivalent representation where P s and P n are things that we can actually measure in a communication system. Now this is nothing, but P s by P n times T b times B equivalent, let us just rearranging the terms.

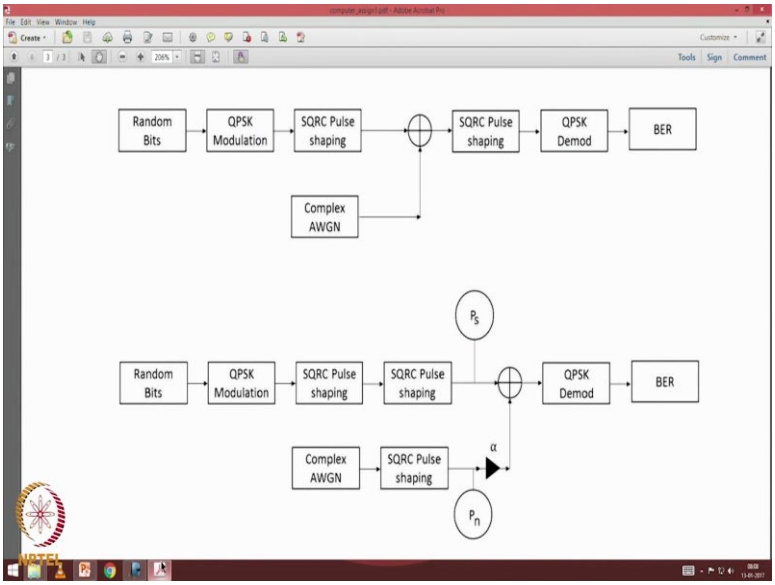
(Refer Slide Time: 08:51)



So, I would now like to give you a property of the square root raised cosine a filter which is useful for us to keep in mind, and that would be the understanding that the equivalent bandwidth of a square root raised cosine is approximately 1 over T s or the symbol rate

bandwidth is proportional to the symbol rate when you use the square root raised cosine as your pulse shape at the transmitter and receiver.

(Refer Slide Time: 09:23)



So, for us E b by N naught that is a quantity that is theoretical, but not very practical can be related to a very practically measurable quantity P s by P n notice when we looked at when you look at the simulation you can actually put the meters or in basically take the magnitude square of the complex numbers, and average it that will give you P s and P n. Once you have a ability to measure P s and P n and this term becomes T b by T s right T b times b equivalent b equivalent is proportional to 1 over P s, and this is nothing but one-half under the assumption that we using a raise a root raise cosine at the transmitter and receiver this is approximately one-half. So, whenever if I were to write it in dB E b by N naught in d B, is P s by P n in dB minus 3 dB that is it.

So, you actually have a very precise way of calibrating the amount of noise that you will add and actually get the bit error rate for a specified E b by N naught this is a simple, but it is good to do it once because only then you feel comfortable saying E b by N naught is a very N naught particularly is a quantity that is it is a conceptual term, but actually when you want to measure you want to measure it. And that the challenge now becomes measuring the measuring the noise power and that is why we did a basic rearrangement of the simulation system because the square root raise cosine pulse shaping that is the receive filter it is a linear operation.

So, I can the signal and noise get added that is how the channel would work and noise would get added to the channel in the channel and then you pass it through the receive filter. But invoking the property of linearity or from signal processing, we can say that I can move the summation to the right hand side basically I without since it is a linear operation. So, which means that each of the branches must go through a square root raise cosine pulse shaping that is what you see here.

So, basically I have moved it for the purposes of convenes move the c filter to the right to the left, and then applied my signal power and noise power because this is exactly what is coming in into my receiver and the because it is a simulation I can do that it actually helps me control it. Now if I want to set different levels of signal to noise ratio 6 dB or 8 dB or 10 dB that is controlled by controlling alpha. So, hopefully as you look at it the complete expression would be alpha square because alpha is also present in your expression in your further simulation you would get P s by alpha squared P n minus 3 dB will be your expression that you should be able to map and that should match very very closely as you plot the bit error rate versus the call it P s by P n if you want or E b by N naught whichever one you want make sure that you though the correct one you will get the different simulation graphs and then you will find that the theoretical graph actually passes through. So, this is what we would like to get hopefully it will be a very in interesting and instructive exercise.

So, this is pretty much what we covered in the last lecture. Any questions on either the simulation or on the material that was covered in the last class, if no we move on let us pick up where we left off in the last yeah.

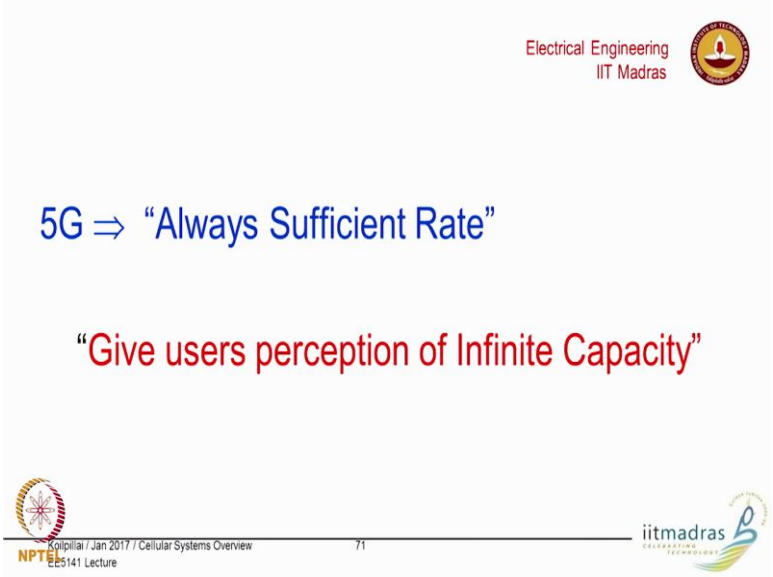
Student: How does?

The question is how does voice over LTE, a voice over LTE is a mechanism which is there in the fourth generation for the carrying of the providing the voice service. So, basically the delivery of packets is like any I P application that you have like you know whatsapp or browsing, there is a addressing mechanism which tells you know how to route the packets where what the destination is going to be, but the information that going into the packet is very similar to what happens in a conventional circuit switch call basically your voice gets coded into information which is then encapsulate into the packet and then transmitted through the system.

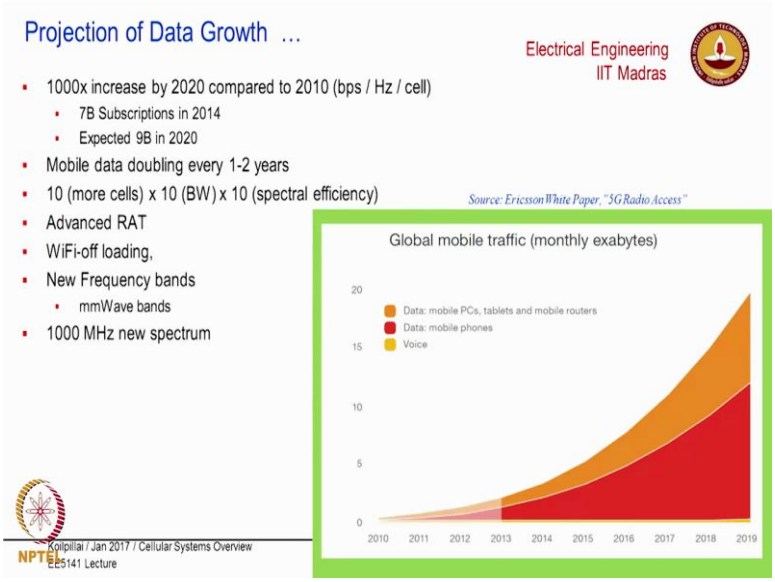
The ability to go from voiceover LTE to a conventional voice device, basically once it goes into the cellular network and the network recognizes that it is a voice packet and it has to talk to let us say 2 G phone then it will route it through a gateway which will then convert it into a analog basically a normal voice call and establish a circuit switched path to the to the user. So, voice over LTE can exist in its own domain talking to other voice over LTE devices it can also connect to a PSTN or to a regular 2G phone using a appropriate gateway.

Let us pick up today's material, hopefully is will be a lot of information, but hopefully this is something that will help you as you read about the material in different context.

(Refer Slide Time: 14:38)



(Refer Slide Time: 14:41)



So, 5 G as we mentioned the goal is to give enough bandwidth so that the user has a perception of infinite capacity. Now here is there are lots of projections that that are made it is good to have an idea of how the market is growing and how fast it is growing of course, a projections of a number of cellular users in India have always been you know smaller than what it happened in reality, but again it is good for us. So, here is a representation of what the proportions will look like in the year 2019.

So, if you look at there are 3 colors there you almost will miss the third one if you do not look for it carefully, it is way at the bottom the all of the voice calls that voice traffic that we see today which is a huge amount of traffic in today's cellular networks is going to be that small line very narrow line what is the rest of it is going to be a mobile data and of course, all of the broadband applications that we are talking about are going to be. So, it is orders of magnitude more than the voice traffic, the voice traffic is also growing, but the rate at which the mobile data is growing is in several orders of magnitude. Now they classified as you know how much will go on actually handheld devices and how much of it will be on a devices like lab tablets and, but now that is sort of merging smartphones are somewhere between a phone and a laptop. So, again it is interesting to know that the data component is very very strong.

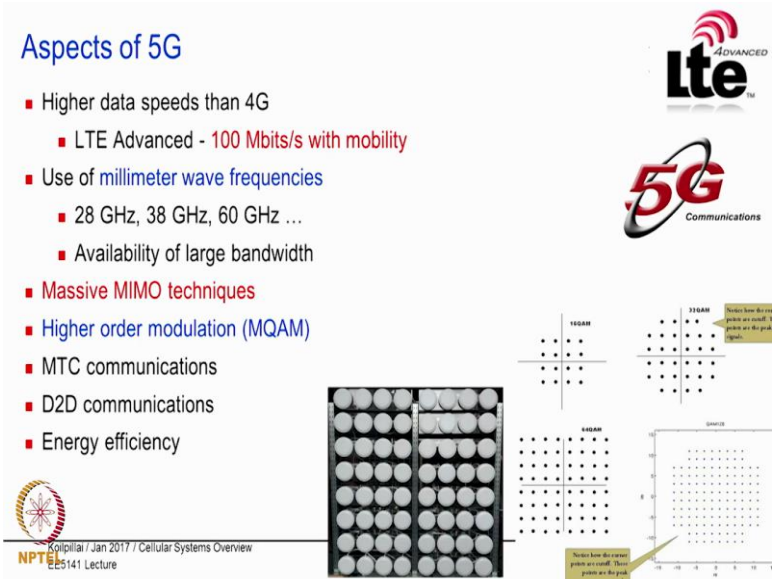
So, they expect that with respect to 2010 what we achieved in terms of the capacity of the network, there will be approximately a 1000 times increase in terms of capacity

needed in the networks. So, basically how do you plan for a 1000 fold increase in the existing network; the one easy method would be say ask for 1000 times a spectrum and that is not going to be available. So, how do you do that within the existing mechanisms? So, here is the way the at least the broad idea is going to be, they will ask for 10 times or more bandwidth, more spectrum will be found somewhere in the RS spectrum range they will create 10 times more cells, each time you increase the number of cells the capacity is going to grow.

So, if you increase 10 times the number of cells as with respect to today's your capacity is approximately going to scale by 10 and the last number is very very important they want to send 10 times the traffic in per channel as they are sending today 10 times the traffic which means that you are asking for very very high spectral efficiency again how do we achieve that a lot of it is going to be the work for the researchers who are going to be working in the area of wireless.

So, it is interesting to see how the whole system will evolve and why we are doing the or why we are studying these topics with interest.

(Refer Slide Time: 17:46)



Some elements of a 5 G which will be enhancements over 4G basically today we are talking about the speeds which we are in that in that 10 mega bits per second you know it will likely to go even higher 100 mega bits per second they are also talking about one gigabit per second on wireless links it is interesting for us to see how that will be you

know there today we transmit primarily up to 2 gigahertz slightly about 2 gigahertz. We are now talking about because you want 10 times more spectrum they are looking at the millimeter wave band 28 gigahertz 38 gigahertz, 60 gigahertz again these are spectrums a parts of spectrum are a spectrum where there is almost no users.

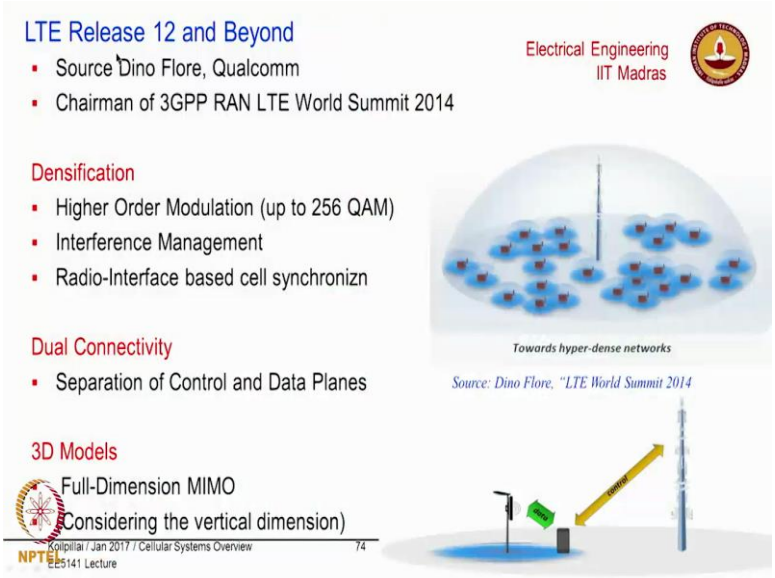
So, if you go to 60 gigahertz and ask for one gigahertz of spectrum it is probably there no problem because you know, but if you ask for such amount large amounts of spectrum in the lower bands not no way because so much of users are there.

Now as you go higher in frequencies your wavelength in decreases your antennas are proportional to your wavelength, so which means that your size of the antenna keeps getting smaller and smaller. So, they are now talking about not MIMO, MIMO would be about 2 antennas 4 6 8 antennas a 8 at the upper limit now they are talking about maximal MIMO 64 antennas 100 antennas 100.

So, basically it will be potentially an array of antennas which can achieve for you orders of more a better efficiency than what an a normal MIMO system could be. So, again interesting to see you know how this will play out higher order modulation today we do a QPSK and a good channel condition 16 QAM very very rarely into 64. Now when they talk about 5G and they talk about a very good channel conditions they are saying why not 256 QAM. So, again it the challenges are yet to be seen, but again all of this is so that we can achieve the type of growth in a data that that has been forecast. So, it could be voice traffic small growth, but bulk of the growth happening in the machine to machine and in the data applications that we are seeing.

So, those are a aspects of a 5G again you will see it in a few years a lots of interesting things to work on, but 4G systems are not going to sit and you know basically it is not going to be a quantum jump when it come there it is going to be a gradual evolution.

(Refer Slide Time: 20:30)



So, today's system LTE the version that is going to be deployed in a few years it is called release 12, again each a year there is a release or up gradation of the system LTE started out in release 8. So, basically this is the fifth upgrade that will happen of the LTE system and here are some thoughts that are already pointing to what it will be in towards the fifth generation.

So, notice higher order modulation will be introduced in LTE up to 256 QAM, they will look at a several methods of improved a interference management and one of the ways that it will be done is that through the through the process of creating these small cells contour cells basically large number of small transmitters that are connected that through to which users are connected. So, not many users are connected directly to the to the macro tower. So, this is called densification of the network, a extreme densification of the network in order to achieve the capacities we are saying increase the number of cells byte number a byte a factor of 10, this is a one way in which will happen lots of small cells being created. Of course, they will all inter likely to interfere with each other that is why the interference management is very very important.

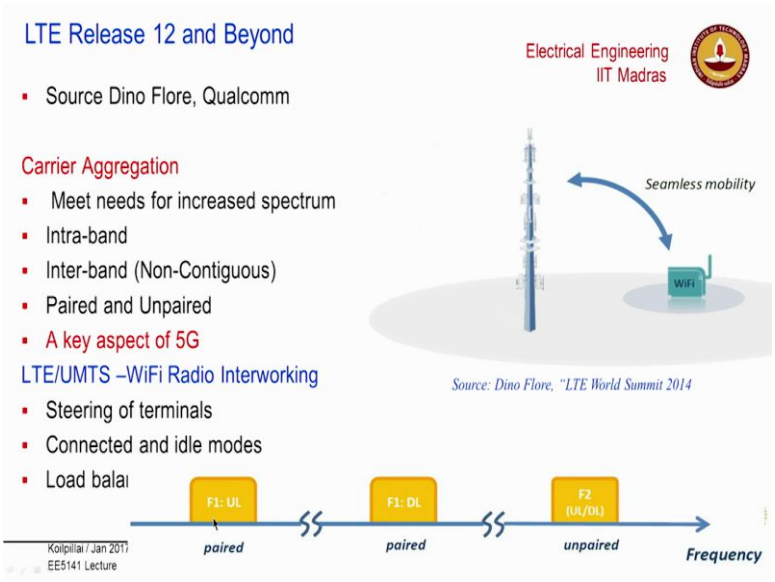
Now, another a very interesting phenomenon that is already being discussed is that there is a macro network and that has to sort of control a how the information flows to the different users, but the actual data which comes to the user there are two things one is telling you that you have some incoming call or there is a application that wants to

connect with you, and then the actual application where the huge amounts of data are transmitted. So, there is the notion of control and actual user data. So, what they call as dual connectivity is that the macro network will still give you the control information it will just tell you have an incoming call or you have a data application that wants to connect with your device. So, basically it just controls the entire network, but the actual data that flows this is only a few hundreds of bits, but this will be megabits of megabits of megabytes of information that is a thick pipe that comes to you from the small cell that is nearest to you.

So, today control and user data come on the same link and, but in the future they could be coming from different base stations and you do not even as user do not know, but it is a very more efficient way because this is at a low rate and it has to connect to all the users this is at a high rate only to a few users. So, therefore, it makes sense to connect to your nearest base station. MIMO is today as we understand it special it a helps you to do special a resolution of users I can differentiate between user in this direction to a user in this other direction they are talking about this is two dimensional x y plane; these evolution of cellular systems where we also have a coverage of users in high rise buildings that there is a third dimension basically there is x and y and then there is a vertical dimension.

So, 3 dimensional MIMO you could have beams in these two directions you could also have a beam in a different in the z plane which gives you additional a capacity again that is under consideration.

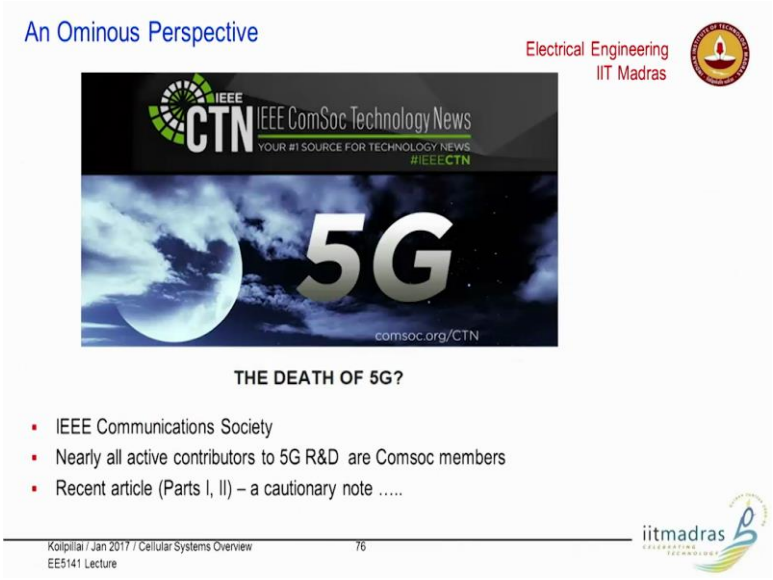
(Refer Slide Time: 23:55)



The spectrum that is available today in the 2G and 3G is scattered in different frequency bands 800 band, 1900 band and in the 22.3 gigahertz band. The aggregation of a carriers. So, typically if you want 10 megahertz you like to have it all 10 megahertz together contiguous, but if you do not have 10 megahertz contiguous can you aggregate carriers from different frequency bands and that is also being talked about.

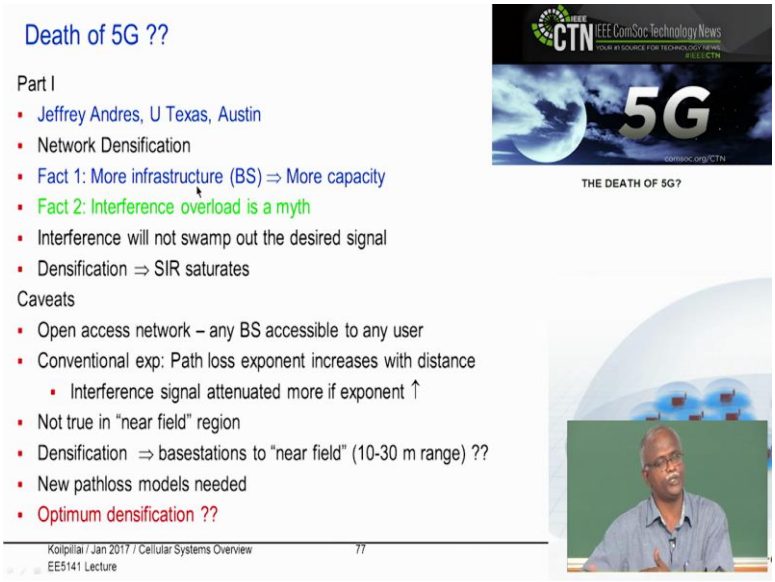
Probably the most important and interesting one along the lines of what we saw in the previous slide, this splitting of the control and data is going to happen in another flavor that that flavor is going to be the incorporation of Wi-Fi, instead of using the small cells if you have a Wi-Fi access point; that means, the macro network will do the basic control operation and once it comes to the data transfer it shifts you over to the Wi-Fi system. So, therefore, the Wi-Fi is something that is free of cost you do not have to pay the cellular network the cellular network operators is very happy because you have gone off the network and you are taking your megabits of second to a second of data from a different resource. So, again it is a win win situation. So, this is a something that is happening they call it seamless mobility between the cellular network and the Wi-Fi network again there are a challenges in terms of mobility, but this is a model that I believe has a lot of merit I am sure you will see more of this.

(Refer Slide Time: 25:19)



Now, engineers are sometimes skeptical this good in a good way you know because some people have said look 5G is too ambitious, you are trying to do too many things to very very complicated. So, there is a group of engineers who have predicted that 5G will die before it even comes becomes a reality, and here are two reasons why they again it is it is not to say that if the 5G will not happen they just it is an alert saying that yeah you know do not think everything is rosy everything is easy there are some a very significant challenges that are present. First of the caution note saying that if you do not address this 5G will be affected this is with the aspect of network densification.

(Refer Slide Time: 26:01)



Now, there is a fundamental assumption that we are making with densification which says the more cells that you create or more base stations you create there is more capacity in the network. Now what about interference? I am going to generate more interference, there is always the assumption that you know what I am my user is closer to me. So, therefore, I transmit with less power and therefore, the overall interference to the network is less, but because there is more number of such small cells interference will grow up to a certain point and then it will saturate it will not grow to the point where you cannot communicate. So, basically it will not become an interference over load onto the system yes interference will be there, but it will saturate and everybody will be happy more users and now the caution that is being made is very true is that says that this assumption is true, if you allow every user to connect to the base station that is closest to them that is the assumption.

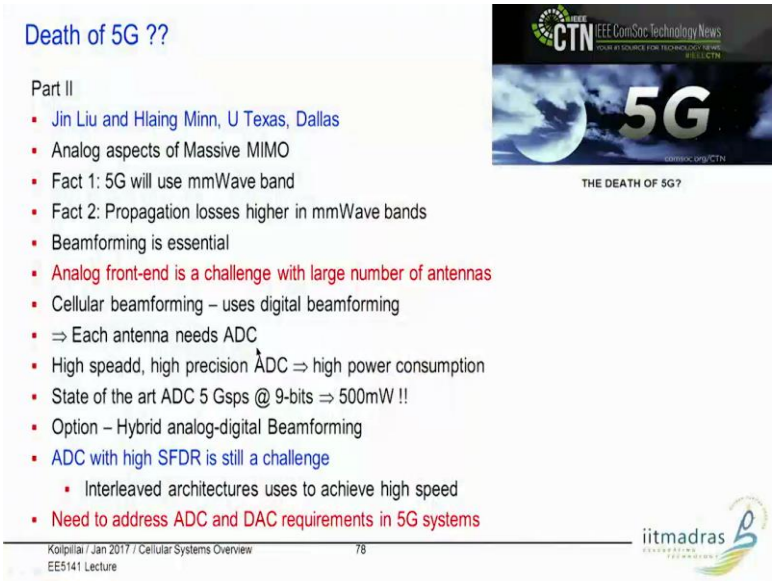
Now, let us say you have set up your own a contour cell and your neighbor says can I connect through your femto and you say no then what is the what option does your neighbor have just to connect to the macro network. So, that is a scenario that you know you may have created a zone and in which you have reduce the interference, but if the others cannot connect to the to the to the nearest base station then they are going to create actually a more interference because you are causing interference to your neighbor, neighbor has to transmit with more power to reach the network. So, there is a in implicit assumption that there may be some things that we need to look at the statement which says more cells implies more capacity, because you have you have not yet addressed the issue of who will be allowed to connect to the nearest base station. So, if it were in open access network anybody can connect to any base station the fact number one is good, the fact number two is also questioned because the propagation changes in electromagnetics when you are when what is called the near field. Near field is 20 10 to 30 meters and then a far field is beyond that.

So, basically if you are now very close to your base station the propagation aspects change. So, you cannot always assume your interferer is in the far field because you know interferer may be somebody who is very close to the base station and therefore, will cause a lot of interference. So, again the interference elements also need to be looked at because you now have small cells. So, again engineers are good this is the problem it is good for us to study and come up with interesting solutions.

The second question that was given was in order to do the MIMO systems, the way the 4G systems will have designed it is that they use one analog to digital converter per antenna basically each antenna signal is all the processing is done in the signal in the DSP and then eventually you convert it into analog and then each antenna needs a d to a converter also needs an a to d basically on the receive side is an a to d on the transmitter side d to a.

So, now if you are going to do massive MIMO, and I have got large number of antennas I have to worry about how many ADCs are going to be running in parallel how many d a c's are going to be running in parallel and again you are saying I want to transmit at very high data rate.

(Refer Slide Time: 29:39)

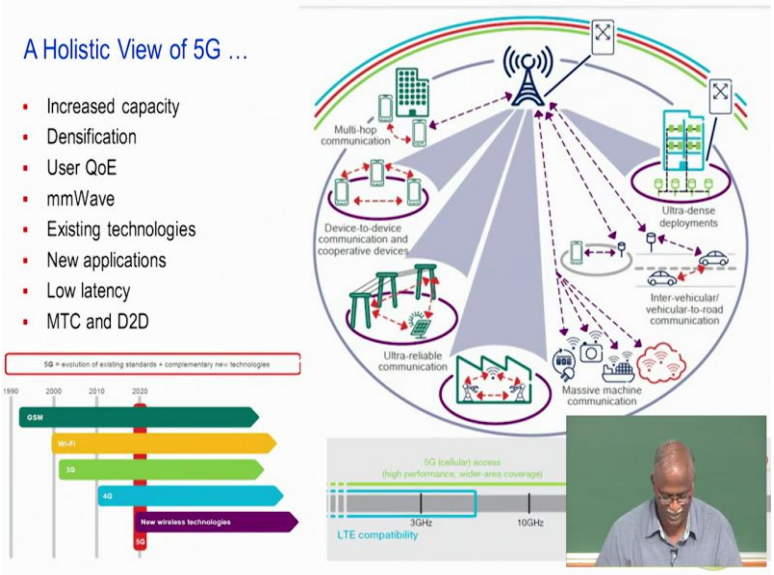


Let us say you want to transmit at 100 megabits per second, then the caution is that today's ADCs that have to run at such high powers such high speeds with resolution of 9 bits or 12 bits will consume a lot of power. So, for example, today's state of the art a to d converter at 5 giga samples per second 9 bits precision actually consumes 500 milliwatts that is a lot of power if you have now 64 of them running in a device you know it will be very very power hungry.

So, again ADC is going to be a challenge DAC is going to be a challenge. So, how do you address it do not just say you know massive MIMO will give me 10 times capacity you know you actually have to build devices that that actually can meet those

requirements. So, caution well taken I think we want to be realistic and say that maybe massive MIMO will be 16 cross 16 or not 256 cross 256.

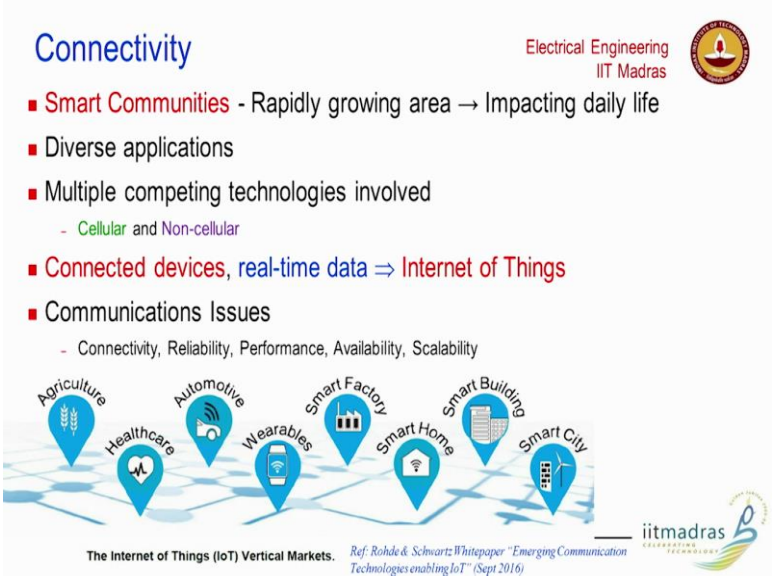
(Refer Slide Time: 30:40)



So, a holistic view of 5G, we have to address increased capacity that is number one, a densification will happen how much we have to see it has to be done in a controlled manner. Millimeter waves will be introduced because we want more spectrum and very very important we are looking at a lot of machine type communications which have low latency and high reliability.

Why because you may have factory automation, you may have a vehicle communications also part of this and therefore, these have to be very very robust and reliable. So, much for cellular we have talked almost 3 full lectures on cellular, I think to do justice we must also look at non cellular technologies because until recently cellular was the dominant technology and therefore, what cellular did the rest of wireless did, but not so as we go into the future what is changing.

(Refer Slide Time: 31:42)

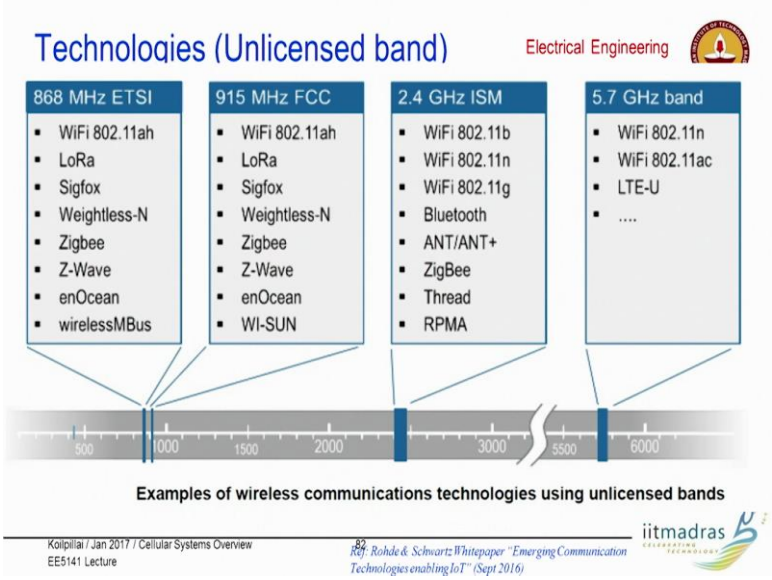


We now here a lot of discussions around smart cities, it is not a buzzword because from the point of view of communications it is a reality, because if you want to introduce any form of intelligence in your healthcare, automotive in terms of factory, in terms of homes, in terms of water distribution power distribution you must have a lot of monitoring. And all of these devices have to send data to some central node and today they are not wired for that and therefore, the only way they will communicate will be through wireless devices.

So, at the minute you hear the word smart city, smart community, smart transport good that is communicated work for communications engineers. So, lots of applications technologies that will meet these solutions can be cellular or non cellular there is nothing that says that it has to be a cellular technology most of these are requiring connected devices they have to do real time communications and again the popular term is internet of things, but we look at it as a connectivity of these large number of devices is what we are looking at.

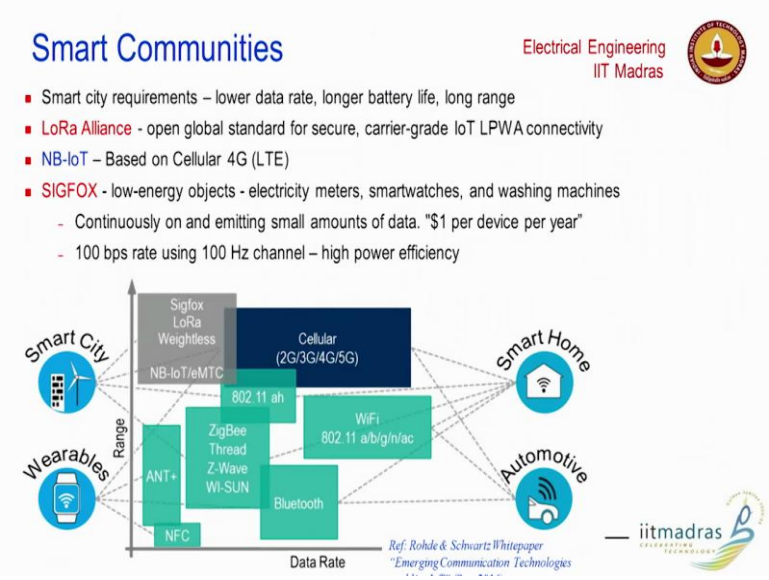
So, communications issues will be to provide connectivity reliability to make sure that you can scale your network because these will be thousands of devices that are communicating.

(Refer Slide Time: 33:05)



So, interesting; interesting challenges that we have you may have thought 2G, 3 G, 4G 5G how many technologies are there, now look at what is there outside of cellular. So, if you were to take only those unlicensed band; that means, you can use the spectrum without paying any fee 2.4 gigahertz that is where our Wi-Fi normally works Wi-Fi 802 dot 11 b. Now notice that there are lots of other technologies in addition to Wi-Fi Bluetooth there is a technology called thread, there are several others go to other unlicensed bands there are technology called Lora long range, Sigfox is a signaling technology there is a technology called weightless, again there is a lot of them and you ask the question what are they doing why did the people develop these technologies and why are they there what are they used for.

(Refer Slide Time: 33:55)



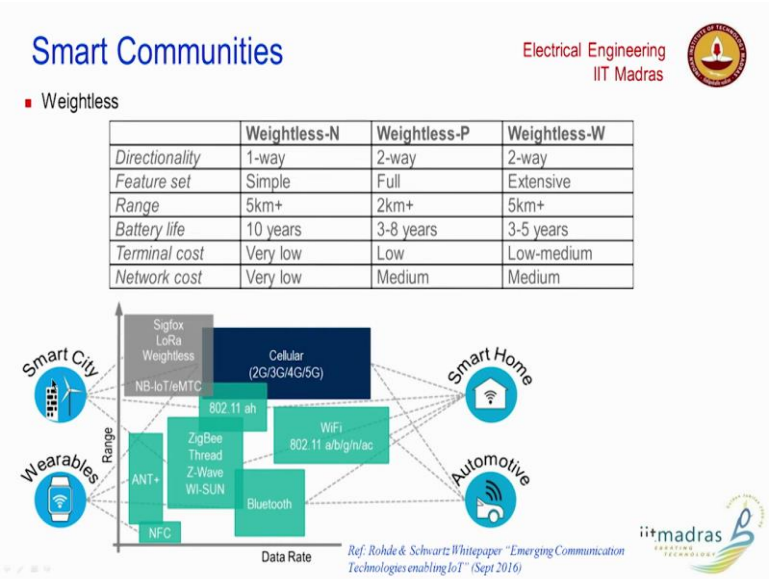
So, very interesting to see this is what these technologies have been developed for. So, if you talk about smart city requirements you want to control the let us say all the traffic lights. So, you are talking about a large number of devices and many of them may not have electricity connection. so which means that they must have good battery life you are deploying it across the city, So, they may want you may want to have long range, but generally these are monitoring devices for low data. So, LoRa is a stand LoRa is a long range has been developed very precisely for this, it is something for long range low data rate and long battery life it has been designed for. So, that is nothing to do with cellular it has been developed very specifically for this type of application.

Now, at the same time the cellular community said you know we can actually modify our system to meet the requirements of such a (Refer Time: 34:59) because we already have long range the only thing is we do not have as much battery life we can do that. So, they have come up with a something called narrowband IoT internet of things that is actually a offshoot of LTE, 4G LTE. And there is another proprietary system called Sigfox it is been designed very specifically for electricity meters, for in domestic appliances basically to monitor it. So, what is the data rate? 100 bits per second you know is there an application for 100 bits per second, you can you can see that this is this is one such scenario and it only requires 100 hertz channel not asking for megahertz and it works with very very high efficiency.

So, if you remember in the first presentation first session we talked about a classification of technologies using a two axis method; on one axis it was range on the second axis it was data rate different, but the same two axis. Now put all of these new technologies in this one there we had only a cellular and Bluetooth and a Wi-Fi, but now let us put the remaining technologies you can see that their cellular looked like the you know that was not the so good because you know Wi-Fi and others were much better, but now cellular is sort of the one that everybody else is at lower data rates and, but a lower range, but they have much much better battery life that is where the advantage comes.

So, if you are talking about an automotive application maybe cellular is the dotted lines tells you which are the likely technologies that will meet your requirements automotive cellular is probably going to be a good technology, but if you are talking about short range communications once you enter a certain a like a parking lot then Wi-Fi could equally well be a option. Smart home which means that it is to do monitoring of the devices in your home may not require cellular probably Bluetooth or a system like ZigBee would be done and there are comparators to ZigBee as you can see there are several others which are very very similar to ZigBee. So, you would have to look at some of those and if you are talking about a smart city again some set of systems.

(Refer Slide Time: 37:14)

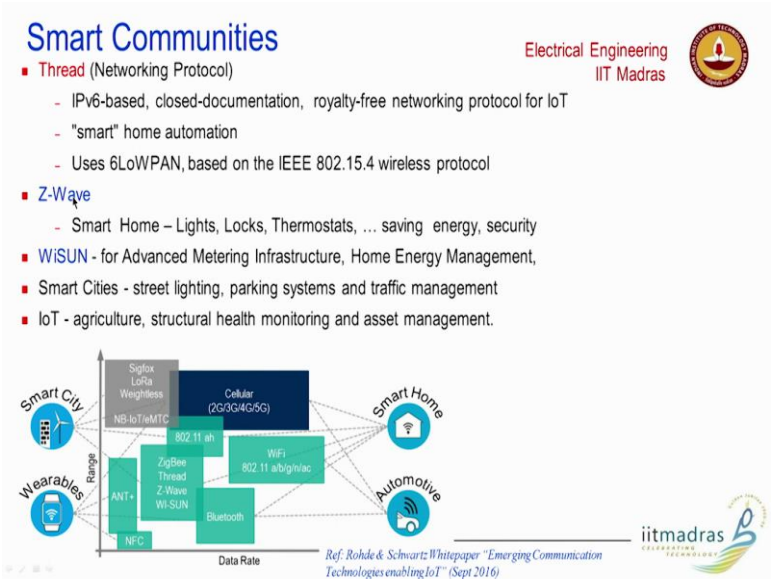


So, let us look at one of those there is a technology called weightless, this is a technology that is being specifically optimized for long range, but how does it achieve battery life of

10 years on a system. So, or you know even for that matter 3 to 5 years is. So, weightless has got 3 flavors again this is more for concept the details are just what you get a feel for; if you willing to say that some devices are only one way transmitters or one way basically they will receive and not transmit anything or basically they only do one way transmission. So, very simple they can last for 100, 10 years as a battery life. Now the same weightless may say that there are it is a two way device, but not as frequent communication in frequent communication then you can get a certain amount of range and then if you want to have a two way more interaction then you get lower.

So, basically each of these technologies will also give you multiple flavors to then say that you can when you deploy a network with my technology then you will find that you have certain advantages with respect to the others, interesting for us to see some of those elements.

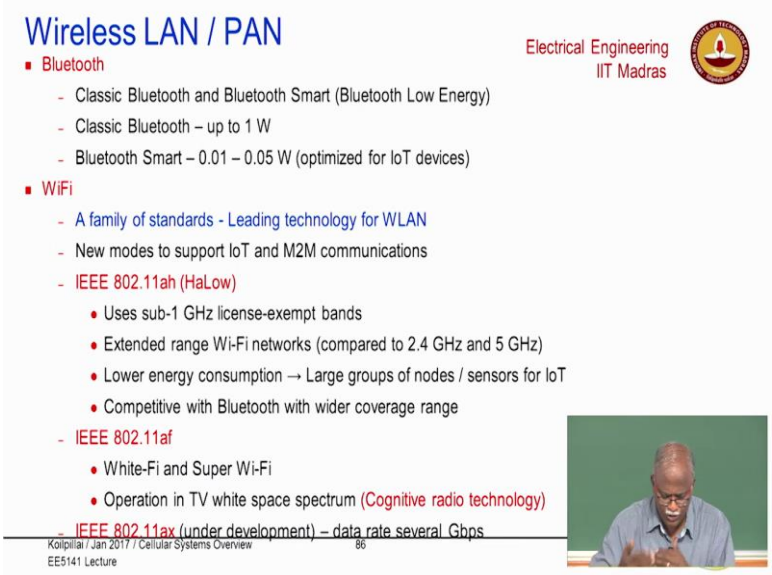
(Refer Slide Time: 38:33)



Now, most of you are a familiar with the ZigBee protocol, it is built on a IEEE standard called 802.15.4, there are other technologies which are built on the same physical and MAC layer there is a technology called 6LowPAN, there is an another technology called thread which is built on that the a wireless smart utility network that is another standard that is of a products have been developed primarily for in metering infrastructure electrical power metering, this a smart utility network is also designed for street lighting parking traffic management. So, basically it is designed for large scale deployments Z-

wave is a technology like a ZigBee it is meant primarily for you know turning on devices turning off setting locks and things like that basically for home management.

(Refer Slide Time: 39:27)



Again just to give you a flavor the old ones old timers a Bluetooth and Wi-Fi each of them have now got different flavors. So, Bluetooth for example, if you can see now has a low power mode which is optimized for these applications such as IoT.

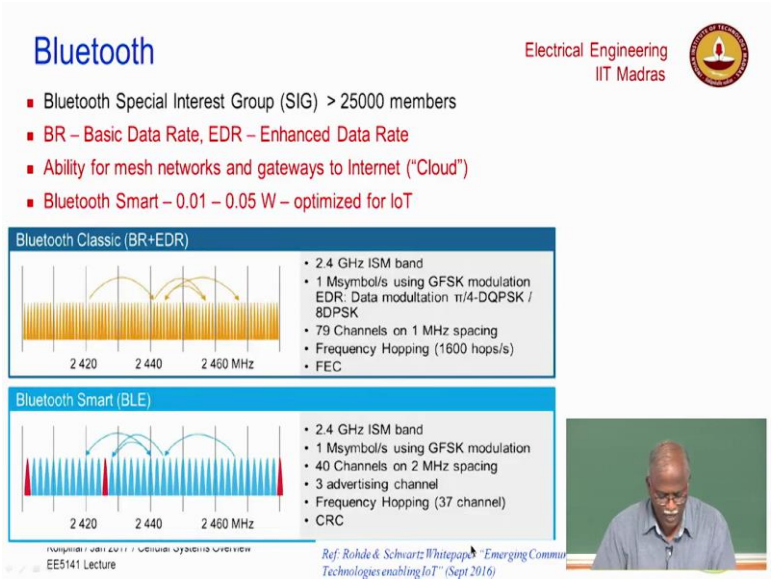
So, basically they call it a Bluetooth smart or Bluetooth low power which is optimized for that classic Bluetooth is itself low power, but now you are talking about something that is even more optimized. Now Wi-Fi most of us think of it as 802.11 be the one that you see in airports and shopping malls in different parts of the academic zone also, but actually a to a Wi-Fi is not a single standard it is a whole family of standards. Some new standards that you may not have yet heard of there is a 802.11 it is called HaLow basically low represents that it is in the lower frequencies right.

Today it is deployed in 2.4, now they have introduced a version that will operate in unlicensed bands, but below 1 gigahertz; that means, what used to be 100 meters range will now probably go to 500 or 600 meters. So, basically extended range can be achieved compared to the traditional deployments in 2.4 gigahertz, and at the same time it is also low power consumption to compete with Bluetooth yesterday there was a question you know why do these technologies you know all are trying to compete. Basically the market is very attractive and therefore, they are looking at it.

There is another flavor of Wi-Fi which is operating in the unlicensed in the what is called the white space, white space is a current TV channels, TV channels were all given a radio spectrum, but most of the TV channels today are either through cable or through satellite. So, they do not do terrestrial broadcasting. So, therefore, those channels are actually not being used for anything else and they are all in very very good propagation a frequency band.

So, white space combined with Wi-Fi they call it as White-Fi and that is a that is a optimize system to operate in the TV white space, and as we speak there is also a development of a Wi-Fi system that will touch gigabits per second over the air, so again interesting one.

(Refer Slide Time: 41:45)

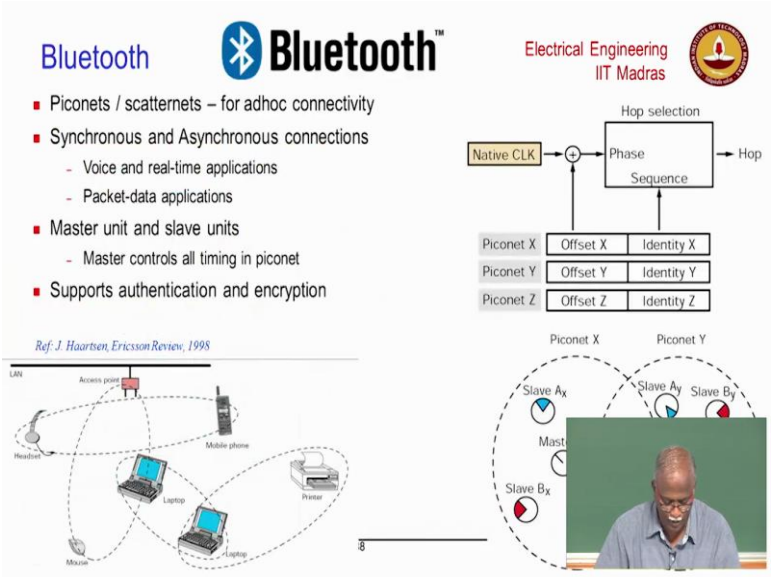


Now interesting to also ask the question how do these devices avoid interfering with each other. You know so many of them are all operating in the unlicensed bands. Bluetooth has got a technique called frequency hopping. So, every few milliseconds the Bluetooth network keeps hopping, it hops at the rate of 1600 hops per second. So, less than a millisecond is what it stays in each of those frequencies and it keeps hopping. So, the goal is that it keeps hopping frequently; so frequently enough to avoid any harmful effects of an interference.

So, let us say there is an interference in one portion of the spectrum it may hop to a frequency in that where there is a heavy interference, but less than a millisecond it is off

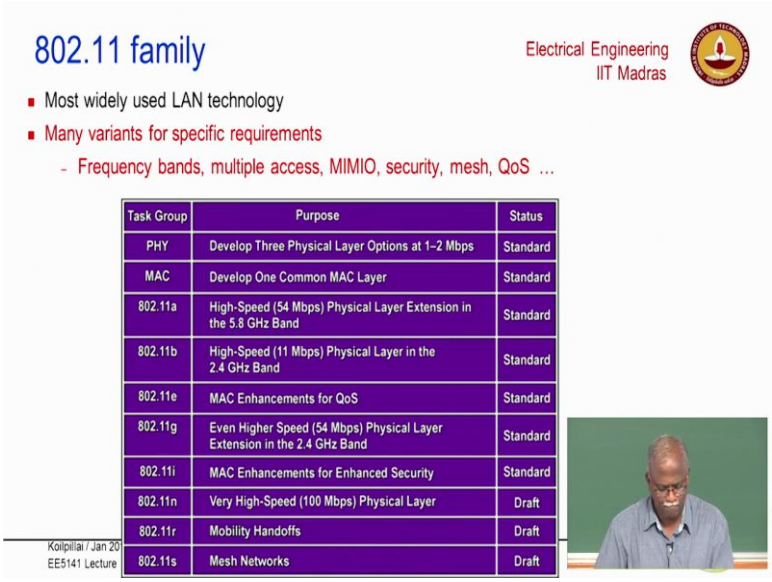
to some other frequency which will probably have better channel conditions, but that requires a fair amount of power consumption because it is changing frequencies and the Bluetooth, low and a low energy consumption one has optimized the hopping basically reduce the hopping rate as well. So, interesting ways in which a Bluetooth is evolving forward.

(Refer Slide Time: 42:55)



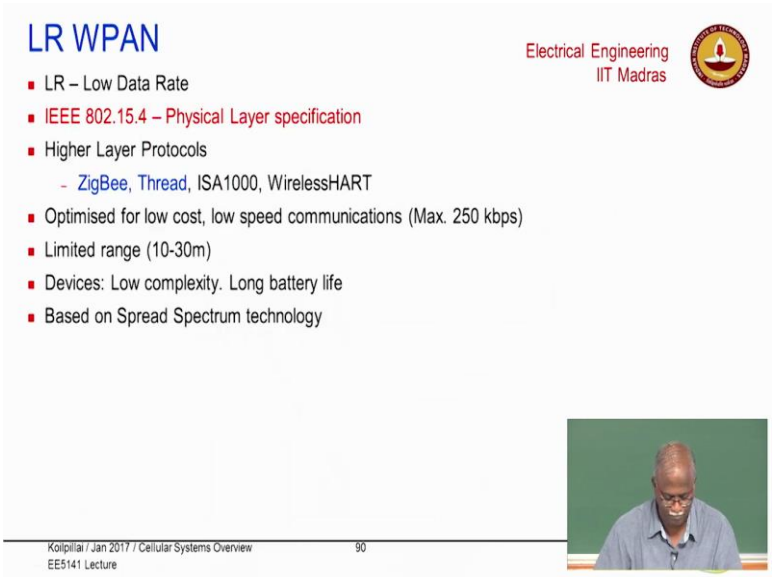
Bluetooth as you know is a technology to connect lots of independent pairs of devices. So, what you can create is a lot of a parallel connections, but remember this hopping requires you to be synchronized because you and your the device that you are talking to must change frequencies at the same time. So, this notion of how the clock is controlled is very very crucial if you are interested you should read up about that, how do you maintain uncoordinated network where every pair of devices knows exactly when to change frequencies. Every pair will hop at a different time and there are devices that are connected to two networks, how do you hop your frequency to talk to two people at the same time very very interesting problems it has been solved very elegantly.

(Refer Slide Time: 43:41)



802.11 as I mentioned is not a single standard, it is a whole family of standards when you get a chance you can look at this slide and see you know all the different flavors, we started out with 1 to 2 megabits per second then went up to 54 megabits per second 100 megabits per second and now we are talking about gigabits per second in the same family of evolution.

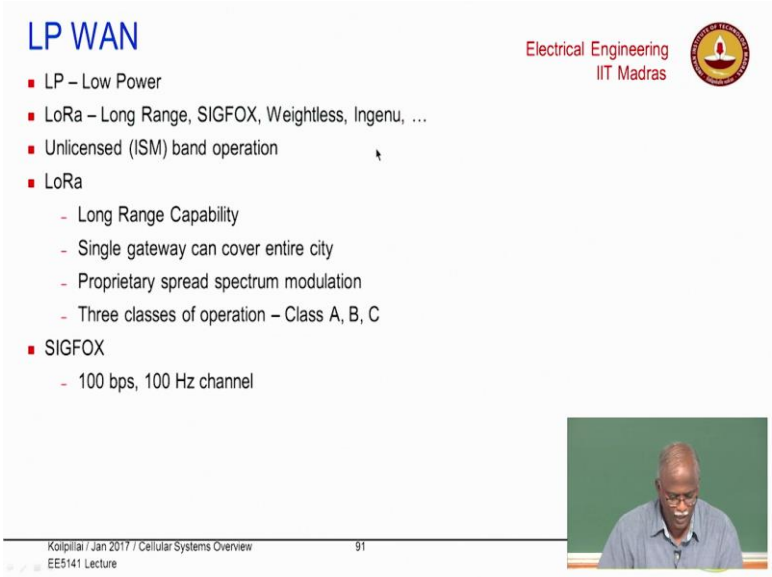
(Refer Slide Time: 44:05)



There are some other technologies which I will just mention, in case when you are reading it if you come across built on the 802.15.4 that is the IEEE specification of the

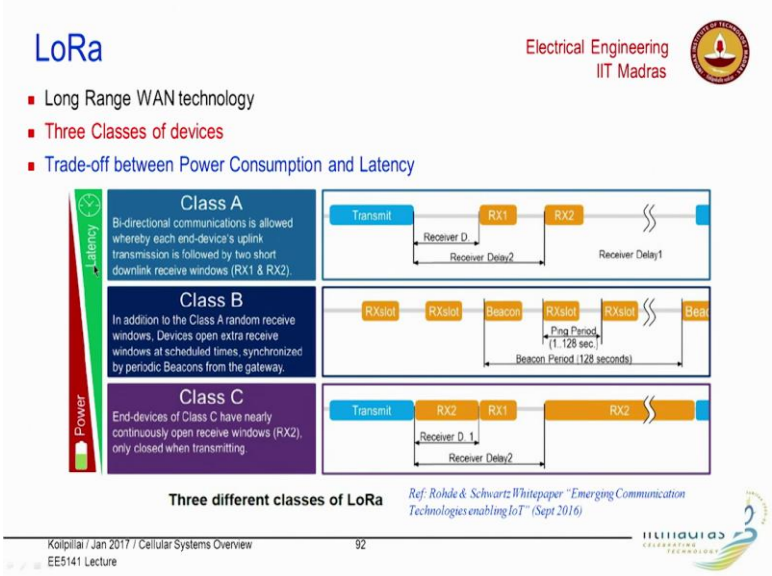
physical layer, on top of that you can have a standard called ZigBee or thread there is also standards called the wireless heart and these are devices which have very long battery life and range is limited 10 to 30 meters, but again I have got very unique niche applications. Long range LR that that acronym always stands for long range wireless personal area network. So, short LR low rate low rate wireless personal area networks.

(Refer Slide Time: 44:51)



LP is low power and again these are devices that are optimized for very low power, a LoRa is long range combined with low power and a Sigfox is actually low rate combined with the with low power.

(Refer Slide Time: 45:06)



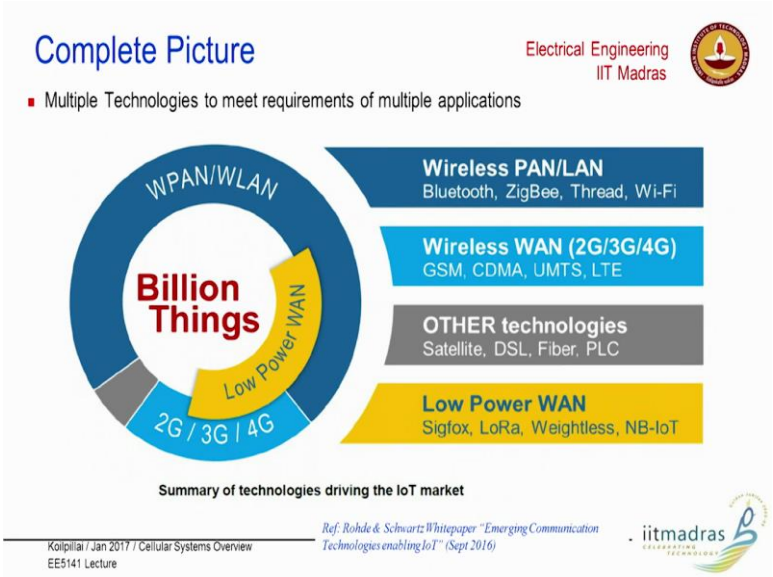
Now, Lora technology which is actually designed for long range how does that achieve low power consumption, and it is interesting for us to sort of get a feel for the all this is very very intuitive. So, the y axis tells you how much power consumption, if the triangle becomes narrower; that means, it consumes less power, and the green arrow tells you how much delay is likely to be for data that is being sent by that particular mode. So, class A is very low power, but may incur large latency. Class C on the other hand is the one that is a very low latency, but will require more power, but still overall it is still low power, but the there is still optimization within that how does how does that optimization occur.

So, the optimization basically says that you transmit and then you shut off everything. You periodically wake up only twice to see if there is any downlink transmission, if there is no transmission you go back into what is called sleep mode and you shut off all other devices. So, this basically says that if you have to communicate with this particular device you have to transmit you can only communicate when the receiver wakes up, which means that there could be a lot of delay in communicating, delay of the order of milliseconds.

Now, class B says I will have more times when I wake up. So, which means that you know you will consume a little bit more power the latency reduces a little bit, but and then there is a class C which the receiver says you can talk to me anytime I will be awake

I will wake up and communicate. So, again you can see that how the optimizations occurs for the different systems, how Bluetooth avoids efficiency, how Lora reduces power, how the weightless technology reduces power. So, again all of these are optimizations that you see happening in the wireless technology for the specific application that we are looking at.

(Refer Slide Time: 47:05)



So, this is the non cellular view of the world as I say the cellular always draw a cellular big and everybody else small, but you know here is our view of the things. They say that you know the wireless personal area networks wireless PAN and wireless LAN that is going to be the dominant technology that is what they feel. So, they said that billions of things are going to be connected much more than number of human the people. So, therefore, that is going to be our technology and of course, low power is very very important that is going to be a huge a part of the market where a cellular oh by they will give them a small portion. So, there is this portion. So, again this is a slightly different perspective on how the wireless market will be they are looking at connectivity of devices; you are not talking about total communications or profit or a total data they are saying that when it comes to connect connecting devices it is going to be the non cellular technologies that will be dominant.

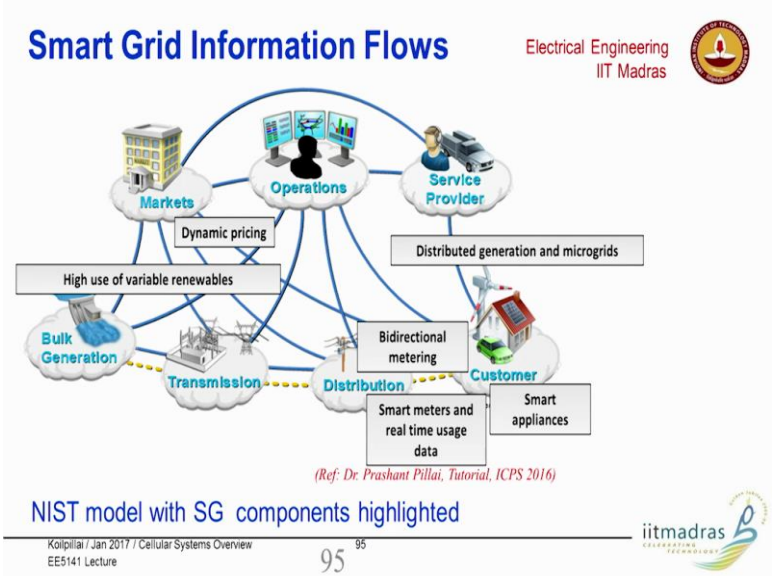
But final decision the market will decide which will be the winner. Let me make a couple of comments with regard to the upcoming classes. There will not be a lecture on 17 1 we

will have a makeup lectures. So, basically next Tuesday there will not be a lecture I just wanted to inform you regarding that, but the there will be an uploaded reading assignment and a written assignment and the TAs will be available during the Tuesday lecture hour, but for a discussion if you have doubts on the computer assignment or on the written assignment they will be available to answer any questions. And we will let you know through model which room this discussion will take place. So, in case somebody has not is having difficulty accessing model please do stay back because we need to make sure that everybody has access to models. So, that we can we can send this information to you in a in a reliable manner; and the regarding the makeup lecture also we will announce well ahead of time when the makeup lecture will happen, but the makeup lecture will be take place a here in the in the studio. And feel free to stay back after class after lecture a few students do if you have to any doubts to clarify and if there are questions that I believe will be of benefit to the entire class I will take it up and I will also answer those questions repeat the answers in the next lecture that is present.

So, let me pause for a moment if you have any questions on what we have talked about. Today we have talked about lot of non cellular technologies and what they are doing and any questions on what we have covered today. So, the question is what is the role for satellite; the element to keep in mind is any satellite link we will have longer transmission delays compared to a terrestrial system and particularly if you are talking about a medium earth orbit or a geostationary orbit, the transmit power required is going to be more. So, the satellite based a communications are OK, if where there is no form of terrestrial coverage, but when terrestrial coverage is present satellite communications always becomes a more expensive technology because you need more power, you need to have you know more expensive equipment; when it comes to connecting a devices satellite will definitely not be at a option because the power required will not be anywhere close to what these low optimize power systems will achieve.

So, satellite has got a role, but it is only where there is no coverage today terrestrial coverage today you know if you over the ocean there is no coverage its satellite phone is the best way to communicate, but you know, but if you are in a metro definitely satellite would not be a good option not for voice not for a machine communications. Let me just show you one slide and then I will pick it up from there.

(Refer Slide Time: 51:14)



Basically when we talk about smart x probably the most common thing that from a communications perspective that will happen and how a huge impact is adding communications to the electricity grid; I just explained in one minute what this means and then we close with that.

So, today the way the electricity works is that you generate you have a generation point then there is a transmission point typically at some high voltage 110 k b or some and then there is a distribution system I T has got a distribution system which is on a 11 k b ring, and then you have your customers like your hostels or a residences where it will it that is come it is converted from 11 k b down to 440 volts and then you supply the supply the customer. The future, when you start doing things the first thing happens is let us say the customer is generating a renewable energy and wants to feed it to the grid. So, the customer should be able to tell the network how much they are producing and how when they are producing and they are going to be feeding it.

So, the flow of power is no longer one directional it is now bidirectional. So, basically there is in a there is power flow from the customer onto the grid, now you have to measure how much power the customer is feeding. So, that is the metering part you must also know when the customer is going to ask for power. So, basically consumption that information is through smart meters and through smart appliances. Now you as a customer can no longer have to buy only from one power source you can buy power

from in the future probably from your neighboring state or from a third party who is willing to your supply. So, basically there is going to be dynamic pricing just like stocks everybody is going to be putting up their prices and then you optimize and say that I am going to take it at this time. So, what we see today as the grid is completely changing because of the introduction of renewables, because of introduction of a dynamic pricing and the ability to buy power not only from your a local the distribution agency, but from anywhere in basically from a variety of other sources.

So, this is something which we believe will be a good model for a smart grid and what type of communications will be needed in a smart grid type. So, we will just spend a couple of minutes trying to answer that question and then bring the whole discussion to a close at the start of the next lecture.

Thank you.