Wireless Communications

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Lecture No. # 02

Types of Wireless Communication

Let us look at the types of wireless communication systems available today. The first and the foremost is the radio transmission systems. This was one of the earlier systems and are popular till today because they can be very easily generated and also designing the hardware is easy for them.

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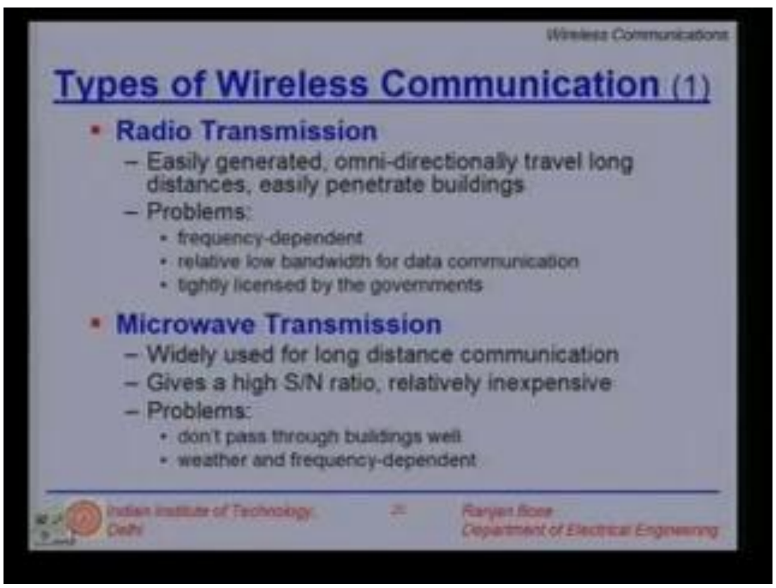

Of course, there are some associated problems like frequency dependency which means raise at a certain frequency, get attenuated differently, then raise at another frequency. This enforces the basic philosophy that air is a band pass channel. Then we have relatively low bandwidth for data communications. For voice, it was good. When we talk about radio, we automatically think about voice related communications. However today, data graphic is more than what the voice traffic is. We have to cater to voice as well as data transmissions. Therefore radio transmission will soon give way to other higher frequency transmission methodologies like microwave transmission. So the next method of wireless communication is to use microwaves which is at a slightly higher frequency & smaller wavelength. Clearly you can use them for long distance communications. Given a high signal to noise ratio they are relatively easy to make, manufacture and use. The associated problems are that they do not pass through buildings very well. Consequently microwave links are point to point- line of sight.

So many times when you are driving down the highways, you will see tall towers periodically placed with parabolic antennas. They are usually the microwave, point to point- line of sight links. These microwave transmissions are also weather dependent as well as frequency dependent.

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Some other types of wireless communications are infrared and millimeter waves. So we are going higher on the frequency spectrum and consequently, we deal with smaller wavelengths. The moment we talk about mm wave, we are touching the 30 GHz frequency band. These are used for short range communication simply because we get a high level of attenuation for millimeter waves. Infrared does not pass through solid objects and walls. We use IR for your remote control in the TV but today IR can be used to build a small personal area network. We also have light wave transmission. These are unguided optical signal such as lasers. We can have point to point links that serve as interconnectivity between buildings. These are unidirectional and easy to install. They do not require a license. The associated problems are that they are unable to penetrate through thick fog or rain.

Conversation between student and professor:

The question is what is the range for infrared communication? Usually it can be about ten meters or so. That is, we can only use it within a large room at the most. Millimeter waves also suffer from this problem. So when we look at millimeter wave communications or ultra-wide band which is not exactly millimeter wave but it goes up to 10 GHz, we are confining ourselves to 10-15 m only. A term “personal area network or PAN” which has come up is the immediate application for these kinds of infrared and millimeter waves.

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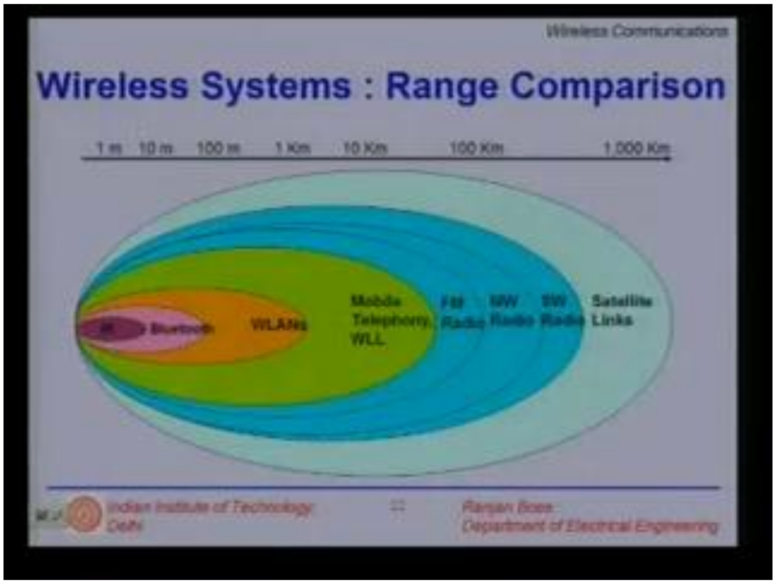

This slide gives a bird’s eye view of the range comparisons and this will answer your questions. If you see on the left most, we have the infrared which is suitable for personal area networks. Just beyond it is the pink circle which is an application coming into the picture. It’s the Bluetooth that is popular. Then up to a 100 m, we have the wireless LANs ‘local area networks’. In this, we have the popular 802.11 B. the WiFi systems, for example. Today we talk about hot spots. So you can go to barista and probably have a hot spot or go to an airport where we have WiFi enabled areas where you can switch on your laptop and you are on the network. Of course, if you go out of the airport, you lose connectivity. So the orange line shows the range comparison for wireless local area networks.

The green ellipse is the mobile telephoning wireless on the local loop. We go into km or tens of kilometers at the most. Later we will see that the distance or the cell sizes used for cellular networks depends not only on how far the signals go but also on couple of other things like interference and capacity. So we will figure out what determines the size of the cell other than just the propagation issue. In this slide, we are only talking about how far the rays will travel provided the input power is fixed at a certain level. Then we go to the blue circles or ellipses here which comprises of FM radio and microwave short wave. This can go beyond the city limits probably up to a 100 km or so. Of course at the end is the satellite links.

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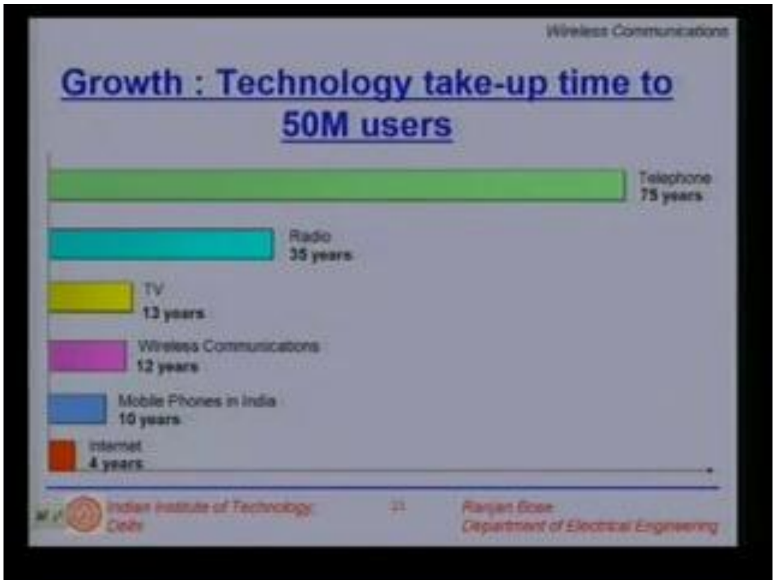

Here we have the growth parameters. This comparison tells us how popular and how fast are these new technologies being accepted. Telephone took 75 years to reach 50 million users. At the same time radio took about 35 years. TV at that time was through wireless. Now it is through cables. TV took 13 years. Your standard wireless communication took 10 years. Mobile phones in India took about 10 years. We have just reached 50 million. An internet took just 4 years because of the nature of the internet. So it tells us that the wireless communication is very much the way to go.

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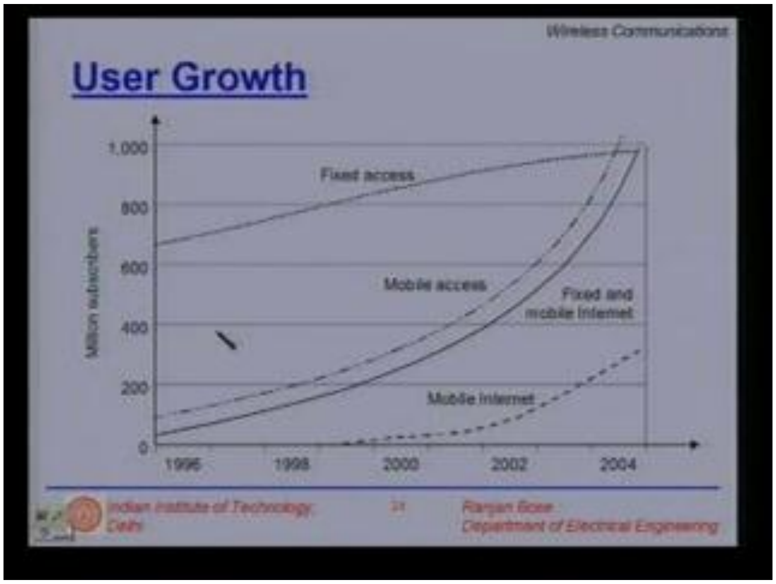

This graph tells us the user growth pattern. On the y axis we have millions of subscribers on the x axis we have the years. So it's up to 2004. What is to be concluded from this graph is the exponential rise of mobile communication systems. A late starter is mobile internet and as we are evolving and getting into the 3G systems, we will have more accessibility of the internet through our mobile phones. So today, a lot of the mobile market is application driven. People talk about killer applications. Here please note I have put fixed and mobile internet. It still is wireless. Its fixed wireless. Today we also talk about fixed broadband wireless access. Another evolving standard is the Wi max, the IEEE 802.16. It is the metropolitan area network. It has a fixed component to it that will give you high speed connectivity for broadband wireless access. So the basic conclusion from this slide is that a good way to expand and improve are penetration in terms of broadband connectivity in India is to go for wireless fixed and mobile connectivity.

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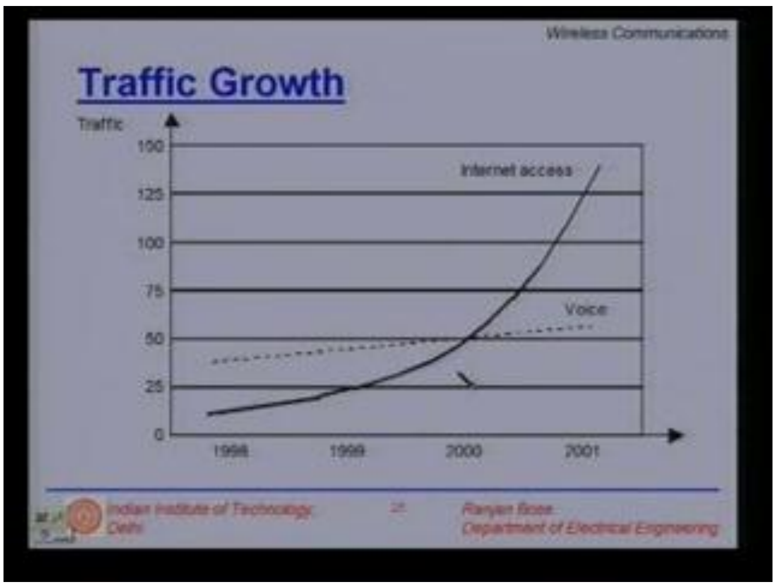

This is a traffic growth. This is instructive in the sense that I have plotted the voice growth pattern and the internet access which is basically the data. One is growing linearly. The other one is exponential. Today, there is more data traffic than voice.

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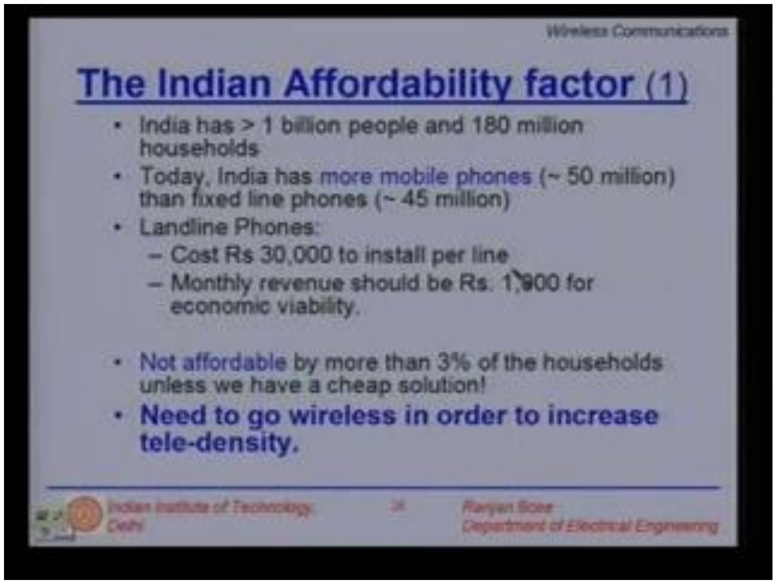

In the next couple of slides let's look at the Indian affordability factor from the perspective of telecom systems especially wireless communication systems because this will drive the growth in the Indian scenario. Today India has over 1 billion people and only 180 million households. It's important to note this figure because most of the telecom equipment will be purchased base on a household. Today India has more mobile phones, about 50 million than fixed land phones as of January 2005. An interesting comparison is the landline phones cost about Rs. 30,000/- to install per line. To recover the cost, if we look at the loan from the banks, etc. it's about 1000 for economic viability. so really if you put in a land line phone from scratch, the subscriber must pay about a 1000 rupees every month so that you can recover the cost. Anybody can say that this is not the way to go if we are going for rural telephoning. Clearly a landline solution will not give us the desired tele-density in rural areas. Smaller cities will also not be willing to pay 1000 rupees per month. It's important to realize because today most of the technological decisions regarding wireless communications are half business decision and half technology decisions. So it's clear that not more than 3% of Indian households can afford a landline phone unless we do something about it and the answer is simple. We need to go wireless in order to increase tele-density.

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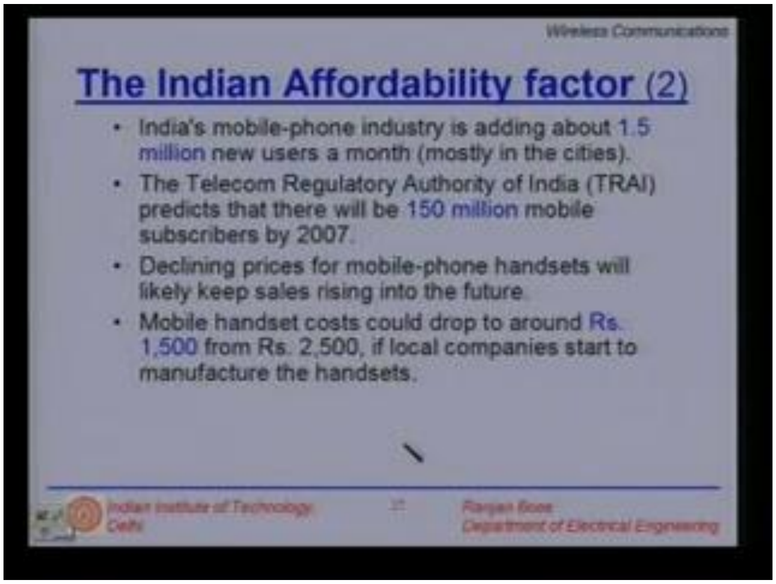

So let's look at some more figures. The Indian mobile phone industry is adding about 1.5 million new users a month. However these are mostly in the cities. I talked about the telecom regulatory authority of India which essentially regulates and makes the telecom policies. TRAI predicts that there will be about a 150 million mobile subscribers by the year 2007. So we are still expecting great growth pattern in the mobile industry in India today. The declining prices for mobile phone handsets will trigger and keep the sales rising into the future. That's essential. So today a handset which costs 2500 rupees, if it goes down to 1500 or less, the growth pattern will continue because of the large geography wireless is also the fastest and the cheapest way to deploy.

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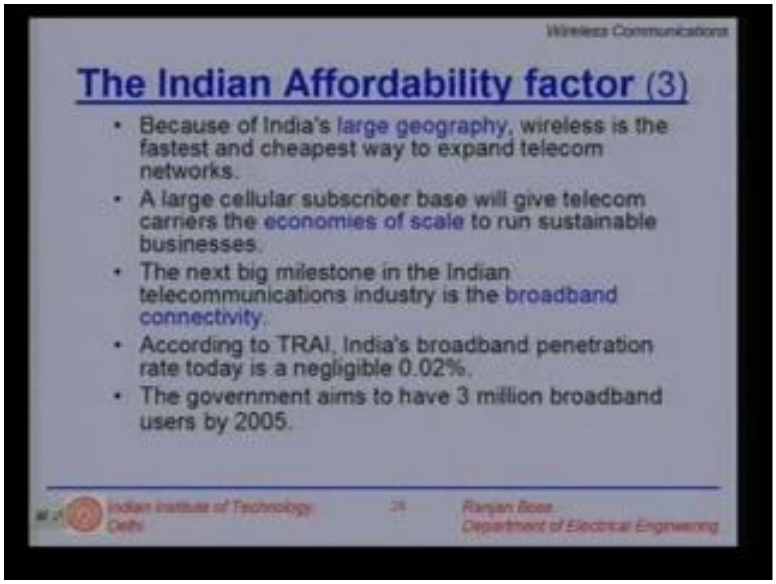

In north east and Uttaranchal for example, people are trying to experiment with the IEEE 802.16, the Wi max which is again an evolving standard to see how well we can depute it. So the trials are going on right now. A large cellular subscriber base will give the telecom carriers the economies of scale .that’s very important. As I mentioned the next big milestone in the Indian telecommunication industry will be broadband connectivity. I should add that it will also be triggered by the wireless broadband access. According to TRAI, India’s current broadband penetration is negligible. It’s almost 0.02%. That’s the place we have to work on. That’s where some of these new standards like Wi max is coming into picture. The prediction is that will have 3 million broadband users by 2005. So the conclusion at this point is we have to do a lot of work from the India perspective. The market is growing but we must know where to focus and what are the current research areas.

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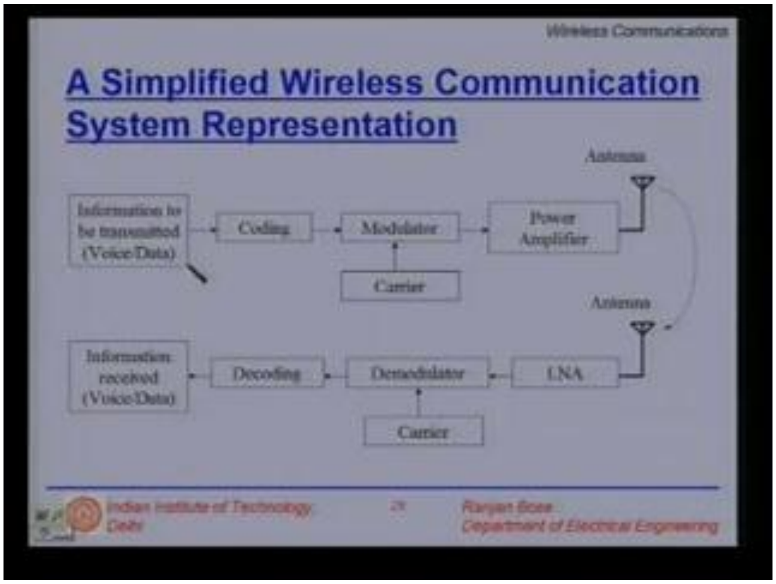

Let us now look at a simplified wireless communication system. We start from the left most block. It is the information to be transmitted. It is either voice or data. We can also add multimedia to it. This could be a person speaking or a person trying to check the internet, download the stock codes or check the cricket update or send a MMS clip to his friend. The data is first digitized whether it is voice or data in the initial format. It is then coded for error correction. So this coding block implies it is getting coded for channel errors. Then we pass it through a modulator and then through a power amplifier on to an antenna. How much power we radiate is also constrained. As we mentioned before, not only a higher power emitted will use up my battery power more, it will also cause extra emissions which can be interference for others. One person's signal may be interference for others so it's like manmade noise. We do not have the luxury to increase the signal to noise ratio just by increasing the power emitted.

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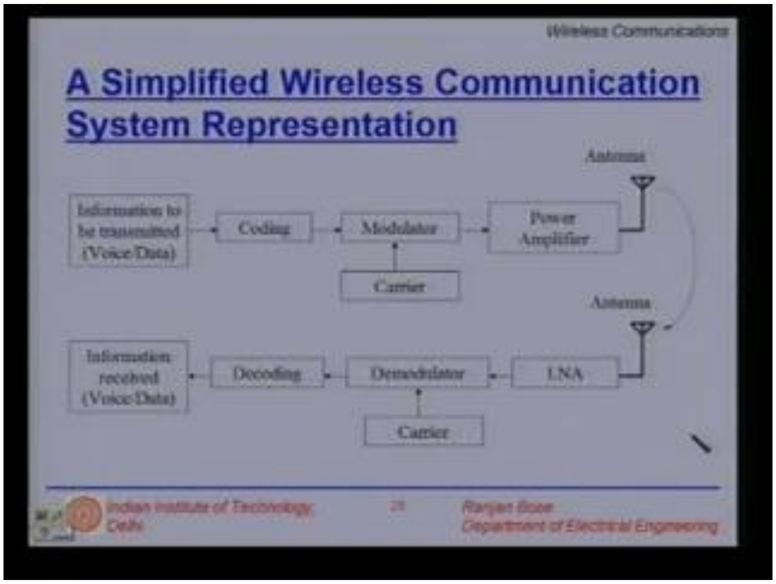

At the receiver's side, we amplify it, demodulate it, decode it and recover the transmitted data. It is the simplified version. As we'll see along the course, we can have not a single transmitting antenna but several transmitting antennas and several receiving antennas. So we can have a multiple input-multiple output system.

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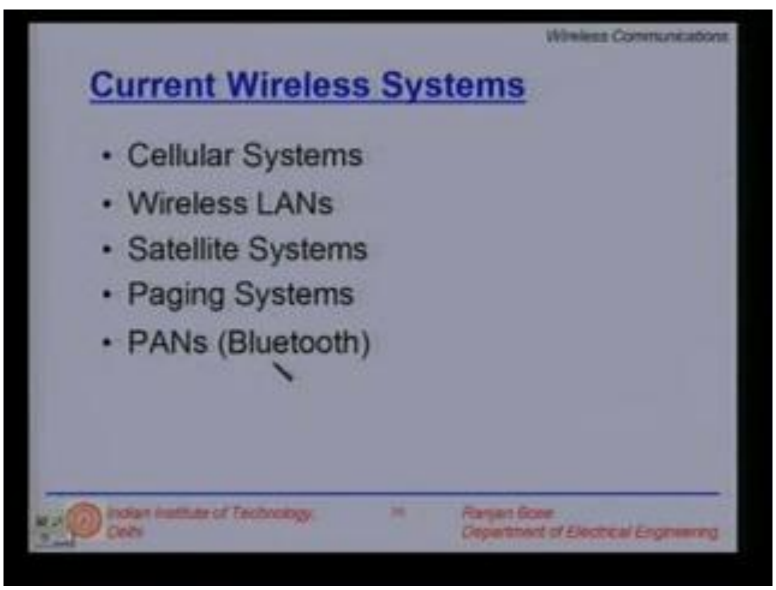

Let us now look at the current wireless systems. The first and the foremost is the cellular systems and we typically says cellular networks because it is a good network. Then we have the wireless local area networks within the home environment, hospitals and labs. The satellite systems and paging systems which have almost been faced out now but we'll still mention them. Personal area networks are the emerging systems.

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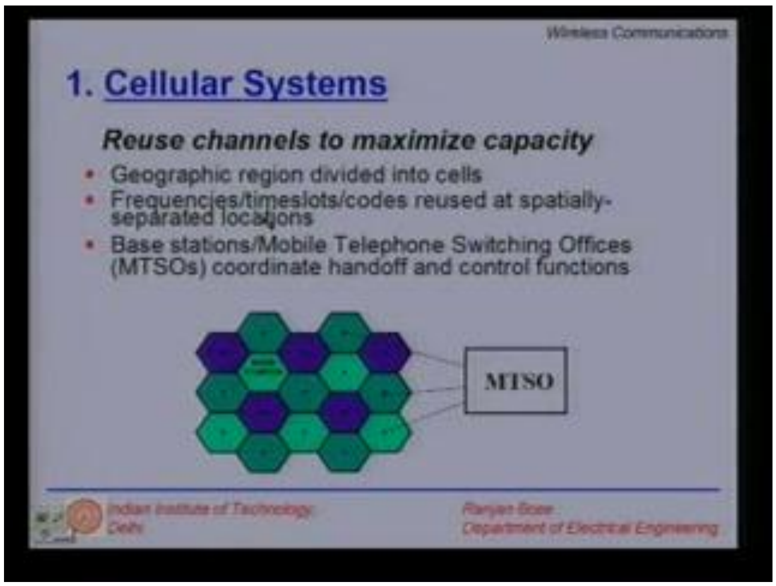

A quick look at cellular systems. The name cellular comes from the fact that the whole area of coverage, a city like Delhi is first divided into cells. We have shown them as hexagonal cells only for depiction. Each cell has a center black point as denoted. It represents the base station base station. However, in real life, the cells are irregular. What determines the cell boundaries? Well, a couple of things. The first thing is the link budget. Link budget is defined as the total power that is emitted and the total power that is received. So if we have buildings or foliage or tall towers in the middle which block the radiation, the received power will be less. Consequently, the cell boundary might get affected. The second thing that determines the cell boundary is the number of people in the cell or the capacity. A cell can only support so many users. For example, if you have an x amount of bandwidth in a cell and if you can support 100 users, the next user that comes in into the cell will be denied service. The other way is the cell shrinks its boundary and only accommodates enough number of users that it can support. In some cases like the CDMA systems, the cell boundaries are not fixed but adaptive. The third thing that determines the cell boundaries is the interference. Where does interference come from? Well, we talked about something called as a reuse of frequency. If you see in this diagrams, there are blue cells which are spaced apart. There are light green cells and the dark green cells. Cells of one color are using one certain frequency band. The frequency is being reused assuming that the reuse distance is such that the received power is below a certain threshold but still it causes co- channel interference.

An interference which is coming from a cell which is using the same frequency is called the co channel interference. Sometimes we would have a lot of co-channel interference because our user is at the boundary of the cell and sometimes the co-channel interference can be less. So co-channel interference itself will also determine what the size of the cell is at the designing stage. In real life, cells must be over lapping as opposed to what is shown here in the diagram. Here, no cell is over lapping. There is a clear cut boundary. However, when we go from one cell to another, a process called ‘hand off’ takes place where one base station hands off the call to the next base station. If there is no overlap, it is very difficult to make before break the connection. In CDMA systems this overlap is phenomenon. In GSM systems it is much less. In any case at a given time for example my mobile phone gets good signal from more than one base station. It maintains a list of good base stations where effective single power is received and it chooses which base station to talk to. So I can be sitting in this room and my mobile phone displays to which base station it talks to and after half an hour, the base station may change even though I have not moved from my chair. This simplifies to the fact that at the same time, we have good connectivity and good signal strength from more than one base station and that is simply because there is enough overlap.

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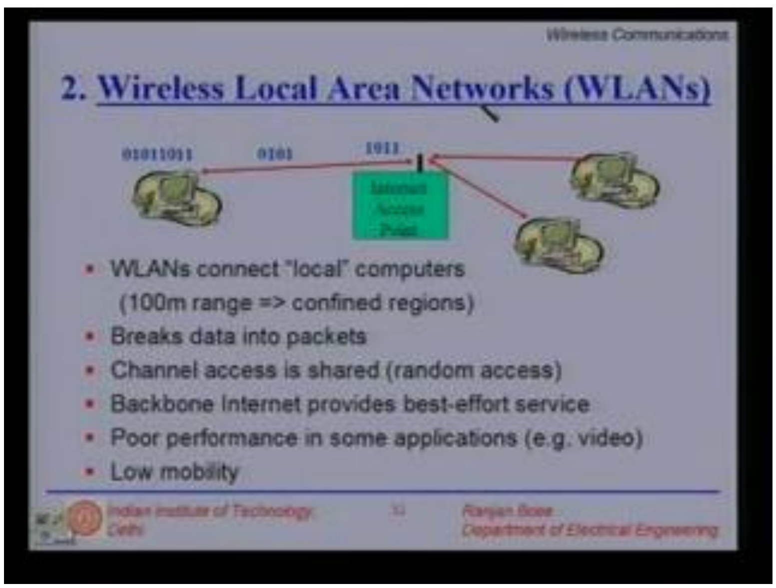

The second system that we can talk about is the wireless local area networks. The concept is simple. You have to have an access point mentioned here as an internet access point. Since it’s a local area network confined to a few hundred meters, you have couple of loads here. We connect local computers and hence confined regions. It breaks data into packets and sends the various protocols. The channel access is shared. So a very important part of the design of wireless local area network is the MAC layer, ‘the medium access layer’. The backbone internet provides best effort service. There can be poor performance in some applications like video simply because of the channel sharing problem.

This is low mobility or you can group it under the heading ‘portable applications’. Today a good example is the IEEE 802.11 B based wireless LAN.

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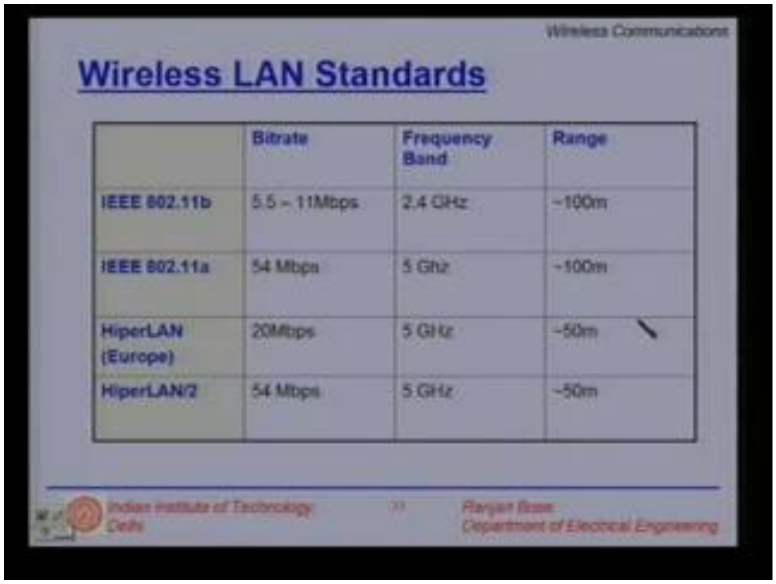

	Bitrate	Frequency Band	Range
IEEE 802.11b	5.5 – 11Mbps	2.4 GHz	~100m
IEEE 802.11a	54 Mbps	5 Ghz	~100m
HiperLAN (Europe)	20Mbps	5 GHz	~50m
HiperLAN/2	54 Mbps	5 GHz	~50m

So the IEEE 802.11 B has a bit rate from 5.5 to 11 Mbps. The ISM frequency band is 2.4. It is license free and the range is about 100meters. IEEE 802.11a has a bitrate of 54 Mbps and newer versions are coming up which can take it to 108 Mbps. It works at a frequency of 5GHz and again the range is about 100meters. European Hiper LAN has a bitrate of 20 Mbps. It operates at a frequency band of 5 GHz and has a range of 50 meters. So this gives you a typical order of magnitude range and the data rates.

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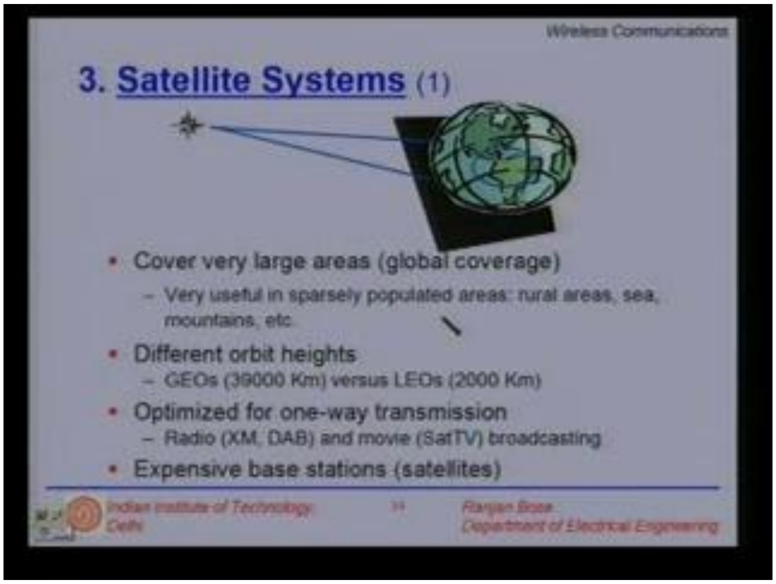

The third is the satellite systems. They cover very large areas. It's good for global coverage. It's very useful in sparsely populated areas like rural areas, the sea, mountains and the areas that are hard to reach. There can be different orbit heights. The GEO stationary satellites verses the low earth orbit or LEO satellite systems. Clearly the LEO satellite systems are not GEO stationary and so they keep on moving and they move in and out from an area of coverage. So a LEO satellite which was having a foot print on Delhi half an hour back might have moved out by now. And so I need a constellation of satellites to make sure that each area is covered all the time. This is a funny scenario in wireless communication where the base stations are mobile and most likely the user is static. So the cells keep moving. Hand over takes place not because the user is moving but because the base station is moving. They are optimized for one way transmission like satellite TV.of course the cost involved is very high.

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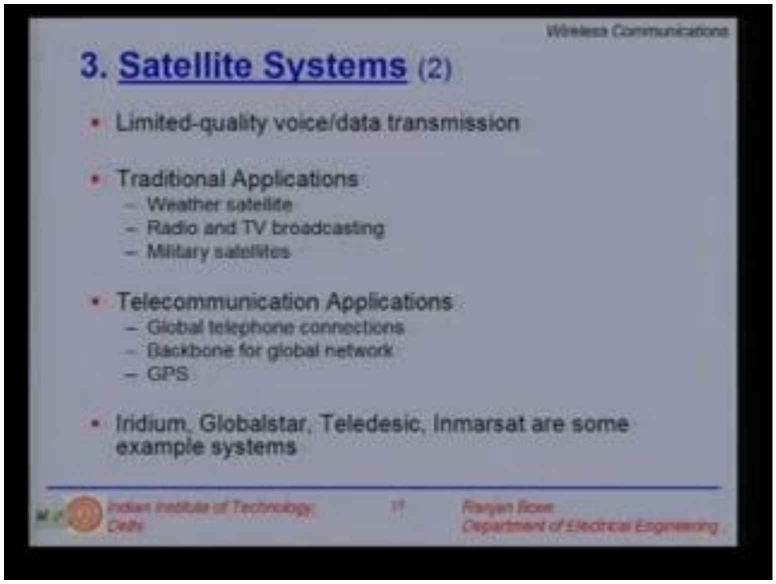

Satellite systems have limited quality voice data transmission. Of course this can be improved today. You can allocate larger chunks of bandwidth and improve upon the quality of voice and data. The traditional applications are weather satellite radio and TV broadcasting military satellites. Telecommunication applications are global telephone connections. They also form a backbone for global networks and the GPS. So today GPS is one of the important applications which is driving the sale of GPS modules. Today you can track fleets of trucks and ships through GPS. some of the expensive cars come with GPS enabled systems that can tell you which way to go or what is the best way to go from point one to point two and various other applications. I can have a GPS based car security system where suppose my car is stolen in the night, in the morning I can know where exactly my car is and I can remotely shut it down if I have a GPS GSM enabled module setting. So these are some examples where you can combine two technologies and develop a killer application. GPS stands for global positioning system. Some of the examples are iridium, glob star, teledesic etc.

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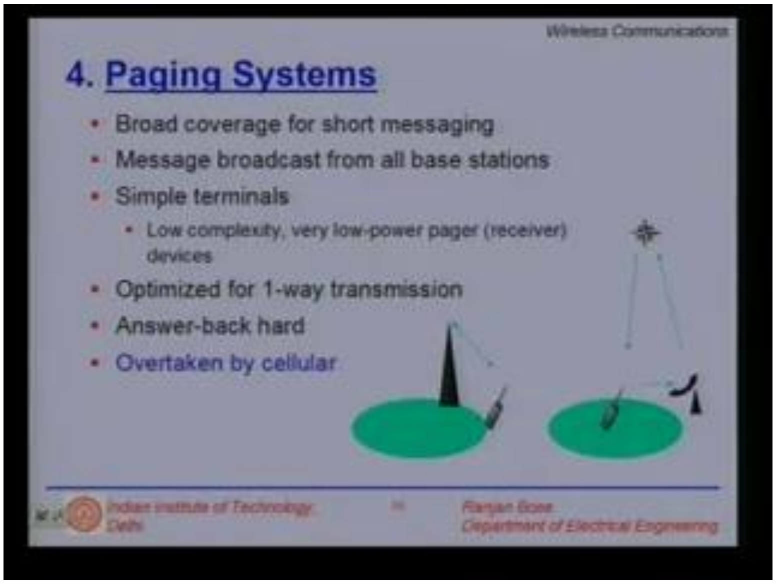

The forth example is the paging systems. These have now been faced out because your mobile phones also work as pagers. All you have to do is give a missed call and you can be paged. But just for the sake of completion, paging systems provide broad coverage for short massages. Message is done in a broadcast mode. So all base stations radiate and your pager will respond to the cell you're sitting in. It has simple terminals, low complexity and low power consuming optimized for one way transmission but answer back is hard. Unfortunately today it has been over taken by cellular communications.

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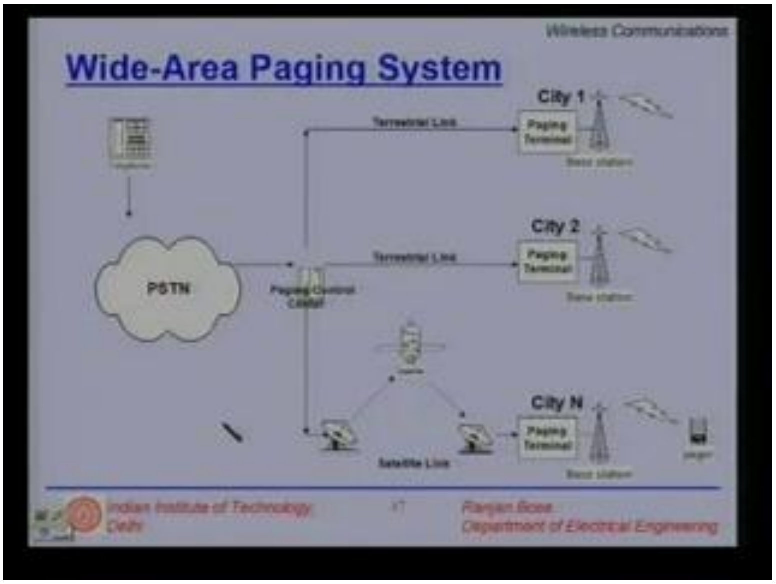

Student: Sir, what do you mean by optimized for one way transmission?

Professor: Paging systems can receive information. Suppose I have a pager. It's a 3 cm x 2 cm box which I carry in my pocket. I call the paging number and I will get a beep and it will show a very short message, 'please call back this number'. But I cannot use the pager to say 'okay, I will call back in ten minutes'. I have to go to a local phone and make a call. So it is optimized only for one way communication. Today I have a mobile phone. You send me an SMS, I can send you back an SMS. So it's a two way communication. I can call you back on the mobile phone. This is an example of a wide area paging system where you make a call to the pager number which is like a telephone number through the PSTN which is 'Public Switched Telephone Network' and it will be transmitted through different base stations. It could be in different cities. So I can be paged in Bombay or Chennai from Delhi.

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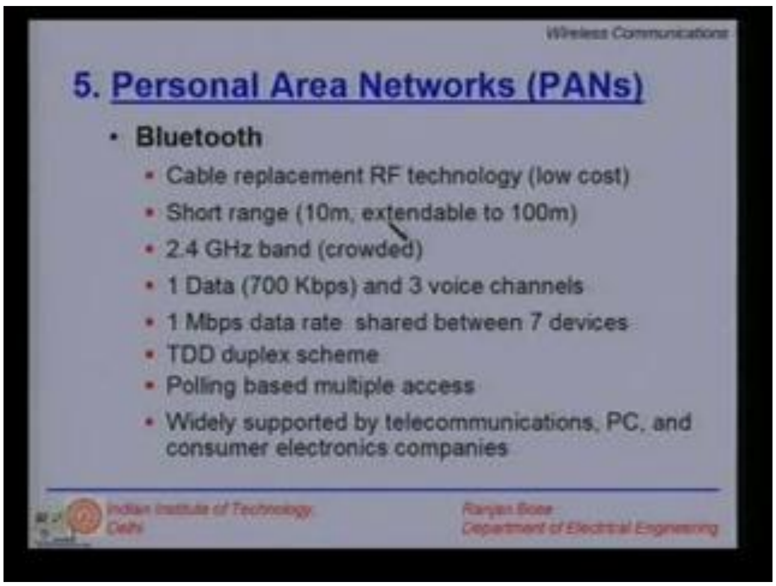

Student: sir, how does a pager get the information to call a number?

Professor: it is a short messaging system. So a pager also has a receiver which takes in digital data. So when I send the data from the base station, I also send a packet which tells me the short message that is to be done. The pager has a small LCD display. Pagers were very popular 5 years back. But now it's very hard to by a pager. So these are some examples of how fast the telecom system change.

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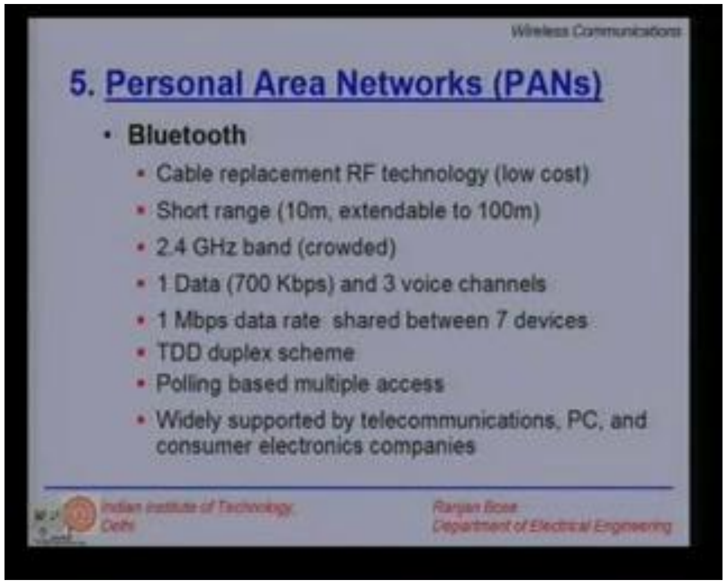

One of the newer systems is the personal area networks like Bluetooth. A good application would be to connect my PC to the printer without the use of wires. However the big brother of Bluetooth, 'the UWB' systems are evolving and it is predicted that very soon UWB or the ultra-wide band communication systems will overtake Bluetooth. the name Bluetooth comes from an ancient king in Norway who tried to unite a lot of small warring nations at that time and the simile holds that at this time, you can unite a couple of applications like the printer, the scanner, the speaker or couple of other small devices to your computer. So that's the origin of the word Bluetooth. Please note it also works on the already overcrowded 2.4 GHz band. The data rate is not good. Hence it will fall free to the advances of the ultra-wideband communication systems where we are going to talk about almost an order of magnitude or more improvements in the data rate per system. At most, seven devices could be connected. Today the consumer electronic market has incorporated Bluetooth enabled ports in most of the systems.

Student: sir why is there limitation that only seven devices can be connected?

Professor: this is a part of the Ad hoc standard. They thought that 'okay, let's think how many devices can I connect to my PC'? I can connect a printer, a scanner, may be my camcorder my mobile phone, speakers or even two printers. So they thought that I will form a piconet, the smallest form of network where my PC will be connected to seven or eight maximum objects. But they have put a limit on seven devices. There is no sacrosanct reason why it should be only seven and not ten. However in UWB, you have no limits.

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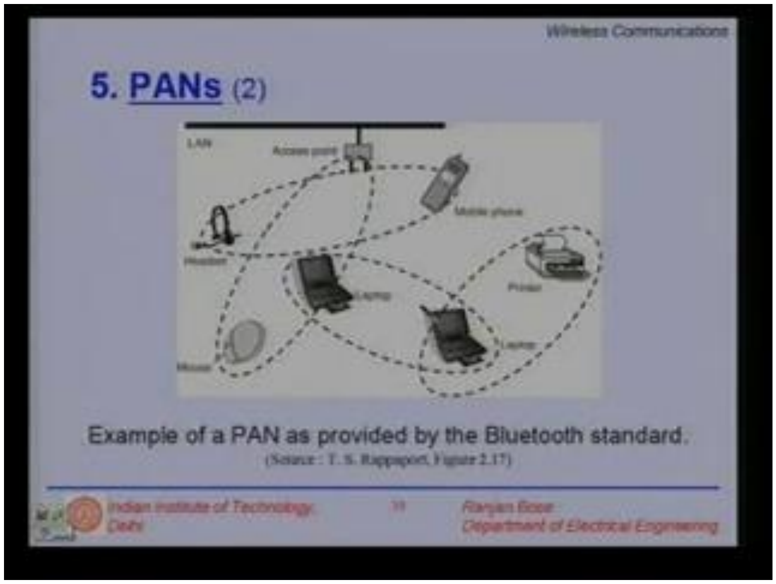

Let's look at an example of a Bluetooth enabled network. You always have an access point which is connected to a local area network. Bluetooth form this own piconets. So I can have a headset but today I am bogged down because of the wire from my headset is coming to the walk man. Why should there be a wire? My mobile phone is connected to my laptop. Why should a wired mouse be there? But I really have to think hard to get more than seven devices to be connected to one piconet.

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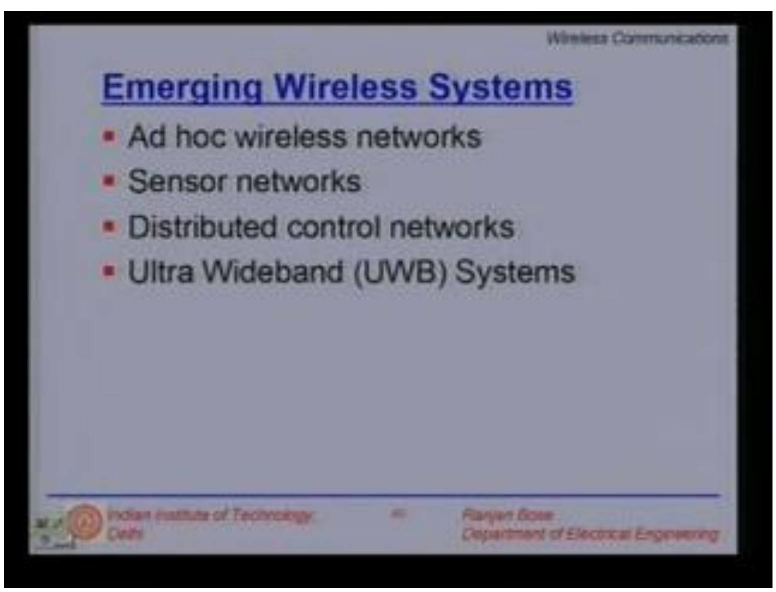

Now there are some emerging wireless systems which are fresh from the oven. One of the evolving technologies is ad hoc wireless networks. We'll briefly talk about it. Then another thing which is being said to be one of the enabling technologies is 'sensor networks'. Sensor networks would be instrumental in predicting massive disasters. For example, the tsunami disaster could have been less devastating if a good sensor network was in place. Earthquakes, forest fires, floods, etc. can be predicted by sensor networks or at least advanced warning systems can be generated. Another evolving technology is distributed control networks. The ultra- wideband communication systems are another emerging system. Let's briefly look at each one of them.

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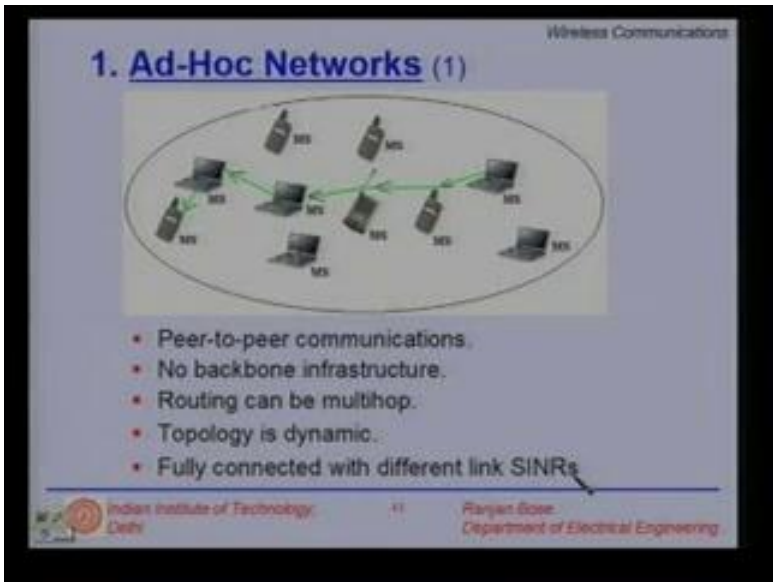

First the ad hoc networks. As the name suggest this has no fixed topology. It's not a star network or a ring network. Each of the nodes become a router. When somebody switches off the phone or the laptop, that node vanishes and the network must reconfigure. Let me give an example suppose we go to a conference and 20 people have laptops. All of them have the ad hoc network software loaded. So the moment they switch it on without realizing, they form an ad hoc network. So they can communicate from one node to another node through this network. You need to have peer to peer communications. There is absolutely no backbone infrastructure. The routing can be and mostly likely multihop as shown by the green arrows. The topology is dynamic. I can pick up my phone, go and sit and some other place. I can switch off my phone, suddenly I switch on my second laptop and it forms another node. So the topology is dynamics. Somebody has to keep track of it. So the MAC layer 'the medium access control layer' again has to be very well thought of and fully connected with different link signal interference noise ratios.

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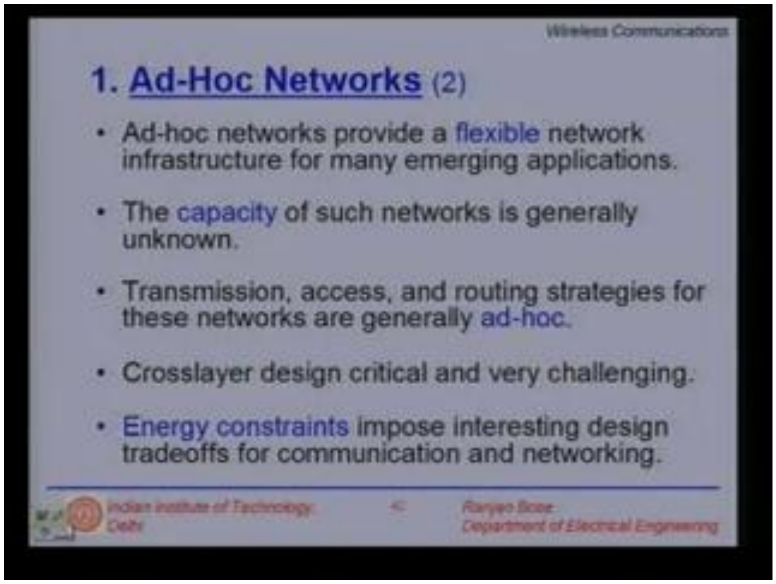

Ad hoc networks provide a flexible network infrastructure for many emerging applications. The capacity of such networks is generally unknown simply because we do not know how many nodes there will be at any time. The transmission access and routing strategies for these networks are generally ad hoc. So there is no 'one formula' that fits all ad hoc scenarios. It has to be adaptive. cross layer design is critical and very challenging like physical layer, network layer, transport layer and of course, energy constraints impose interesting design tradeoffs for communication and networking because we are making each one work as a router.

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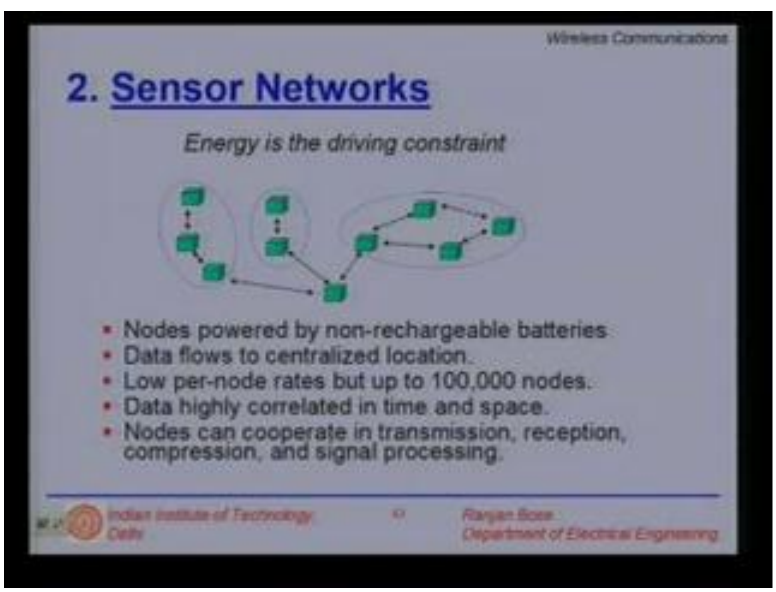

The second emerging area is sensor networks. Here energy is the driving constraint. If you look at the diagram, the green boxes are the small nodes of the sensor networks. Today a word has been coined for them. They are called ‘modes’. The pioneering work was done in Berkeley and they also called ‘Berkeley modes’. These are nothing but small radiating device with little bit of intelligence built into it. They can be as small as just a few centimeters to as large as about ten centimeters and I can put these sensor networks at designed places. For example, if I am looking at earthquake prediction systems, I can put in these sensors at different places in the buildings, under bridges, on roads where I can detect and they can communicate with each other and pass on the information to an advanced processing system. Nodes are powered by non rechargeable batteries. So, some of the modes that you can buy today can last upto 5 years without recharging because if I put up a sensor network to determine forest fires, I cannot go to the forest every year to change the batteries. So, one of the big constraints is energy efficient design. The data flows to a centralized location where it is processed. It has low per node rates but up to a million nodes. Here I have written about ten thousand but you can you can go up to a million nodes. The data highly correlated in time and space. The nodes can cooperate in transmission reception compression and signal processing. So each node can be equipped with basic intelligence. It could be a microprocessor which can process the information and then pass it on.

Conversation between student and professor:

The question being asked is: are sensor networks a subset of ad hoc networks? The answer is yes. But these are something special in the sense that each of the nodes must have a sensor built into it. The job is primarily to sense some kind of an information may be vibration or heat or light and then pass on the information. It is a subset of ad hoc network but for a very specialized purpose. But because of their importance, today sensor networks are treated differently. The problems are specific for sensor networks. Ad hoc networks solve general problems. Ad hoc networks will also have ad hoc routing protocols. Sensor networks will most likely have a fixed routing protocol. Sensor networks are more fixed in terms of its MAC layer.

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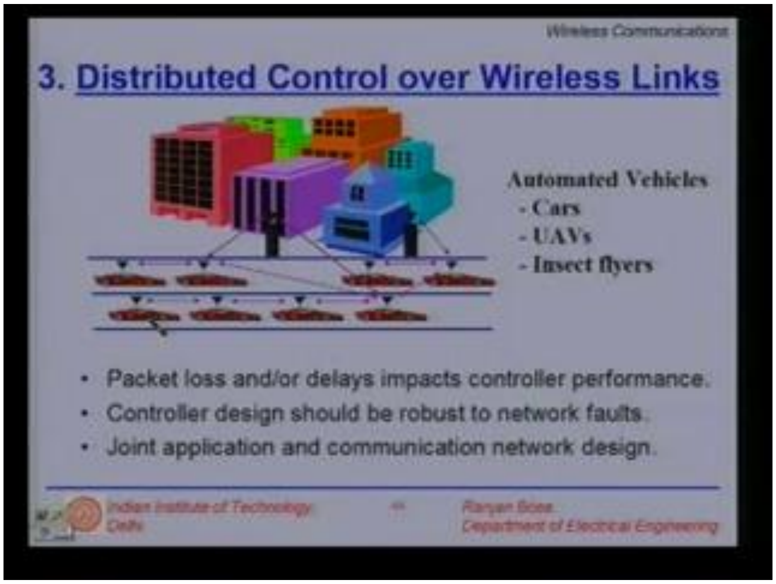

Another emerging wireless area is distributed control over wireless links. Since it is wireless, and have access to several mobile computing resources, why not distribute the computing. Here the problems are packet loss and delays impacts controller performance. Controller design should be robust to network faults. It has joint application and communication network design. You can have automated vehicles which form a part of this distributed control over wireless links. So I can easily manage traffic and figure out through these different nodes in the networks. How to best rout my next set of cars?

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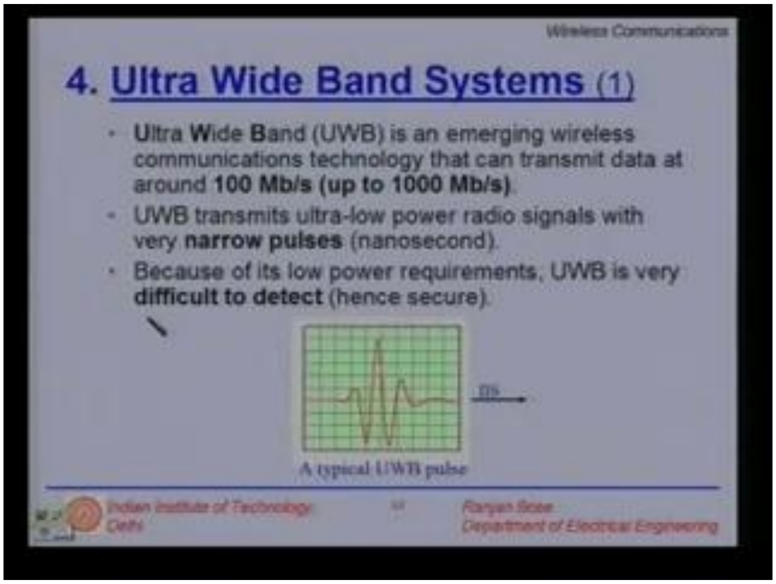

The forth emerging technology is the UWB or the ultra-wideband communication systems. it's an emerging technology and can transmit datas at around 100 Mbps. the next generation UWB systems can go up to a 1000 Mbps. it is still being worked on. UWB essentially transmits low power radio signals with very narrow pulses of the order of ns or even sub ns. There is another school of thought where the ultra-wideband or the large bandwidth allocated for UWB communications is sub divided into sub bands and then within each band, you send pulses. So the pulses are broader in that sense. Generating nanosecond or sub nanosecond broad pulses is a challenge in itself. The receiver design also poses many challenges. However, because of its low power requirements, UWB is very difficult to detect. It is almost in the noise flow and hence inherently secure. Long time back, UWB was very much related to defense applications. Today it is being used for commercial applications.

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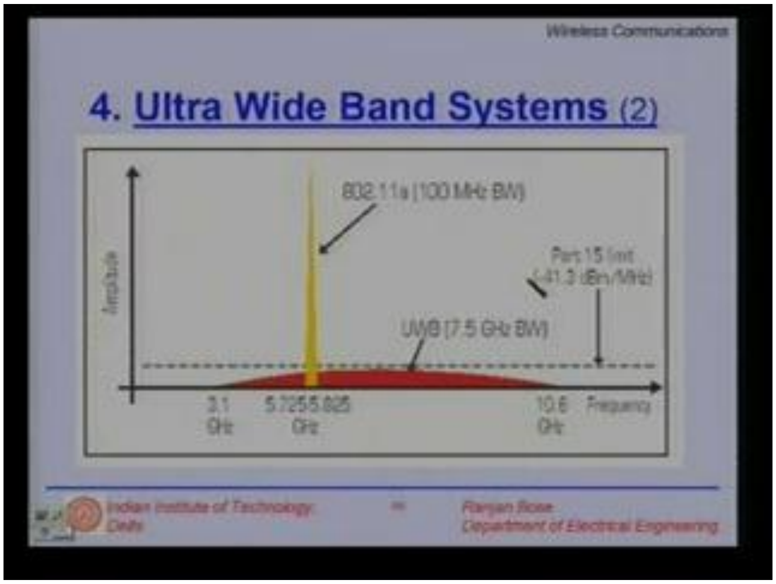

In this slide we have the frequency domain representation for the UWB systems. In the red region, you see the frequency band allocated for the IEEE 802.15.3. It starts from 3.1 GHz up to 10.6 GHz. that's a total 7.5 GHz of bandwidth. It's a huge bandwidth in comparison. Please note the bandwidth allocated for IEEE 802.11 A. it's a meager 100 MHz of bandwidth. On the y axis is the amplitude plotted. You can see that UWB has very low power of transmission. In fact, a dotted line here represents the part 15 limit set by the FCC. This essentially translates to the noise flow. A lot of appliances which work at around 2.4 GHz typically radiate unnecessary power below this dotted line. So anything below the dotted line is acceptable. UWB interestingly has been designed to emit below that level. What does it mean? It means I don't need any license. Let's look at the other salient features of UWB.

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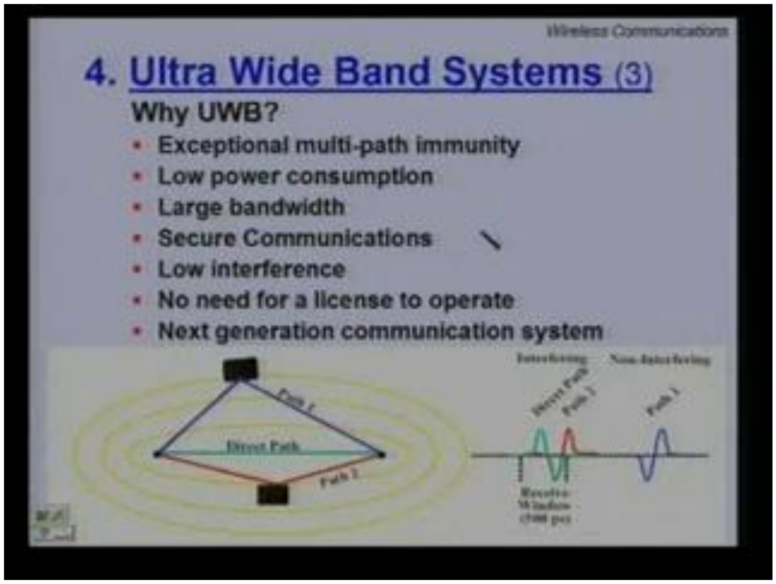

First, exceptional multi-path immunity. Please look at a diagram here. You have a transmitted on this side and a receiver in a room environment for example. There is a direct-path. There is path one through a reflector. It could be a wall or a table and another reflector in the room. For these three paths, what we receive here are the direct path which comes in the first, then the path 2 which is a shorter path and then a longer path because of the distant reflector. What is interesting is each of these pulses are so narrow. They are nanosecond wide or sub nanosecond that each pulses can be resolved. If they can be resolved, they really do not interfere with each other. The effect of multi-path is gone. It takes care of most of the difficult problems related to multi-path fading.

Conversation between student and professor:

The question being asked is: how does it translate to the complexity of the receiver?

The answer is yes, you have to design and carefully design a receiver which can pick up one, two or intended end reflected path. A name for such a receiver is REC receiver which actually picks up energies coming through different paths. Later on when we read about ultra-wideband, we will discuss the design of a REC receiver system. The point to be noted from this diagram is the problem of multi-path by definition gets removed. There is low power consumption to give you a feel. Today a cordless phone or your mobile phone needs to be charged every night because the talk time can last at most one day of normal talking. Suppose you had a home area network where instead of the cordless phone working on the 900 MHz CT technology, it was working on UWB. You have to charge your phone once in six months. That is the saving in power. However I am talking only from the transmitted power. If you are doing a digital REC reception, then you have to sample it at sub nanosecond. Your A to D converter must work at that rate and the A to D itself will consume a lot more of power. So those are the designed constraints. The power is consumed not for transmission but for processing. So, one of the challenges of UWB is to make low power hardware for processing of very narrow pulses. It operates in large bandwidth. As I mentioned before, 7.5 GHz will give you humongous amount of data base. It is secure because I am sending noise like emissions which are very hard to detect. It has low interference because I am transmitting at a level which is below the general interference level of other devices. Hence we do not need a license to operate. We do not interfere with the any other emissions and they are going to be the next generation wireless communication systems.

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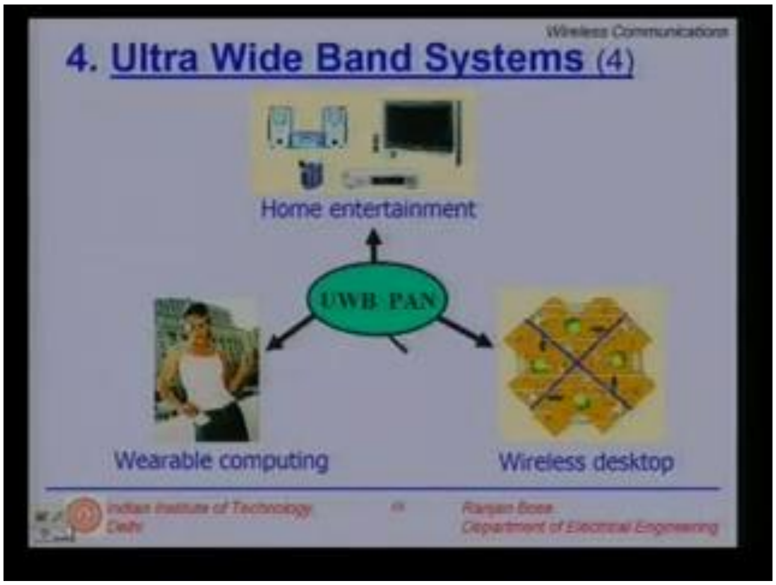

Here are some of the examples where UWB can be used. So as I mentioned before, if I have a TV my music system my camcorder my VCR I can connect all of them wirelessly through UWB applications. I can have a body area network like wearable computing. That's the next generation system and UWB can enable it. So I have a camera here. The Walkman, mobile phone, etc are all wirelessly linked through UWB. I can have a police officer with a gun which is wirelessly linked to a central unit fixed to his belt. So suppose a gun is taken from his hand and it goes beyond a certain distance, the gun will become useless. The criminal cannot operate it. So the gun can only be operated by the police officer. Some of the applications that can be thought around a body area network. A wireless desktop, as I mentioned before, Bluetooth was supposed to do all these things but UWB systems will take over very soon.

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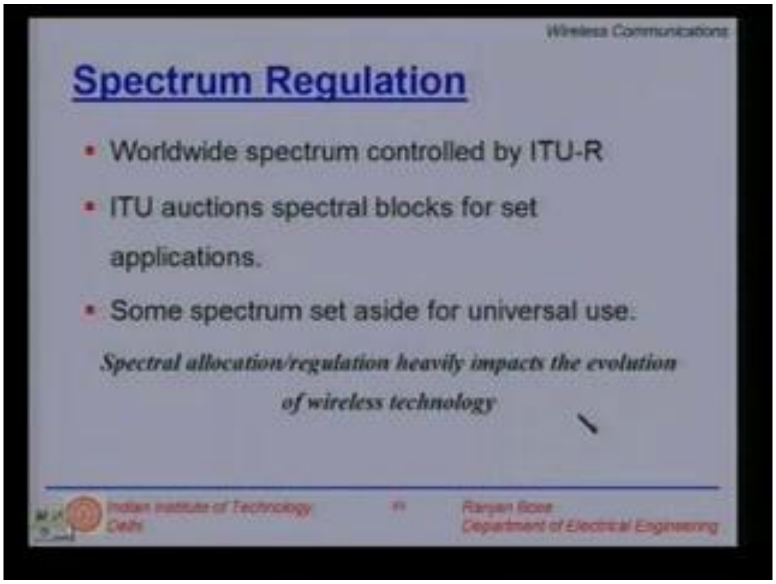

Let's look at a slide on spectrum regulation. UWB doesn't require any license. However most of the other applications do require license. Worldwide spectrum allocation is controlled by ITU-R. It stands for international telecommunication union. ITU auctions spectral blocks for predefined applications. Some spectrum is set aside for universal use. Spectrum allocation and regulation heavily impacts the evolution of wireless technology. Let me give you an example. In India TRAI regulates the spectrum uses. The Indian government also charges a lot of money to license these things. one of the reasons which determines the financial viability and getting into the green of the telecommunication mobile system industries is how much license fee they have to pay. If the license fee is too much that will take a much longer time for them to come out of the rate. So how much money you have to pay in terms of license will determine how much time it will take for you to start making profits.

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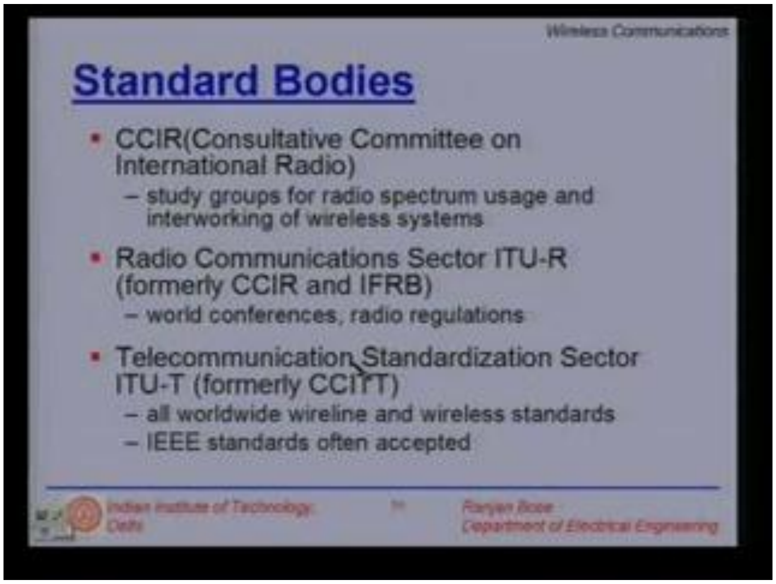

Some of the standardizing bodies are CCIR, the ITU-R and IEEE. So you will be looking at standards certified by one of these bodies frequently. We'll conclude today's lecture at this point. In the next class, we will look at some more cellular systems and other features. Thank you!