Wireless Communications
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Lecture No. # 37
Wireless Networks

Welcome to the next lecture on wireless communications. Today we will focus on wireless networks.

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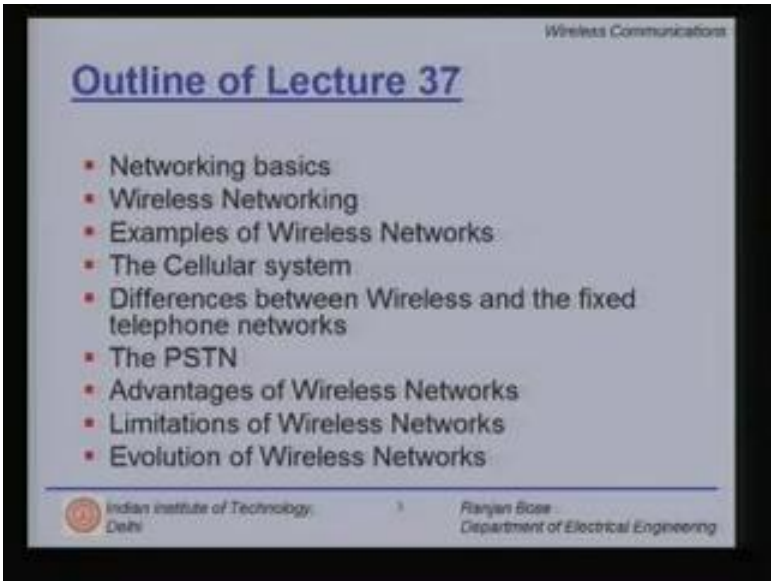

First a brief outline of the talk, we will start with the basics of networking which holds through also for wireless networks then we will focus exactly on wireless networking, we will look at some examples of wireless networks followed by the cellular system and how does it fit in from the perspective of wireless networks. We will then concentrate on the differences between on wireless and fixed telephone networks followed by the PSTN the public switch telephone network then we will look at the advantages of wireless networks followed by some of the limitations.

Finally we'll spend some time looking at the evolution of wireless networks where are we headed to. So this is the brief outline of the talk but of course we will begin by summarizing what we have learnt so far. So a brief look as to what we have already covered.

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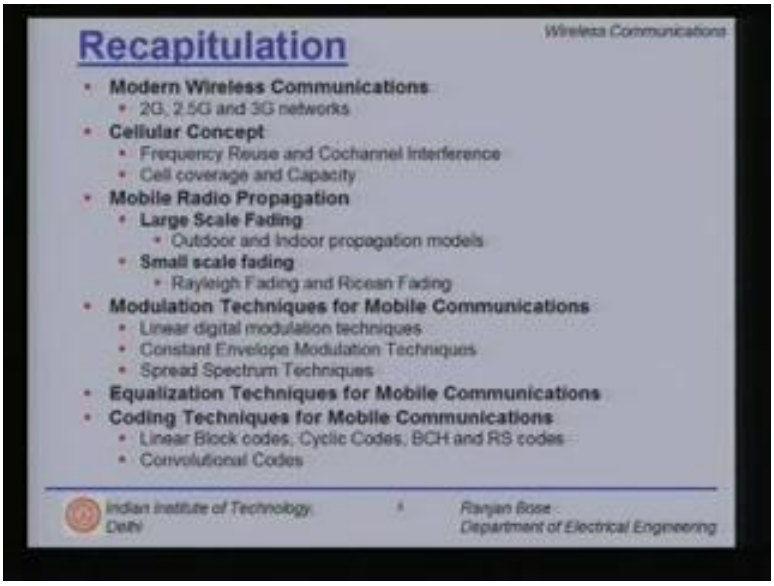

We started off with modern wireless communication systems wherein we looked at the 2G, 2.5G and 3G networks, we will revisit them today also. We then moved over to cellular concept, the requirement to provide high capacity. We looked at frequency reuse and cochannel interference issues followed by cell coverage and capacity. We then focused on mobile radio propagation where we looked at the large scale fading factors, the outdoor and indoor propagation models as well as small scale fading factors, the Rayleigh fading and Ricean fading distributions.

Following this we covered modulation techniques for mobile communication. Specifically we looked at linear digital modulation techniques and constant envelope modulation techniques. We also talked about spread spectrum techniques. Having covered the modulation techniques, we moved over to equalization techniques for mobile communications and finally coding techniques for mobile communications. We focused on linear block codes, cyclic codes, BCH and reed Solomon codes and also on codes with memory that is convolutional codes. So this is the bird's eye view of what we have done so far and today we start with another exciting topic which is wireless networking.

So what are the basics? Networks are a collection of two or more connected computers, hence a network. People can share files peripherals such as modems, printers, CD-ROM drives etc. When networks at multiple locations are connected people can send email, share links to global internet or conduct video conferences in real time with other remote users. So lot of basics pertains to non-wireless that is wide line networks but now these can be easily extended to wireless networks also. So what are the basic components that are required for wireless networks or any kinds of networks?

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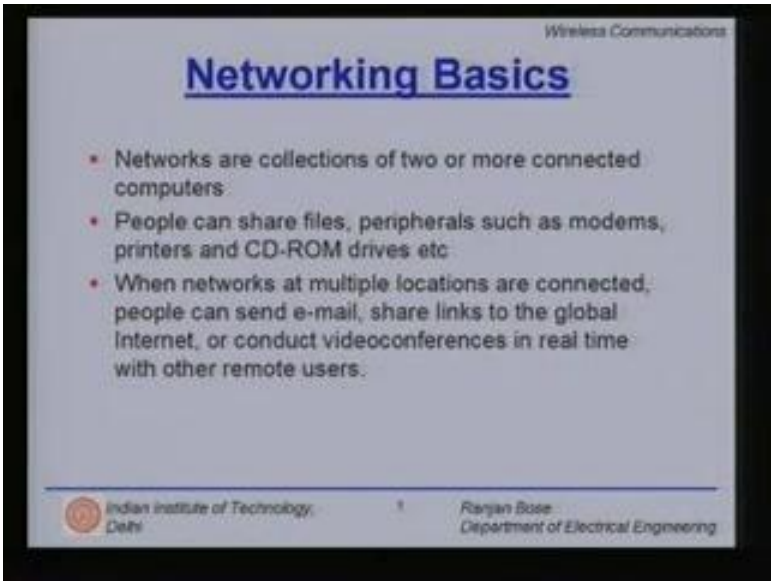

So first of all we need at least two computers, when I say computers these are computing devices. So I can also form an ad hoc wireless network where each one of the components is a small micro controller. So when I say computers they are processing units. So I can have wireless ad hoc networks, I can have sensor networks which are emerging technologies in wireless networks. A network interface on each computer which we defined as a device that lets the computer talk to the network; usually the network interface card NIC or an adopter. In general this may not be a card but could be just an interface. Of course we need a connection medium which could be a wire and also the air which is for the wireless communication channel. Network operating system software, this is the final thing and this can be many kinds but basically this is the software which implements the network layer and above layer protocols.
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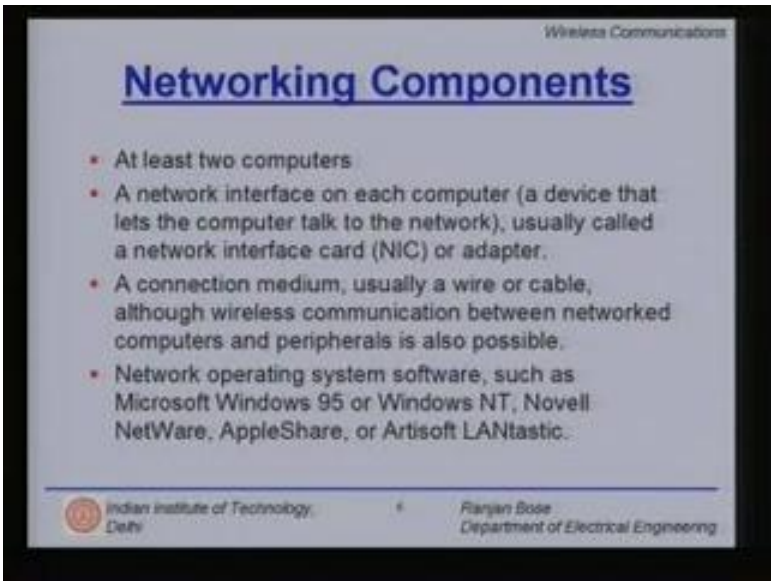

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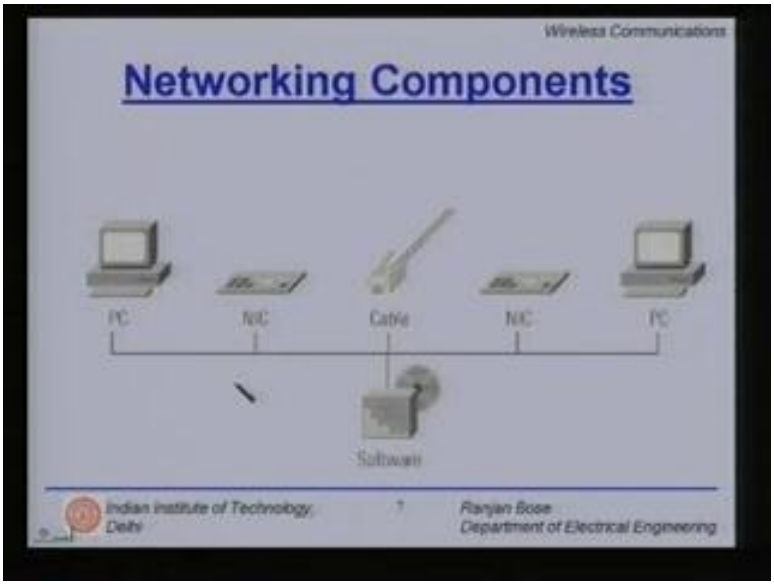

Here is a simple example where I can have PC 1 a network interface card or a cable that can go into it or another PC and a software which controls all of those and I can have all of them being connected wirelessly. Say some using Bluetooth for example I can form of piconet wherein I can connect up to seven devices wireless link. When I talk about ultra-wide band communication systems and we start talking about a wireless desktop then what I mean is my keyboard, my mouse, my printer, my projection device all are connected wirelessly. Hubs; most networks even those with two computers also contain a hub or a switch to act as a connection point between the computers in the network. It's is generic definition, in wireless networking mobile switching center acts as a central hub, this is an example.

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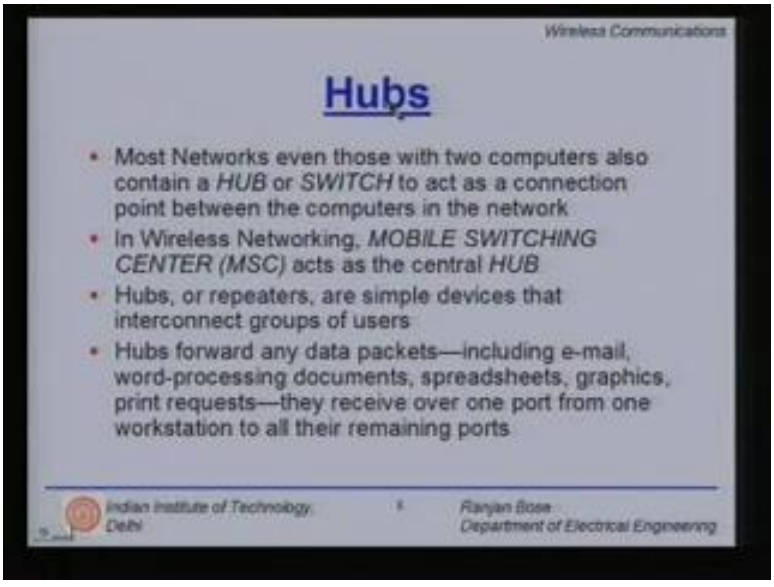

We have come across mobile switching centers in our previous discussions we will revisit it later today. Hubs or repeaters are simple devices that inter connect group of users. What do hubs do? Hubs forward any data packets including emails, word processing documents, spreads sheets, graphics, print request etc that they receive over one port from one workstation to the remaining ports so it's a forwarding device. So I can use a hub to connect to my axis point wherein I can give services to locally wireless local area network.

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All users connected to a single hub or stack of connecting hubs are in the same segment sharing the hub bandwidth or data carrying capacity so the bandwidth is shared. As more users are added to a segment they compete for a finite amount of bandwidth, devoted to that segment. So you have to take this into account.

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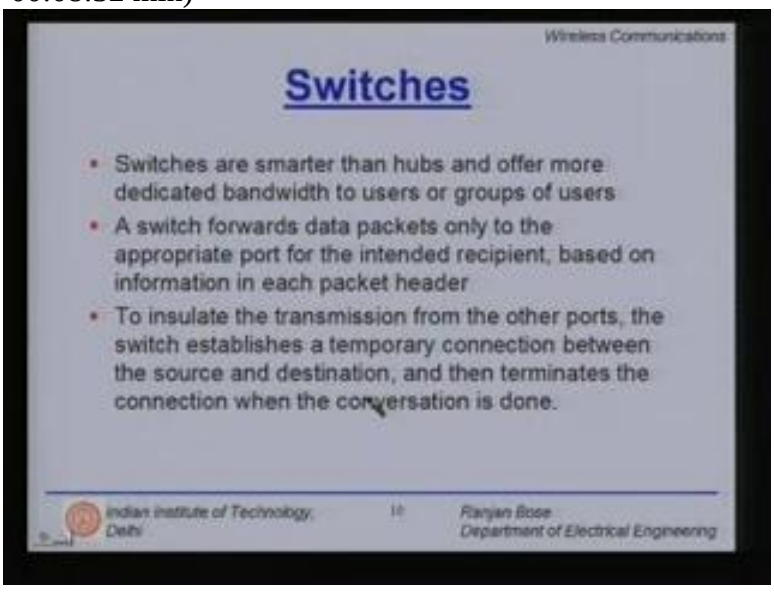

Switches are smarter than the hubs so these are hubs with some intelligence and these offer more dedicated bandwidth to users or groups of users. A switch forward data packets only to the appropriate code for intended recipient based on information in each packet header. So the switches start taking certain decisions. To insulate the transmission from the other ports, the switch establishes a temporary connection between the source and the destination and then terminates the connections when the conversation is done or in this case it could be a data transfer or file download or any such thing whenever that is over the virtual connection is closed so switch is smarter than a hub.

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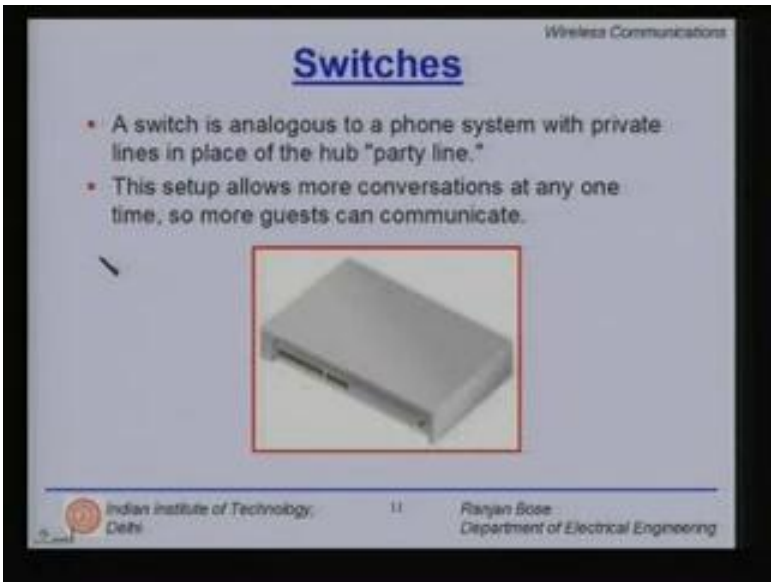

A switch is analogous to a phone system with private lines in place of hub party line. This setup allows more conversation at any one time so more guests can communicate. Basically it is a more judicious use of the bandwidth, you do not forward all the request to all the possible ports. It decides who is an intended user based on the header information and then forward the packets.

The other components are the routers; routers use a more complete packet address to determine which routers or workstation should receive each packet next. Based on a network road map called a routing table, routers can help ensure that packets are travelling the most efficient paths to their destination. This means that if I am sending an email from computer 1 to computer 2 it will be first broken down into smaller packets and all the packets may not traverse the same path in the network.

Based on the congestion and the link quality different packets might reach the destination through different routes. They will be assembled back and then delivered at the receiving end. So based on a network road map called the routing table routers can help ensure that packets are travelling the most efficient path to their destination. If a link between two routers fail, the sending router can determine and alternate route to keep traffic moving. Routers also provide links between networks which use different protocols, this is important.

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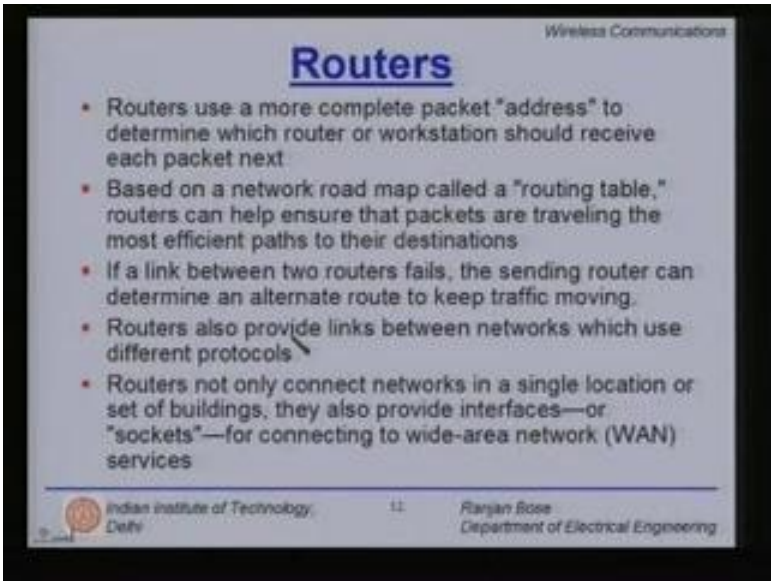

Routers not only connect networks in a single location or setup buildings they also provide interfaces or sockets for connecting to the wide area networks services. So any difference in the protocols is handled by the routers, any difference in the speed of data transfers on two sides are also handled by the routers. So they form an essential component for wireless networking. Now we come to access points. Wireless networks can utilize an access point which performs many of the same functions as a simple hub. So for example if my lab is congested and I cannot draw any more wires I can put an access point and then put these network cards in all of the other computers and create a small local area network.

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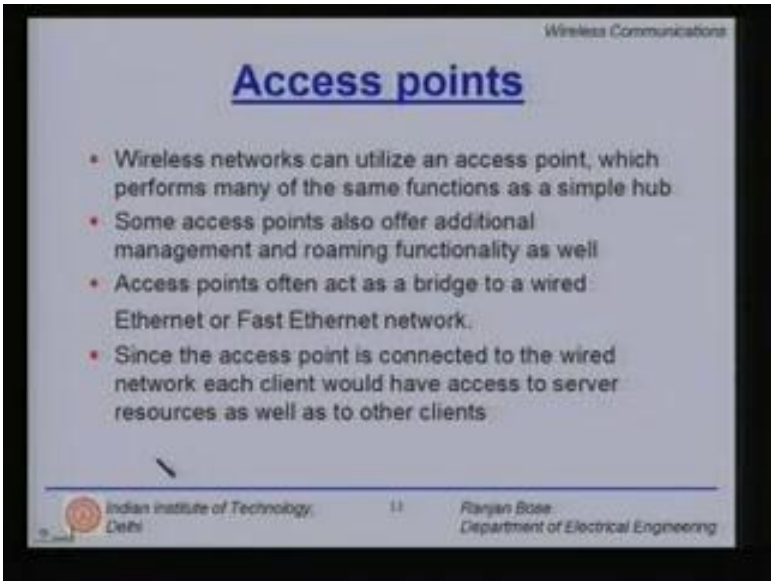

Some access points also offer additional management and roaming functionalities as well. Access points often act as a bridge to a wired Ethernet or fast Ethernet networks. Since the access point is connected to the wired network, each client would have access to the server resources as well as to the other clients. So access points lately have become very popular especially those based on the 82.11 b technology.

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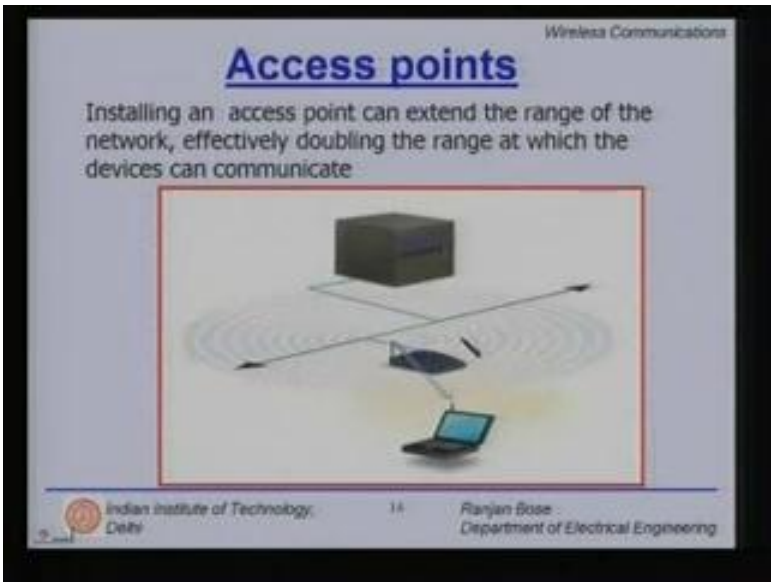

Installing an access point can extend the range of the network, that's a very easy way to extend your network, effectively doubling the range at which the devices can communicate. So I can easily add more and more devices to this extended network. So it is the main server it is an Ethernet and then there is an access point and here is the wireless link, very useful for adding more number of computers in the lab.

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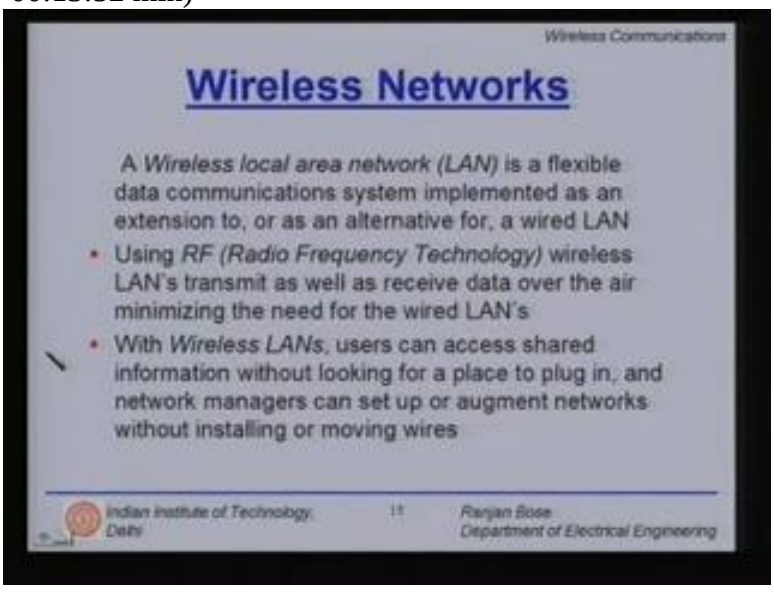

We now come to wireless networks. A wireless local area network is a flexible data communication system implemented as an extension to or as an alternative for a wired local area network. So here first we are talking only about the local area network. Using RF technology wireless LAN's transmit as well as receive data over the air minimizing the need for wired local area networks. With wireless LAN's uses can access shared information without looking for a place to plug in and network managers can set up or augment networks without installing or moving wires, this is a very big advantage of wireless local area networks.

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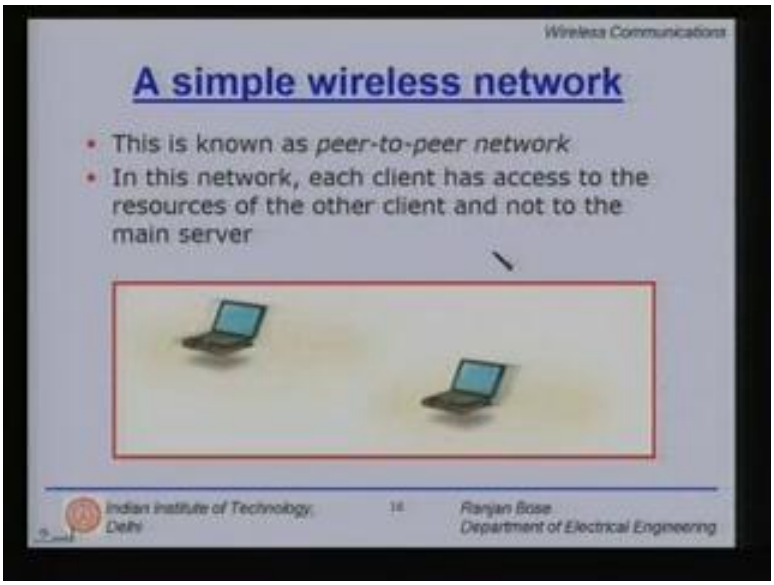

Let us look at a very simple example of a wireless network, a peer to peer network. In this network each client has an access to the resources of the other client and not to the main server. So these two can communicate with each other and the definition of at least two computers is satisfied and they form the simplest possible network, a wireless network. So they can download files from one PC to the other wirelessly. Now the moment you add the third computer, issue start coming into the picture because you have to ensure that each one of them are within the hearing range of the other computer and of course there is a hidden node problem that comes with it.

Let us now talk about network with access points. Access points handoff the client from one to the other in such a way that it is not visible to the client thus ensuring un broken connectivity. So here is a simple architecture, we have a main server connected to a PC and then there is a printer and then we have the 3 access points and here is a wireless network. So this computer can access either the main server or the data base in this PC or give a print command to this computer.

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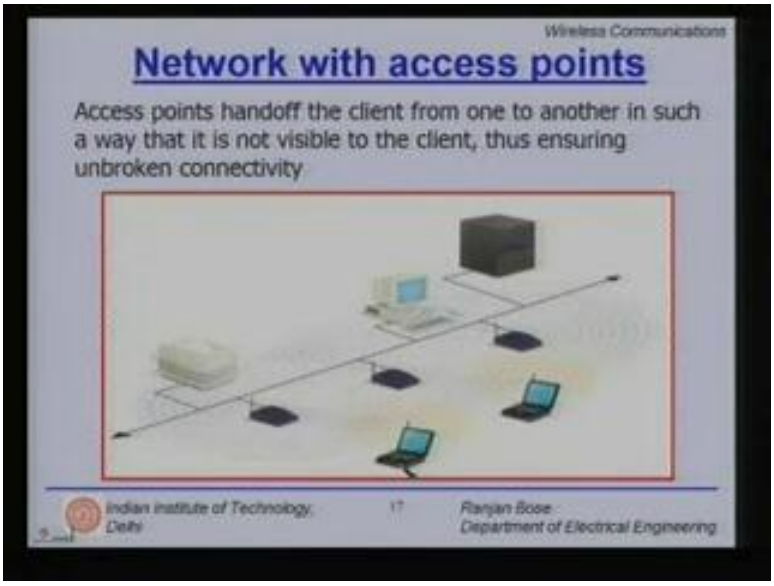

Same is the case for this laptop which is connected wirelessly to any one and which one to connect depends on how many, computers are already connected to the piconet related to any one access point. So for example let us say each access pint has an upper limit of supporting 5 PC's at a desirable bandwidth data rate. The moment the sixth computer comes in, it will be connected here. There is already a protocol in place which will decide which access point will talk to which laptop. Now again this laptop can access the server, access the data base in this PC or give a print command and also this guy can go through the network and talk to this other laptop. This gives a very elegant yet simple method to extend your local area network.

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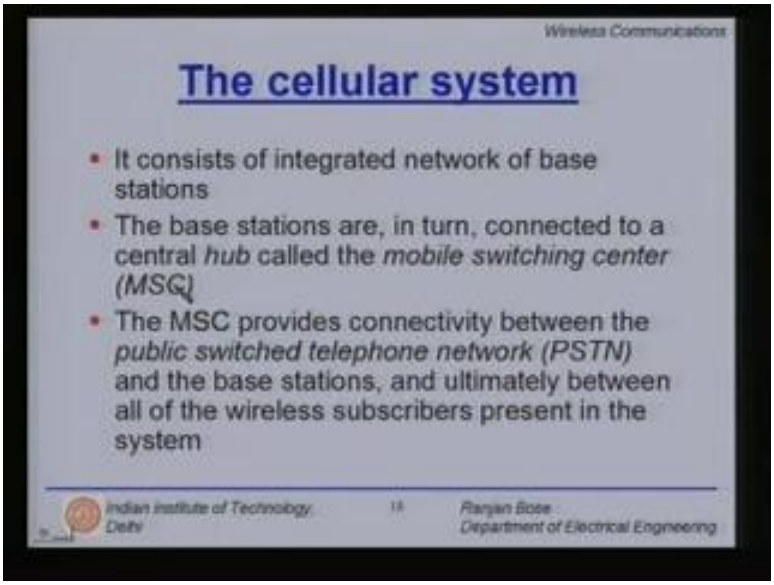

Now let us look at the bigger picture, the cellular system which is an excellent example of a wireless network. It consists of integrated network of base station so instead of having those small access points in the local area network consider the base stations as a big access points. The base stations are in turn connected to a central hub called the mobile switching center. This mobile switching center provides connectivity between the public switched telephone network PSTN and the base stations and ultimately between all of the wireless subscribers present in the system. So this is a big version wherein each of the base stations can be looked upon as access points which are connected to the main mobile switching center which access the hub. It's usually fair to say that it is more than a half, it's actually a very smart switch.

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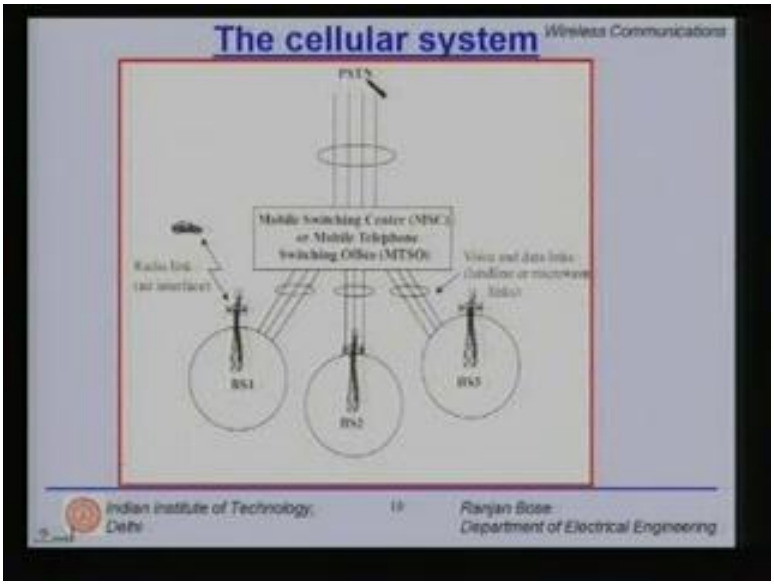

So what do we have? We have here are the smart switch called the mobile switching center MSC sometimes also referred to as mobile telephone switching office MTSO, this is the Braine. It is connected to different base stations either by fiber optics or by point to point micro wave links. I definitely need a large bandwidth connection between the mobile switching center and the base station. Each of the base station acts as an access point and there is a radio link which is an air interface between the mobile and the base station. Since this is a switch it is connected on one side to the public switched telephone network PSTN and ((matter as well)) ((00:20:06 min)) be connected to the internet, how they are connected, what is the architecture we will look at some of the later slides when we talk about evolution of wireless networks. So this is an example of a successful wireless network.

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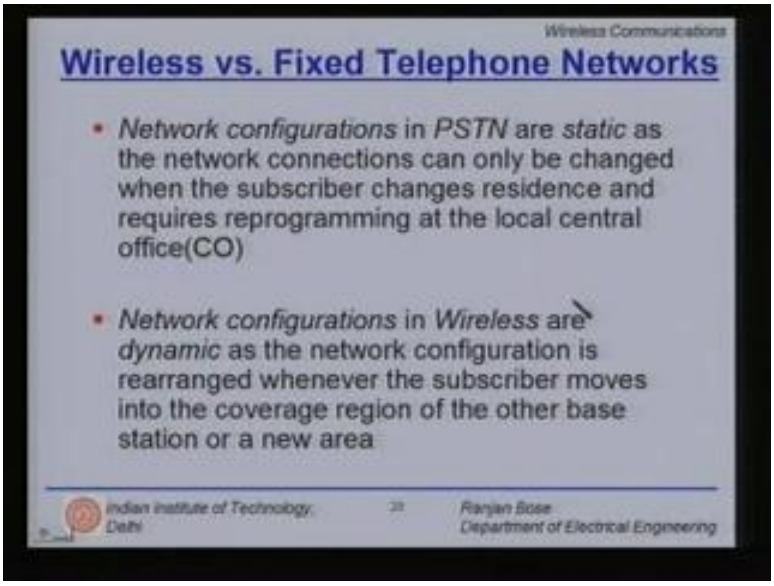

Now let us quickly talk about wireless versus fixed telephone networks, the pros and cons and how we can improve. The network configurations in public switch telephone networks or PSTN are static, as a network connections can only be changed when a subscriber changes residence and requires reprogramming of the local central office. However network configurations in wireless are dynamic, as the network configuration is rearranged whenever the subscriber moves into the coverage region of another base station or a new area hence there is a need for handoff and also to maintain this in some kind of a data base. So as we will talk about the home location register and visitor location register in the context of the GSM networks, your data as to where you are present currently and what is your actual home address are all stored.

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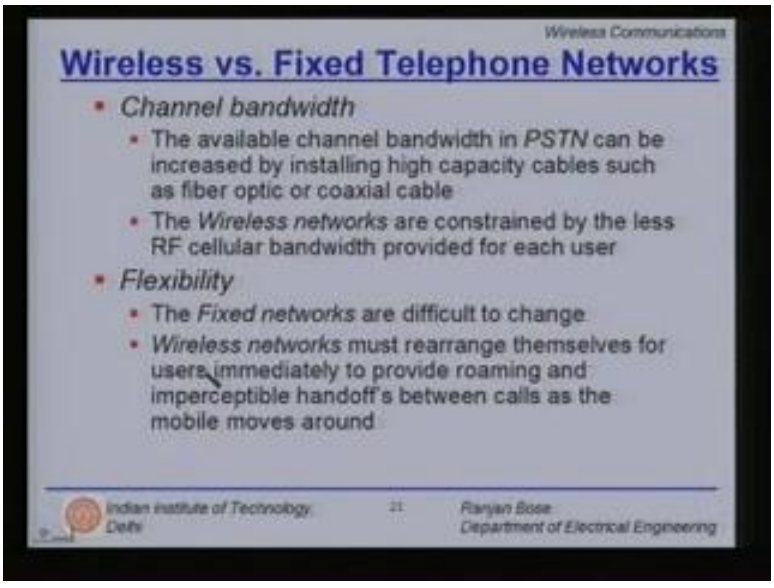

Now let us talk about wireless versus fixed networks from the prospective of channel bandwidth. The available channel bandwidth in the PSTN can be increased by installing high capacity cables such as fiber optics or coaxial cables. However the wireless networks are constrained by the less RF cellular bandwidth provided to each user. This necessitates the requirement for using frequency reuse. What about flexibility? Fixed networks are difficult to change. On the other hand wireless networks must rearrange themselves for users immediately to provide roaming and imperceptible handoff between calls as mobile moves around this an inherent requirement for any wireless networks. If you extend this concept of wireless networks to the emerging wireless networks like ad hoc networks there you have absolutely no infrastructure which is there, the infrastructure comes into place but the various nodes the wireless nodes and the network can change very dynamically.

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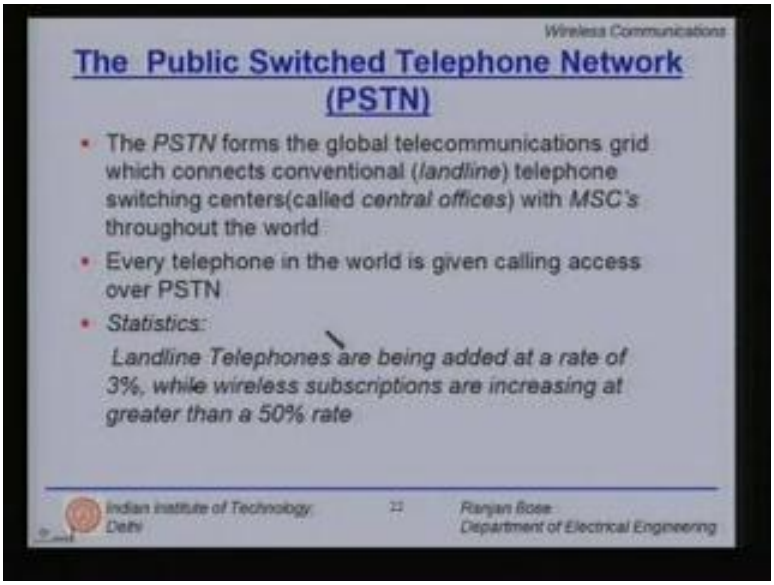

Let's have one basic slide on public switched telephone networks or PSTN. The PSTN forms the global telecommunication grid which connects conventional which are landline telephone switching centers called central offices with the mobile switching centers throughout the world. Every telephone in the world is given calling access over PSTN but here are some exciting statistics; landline telephones are being added at a rate of 3%, while wireless subscriptions are increasing at a rate of greater than 50%. So today there's an ever increasing need to have a good robust wireless network which is expandable.

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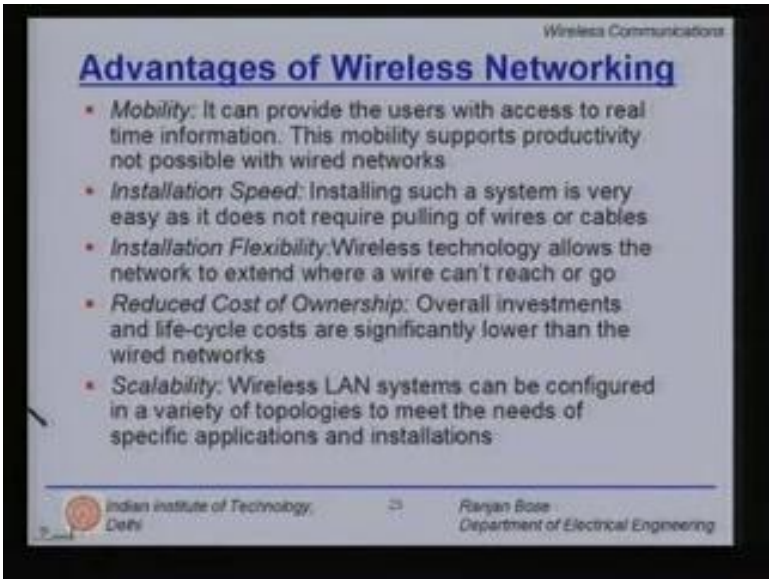

So let us look at some of the advantages of wireless networks. Mobility, it can provide the users with access to real time information, this mobility supports productivity not possible with wired networks. Installation speed very important factor, installing such a system is very easy as it does not require pulling of wires or cables. One of the very popular concept is the wireless in the local loop or WLL where we solve the last mile problem. We can take the fiber connection to the curve but not to every home because it is not cost effective, at least it was not cost effective 5 years back. At that time the fiber was brought to the curve where in a tall tower was erected or put on top of a building and locally within the local loop wireless access was given that is called the wireless in the local loop.

It can provide limited mobility. Installation flexibility, again wireless technology allows the network to be extended where a wire can't reach or go. In wired networks if the customer is located at the farthest end, you have to pull a wire right up to that point whereas in the wireless networks you can give service to the farthest user just by putting a customer site antenna. Reduced cost of ownership: over all investments and life's cycle costs are significantly lower than the wired networks as compared to the wire line networks. So basically it is a cheaper, inexpensive technology. Scalability is yet another important feature. Wireless land systems can be configured in a variety of topologies this is important to meet the need of the specific application and installation.

So if you want to scale up a wired network, a lot of infrastructural calls is required and sometimes the logistics may not be possible. Here we have seen in our previous lectures that I can have sectorization of cells, making cell splits and other factors to ensure that I can increase the capacity of my systems there by adding more nodes in my wireless networks.

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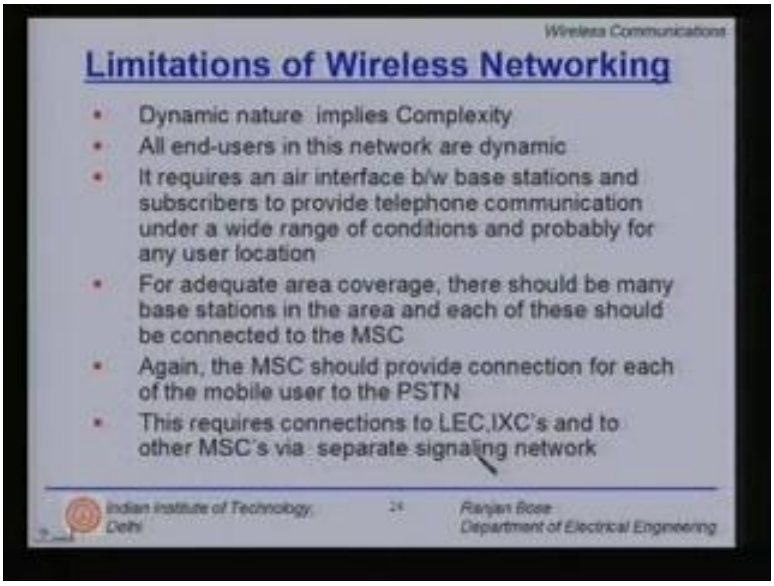

In the other side of the coin limitations of wireless networks, dynamic nature implies complexity so this is one of the research challenges for ad hoc networks and also for sensor networks whereas giving the dynamic nature comes with a cost which is complexity, management of networks, the links are poorer the bandwidths are lower so all these things have to be considered while you depute a wireless network. All the end users in the network are dynamic. It requires an air interface between base stations and subscribes to provide telephone communication under a wide range of conditions and probably for any user location. So wide range of conditions we have already seen in previous lectures, we have a fading environment, it's a noisy channel, you undergo shadowing, there is a foliage absorption, scattering effects a lot of problems with the wireless channels.

For adequate area coverage there should be many base stations in the area and each of these should be connected to the mobile switching center. Again MSC the mobile switching center provide connection for each of the mobile users to the PSTN. So this step requires connection to LEC, IXC 's and to other MSC' s via separate signaling networks. So basically the point is that the mobile switching center has to do all the hard work in terms of connecting it to other networks.

This we know already, the random nature of the radio channel is a big limitation. As the mobile changes location frequently, the mobile switching center is forced to switch calls imperceptibly between base stations. Please note that the random nature of the wireless network could cause another problem. For example in Carnot place there is a big festival going on, so it will attract a lot of mobile users at the Carnot place circle and if all of them are trying to access the network then there will be a big congestion problem.

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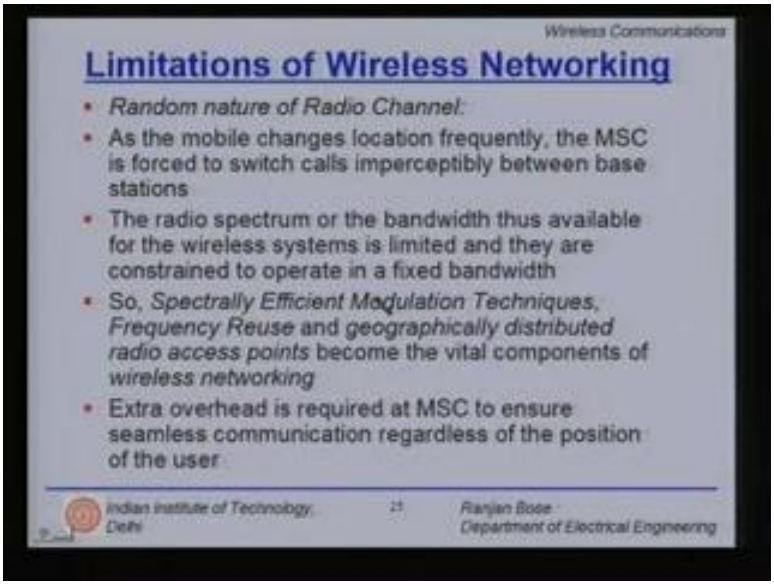

This is attributed to the dynamic nature of the wireless networks. Such kind of a problem is not going to occur in wire line networks. The radio spectrum or the bandwidth thus available for the wireless systems is limited and they are constrained to operate in fixed bandwidth. So spectrally efficient modulation techniques, frequency reuse, geographically distributed radio access points become vital components of the wireless networking.

So if you remember in our previous classes we have talked about efficient modulation techniques, need for a frequency reuse, distributed base stations and access points all of these also form an important component of the wireless networking and the actual networking protocols will take into account what kind of an efficient modulation technique you have which means how much of bandwidth you have, what kind of error correcting schemes you are using which means how good is your link quality and frequency reuse and geographical distribution depends upon how much of the users are being covered and what is the congestion level between links. Also note that extra overhead is required at the mobile switching center to ensure seamless communication regardless of the position of the users.

So a slide on merging wireless and the public switched telephone networks. Until the mid-eighties the PSTN used to send the signaling information along the same trunked lines as the voice traffic. The overhead required for this process was inefficient as it required the voice trunk to be dedicated even when there was no voice traffic present. So what was the solution? The advantage of having a separate parallel signaling channel allows the voice trunks to be used strictly for sending voice signals. So you have a voice network and a signaling network they're independent.

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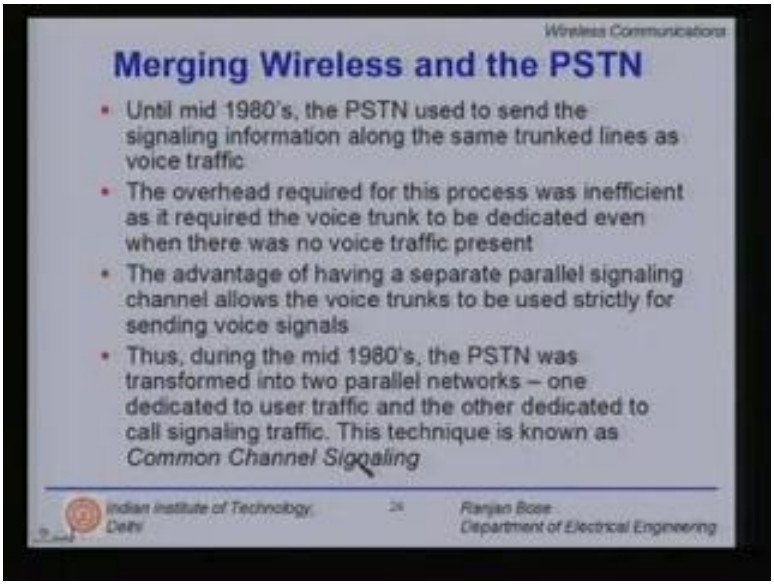

Thus during the mid-eighties the PSTN was transformed into two parallel networks, one dedicated to user traffic voice channels and the other dedicated to call signaling traffic. This technique is known as the common channel signaling. Now dedicated signaling channels have been used by the cellular MSC's to provide global signaling interconnections thereby enabling mobile switching centers throughout the world to pass subscriber information. The point that is being made is there was leapfrogging in technology. there are separate channels set aside in wireless networks purposely for signaling. So there are signaling channels and then there are traffic channels.

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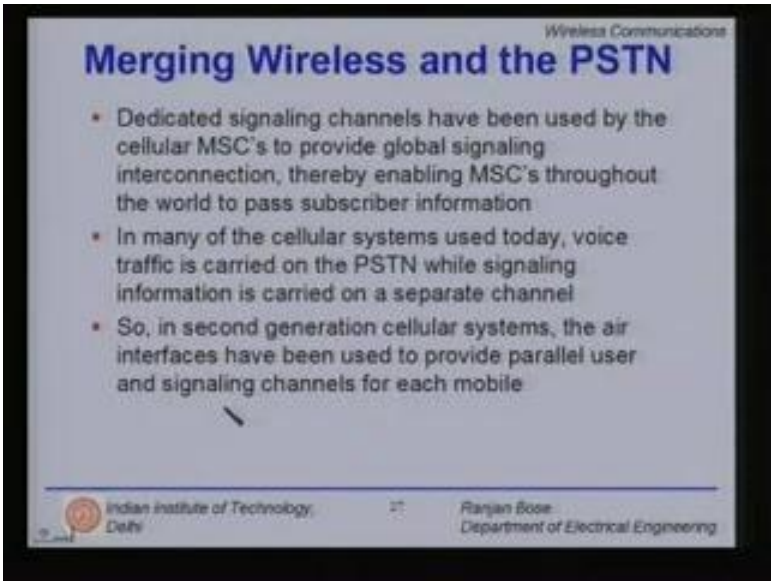

When we talk about GSM networks and CDMA networks in the subsequent lectures we will talk about two kinds of channels, the voice channels and the signaling channels they are in built. In many of the cellular systems used today, voice traffic is carried on the PSTN while signaling information's carried on a separate channel. So in second generation cellular systems the air interfaces have been used to provide parallel user and signaling channels for each mobile. So the concept has been borrowed from fixed landline networks.

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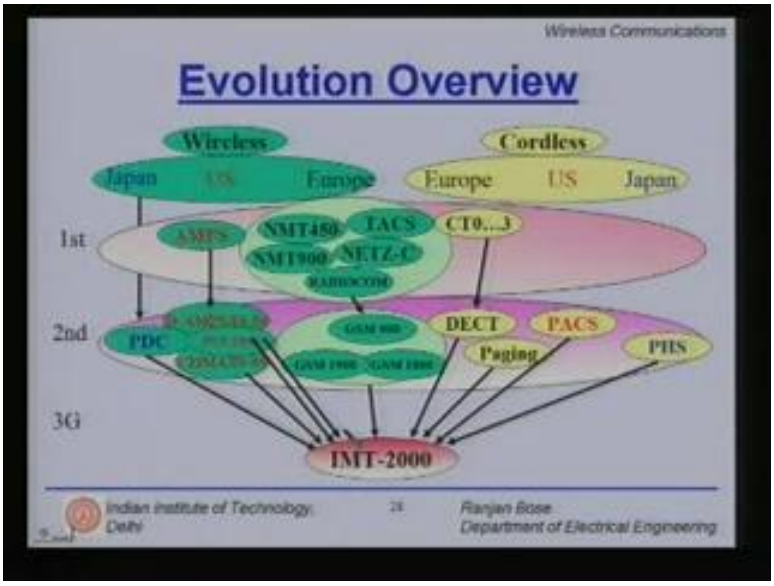

Let us spend some time on the evolution of wireless networks. So here if you see we have on the left the wireless, on the right we have the cordless. It is within the home and outside the home and then we are trying to track the progress of 3 geographical regions even though we're talking about countries here Japan, US and Europe. So in the first generation on this left column we have the first generation, the second generation and the 3G and we're talking about the evolution of wireless networks. Here we have the analog amps and then the Europe we have this TACS and NETZ- C which is the German and radio comb. We of course had in the first generation the CT 1, CT 2 and CT 3 as the cordless telephone standards.

So here in this ovals we have put the specific standards which were used. Now what is important to be noted is that there are many standards in fact there was no real standardization across the globe. Every country tried to evolve its own standard, of course Japan took a leapfrog and came up with PDC in the second generation wireless communications whereas the US went over to have digital amps and then IS 54 followed by PCS 1900 and then CDMA based IS 95 that was the second generation wireless technology being deployed in the US. At the same time Europe did a smart move to move over to GSM 900 which gradually went over to GSM 1800 and GSM 1900 technologies. So these are the second generation wireless network standards, from the cordless perspective we had the DECT, the PACS, paging and PHS which is the Japanese technology.

So this represents the second generation evolution of wireless networks and cordless phone technology. Again please note that they're fairly distributed, the only unification that has happened is across Europe when they're following the GSM technology. GSM has been shown to be one of the most successful wireless technologies so far and it has now spanned almost the entire globe. The move to 3G is depicted by the convergence of all these arrows so the basic philosophy of 3G is to have one world standard. There is a difference between having a philosophy and getting what you desire so apparently we are working towards CDMA based standard but there are again two flavors of it but this is the general move towards the evolution of wireless networks.

Please note the cordless and the wireless technologies also would like to converge. What is not shown here is also the merging of the IP networks into this? So I can have a wireless phone which can connect to the IP so I can make a voice over IP call from my cellular phone. So in a few months' time or may be in a year's time we should be able to buy of the shelf a handset which works as a cordless phone inside your home, works as a cellular phone outside the home and if you are near our access point you will able to make voice over IP phone, seamlessly you'll not even realize which network you connect it. So that's where the 3G's moving towards.

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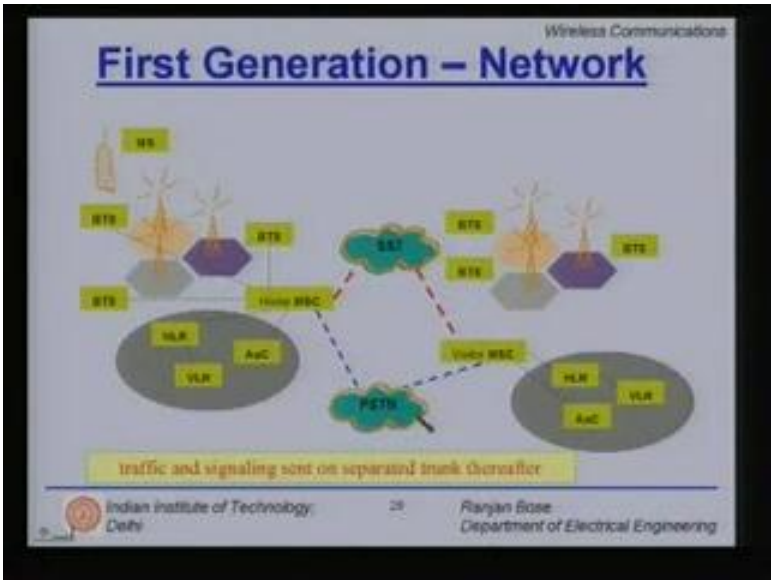

Now a graphical description of the first generation network, again please note that the cellular concept is there but you have the public switch telephone network which is connected through the mobile switching centers and then you have the home location register and the visitor location registers and the base stations are communicating with the mobile stations and you need to handoff when you move from one generation to the others. This is the philosophy used before mid-eighties, a lot has changed. Please note the traffic and signaling sent on separate trunk thereafter using an SS 7 the common signaling channel which is used to send control information other than the voice traffic. So this is the evolution after the mid-eighties the inclusion of the SS 7 signaling channel.

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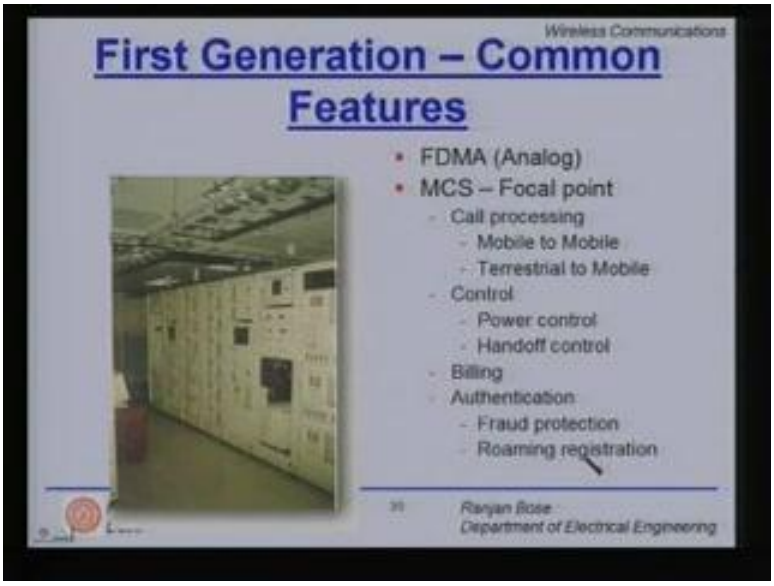

What was the features of the first generation wireless networks? Analog, mostly FDMA frequency division multiple access based and then you have call processing which mobile to mobile calls, terrestrial to mobile calls. You had some control in terms of power control, power of the emitted radiations and handoff control, billing was there. There was some basic fraud protection and very limited roaming, roaming was expensive and not Omni present. This is a snapshot of how the inside of a mobile switching center would look, it would be a big room.

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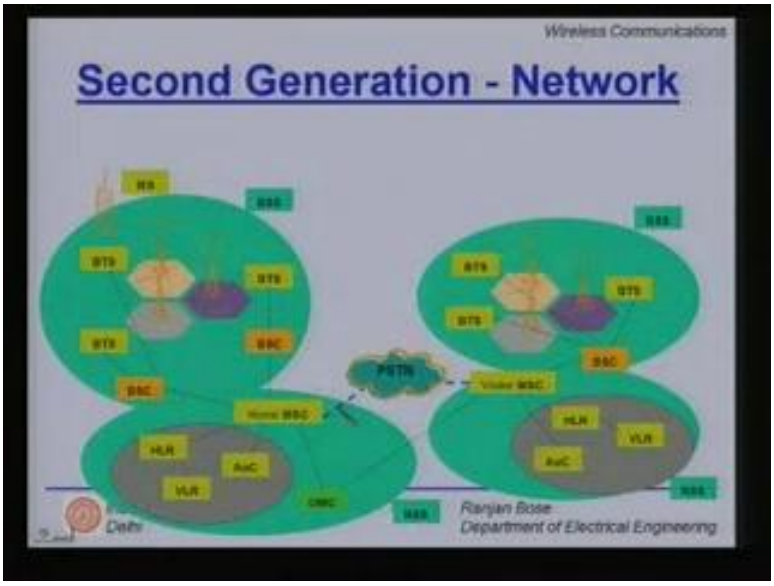

Now when you move to the second generation networks again you have the different coverage areas and you again have base stations and there are cells which are located.

Then you have the mobile switching center and connected to the PSTN network here again you have the concept of home location register and visitor location register and authentication which is being done but on top of all of this you have internet connectivity PDN, ISDN and PSTN which existed. So the second generation is evolved to being a digital network, more robust and the features are as follows.

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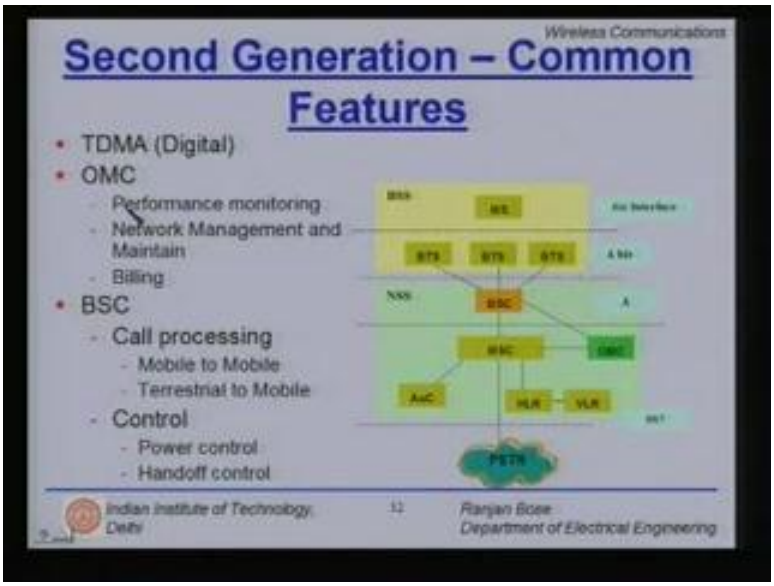

Its TDMA based primarily but of course IS 95 is CDMA based, performance monitoring is there, network management is there, billing is there smart billing. So the users can have options, the service providers can give you options that you can pay when you receive calls or you can pay when you make calls or you can pay only some part of the money to your favorite calling numbers and things like that, all these billing things can be taken care of and then at the base station the call processing is there mobile to mobile, terrestrial to mobile calls are allowed, we both have power control and handoff control.

What we saw in this second generation is higher capacity and mobility, easy frequency planning, dynamic channel allocation in GSM, single frequency band in CDMA concept, better performance. How do we measure better performance, low call drop rate and faster switching plus we had some basic encryption also mobile assisted handoff and also we had the soft handoff concept in CDMA.

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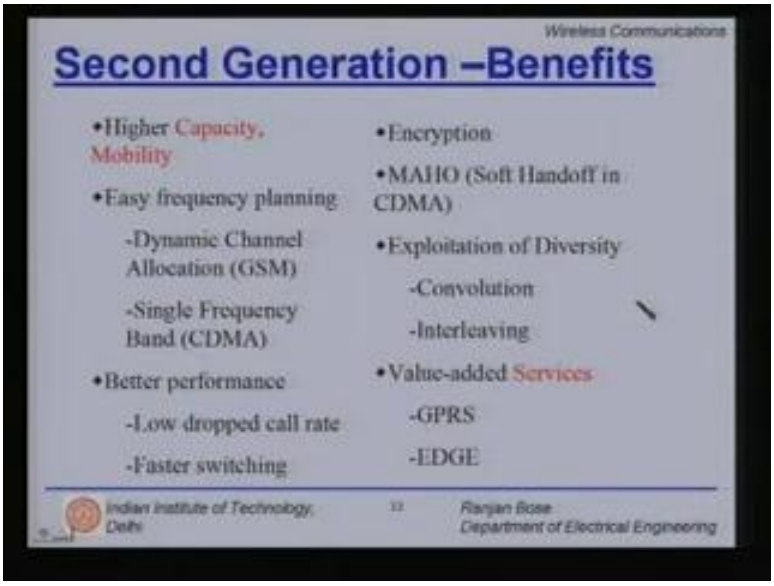

We for the first time started exploiting diversity by having multiple antennas and the transmitter at the base station. We used convolutional coding and interleaving as error control coding techniques. So basically a more robust system as compared to the first generation, thanks to the digital architecture plus we also had some value added services. GPRS the move from GSM towards 3G systems and EDGE. So these are the basic benefits provided in the second generation wireless networks.

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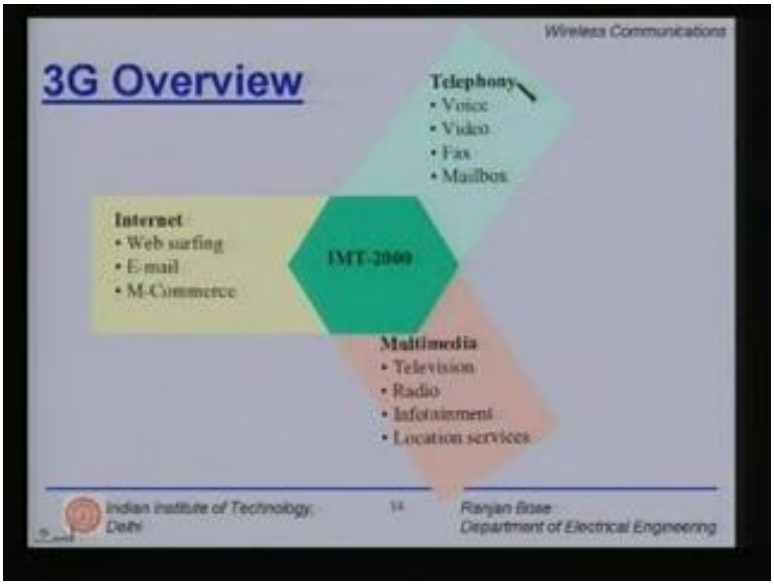

Let us now look at the 3G, the 3G is a combination of a lot of features which have been promised. So when somebody says we have a 3G phone we have to tick mark how many of these features are being provided. So when you have telephony you have voice, video, fax, mail box facilities, voice mail. Again at the desirable rate when you say voice connectivity or fax connectivity you should be able to have these connectivity's even travelling at a certain rate. So even if you're moving in fast car, you should be able to get certain kind of voice quality or video quality but then telephony is just one of the three features.

You have access to multimedia material, television, radio, infotainment and location services as well as the internet that is you can surf the web, check or send emails and mobile commerce. If you can do all of these things truly you are in the 3G domain. So 3G is not only about higher speeds, 3G is about more number of services better quality of service and better mobility. So the whole idea is to merge all of these together and come up with one product which can give you the same features. So that is the basic over view of 3G.

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Now clearly a lot of time and money has been spend and infrastructure has been setup to make the 2 G and 2.5 G systems work. Now the effort is to slowly and gradually migrate to 3 G so in this slide whatever I have put in green shows the 2 G systems and whatever is in yellow is the 3 G systems and the arrows show the migrations. Now there are three kinds of migrations which have been noted, one is an easy upgrade shown by the bold lines and then the magenta dotted line shows the upgrade requiring new modulation schemes and some error control coding techniques and then the orange dotted lines show upgrade requiring, entirely new radio systems that is you have to pull down an old base station and put up an entirely new base station, new antennas.

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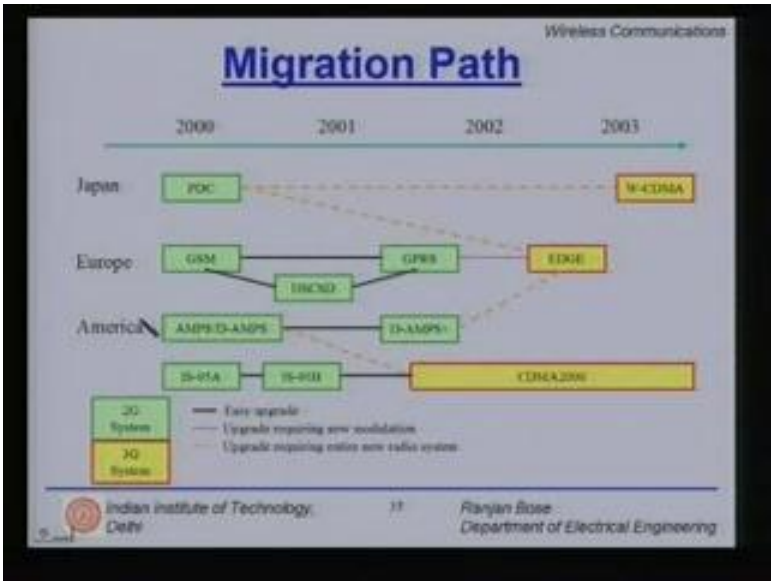

So if you see let's talk about the European standard which is more in line with what is done in India. So you had the GSM standard in 2000 standard 2 G network and then this direct move was to GPRS which is the packet radio service. Here the change was not difficult and today most of the phones, the new phones that have been bought in India also have the GPRS capability. Then you have a simple dotted magenta line connecting GPRS to EDGE wherein you have to somehow require new modulation techniques to go from GPRS to EDGE. Now EDGE tends to be the first step towards 3G system but this is not truly 3G. In Japan the move is towards WCDMA and in the US it is move towards CDMA 2000 so the 3G standards will be CDMA based and today both WCDMA and CDMA 2000 are going to coexist. India is going to look at CDMA 2000 currently we are using CDMA 2001 X EVDO.

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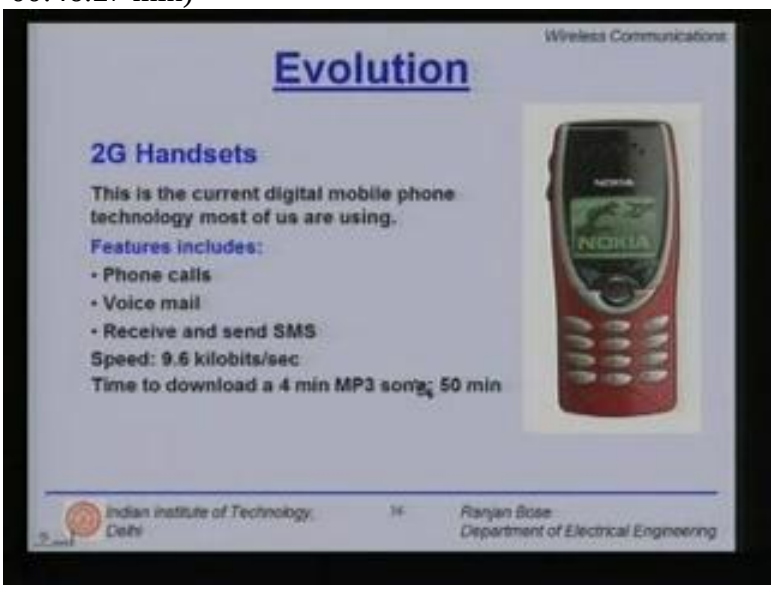

Let's talk about the handsets in the next few slides. So in the 2G handsets the current digital mobile phone technology is what most of us have seen today and are using. The features include simple phone calls, voice mails, can receive and send SMS. SMS which was one of the side services has become one of the main services, people are now spending more money and time on SMS than on regular phone calls as per one of the service. Now the data rate is 9.6 kilobits per second and just to compare if you would like to download a 4 minute MP 3 clip or a MP 3 song, you would require 50 minutes to download it. The data rates are pathetic if you are going to download a song on this one.

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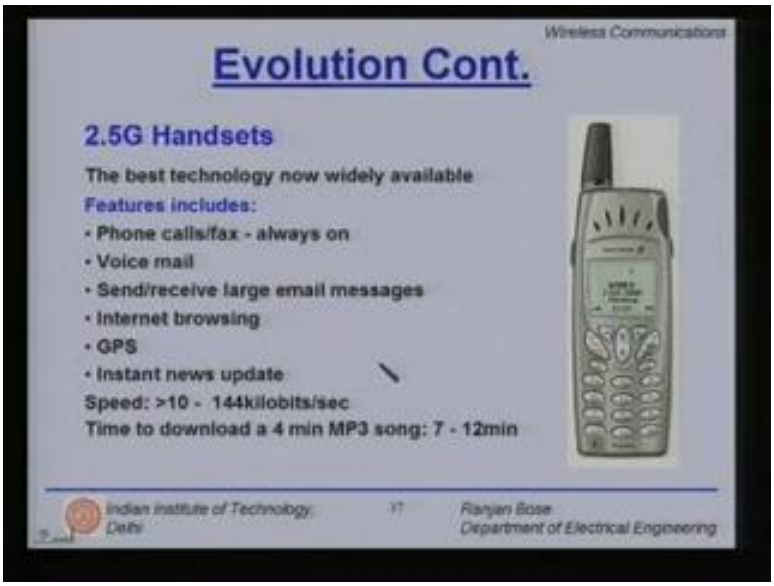

Now if you look at the 2.5 G handsets these are the next generation technologies are now widely available and many of us use the 2.5 G handsets the features are enhanced you can make phone calls, send faxes as it is always on. There is voice mail, you can send and receive larger email messages, you can browse the internet, you can do position location, so you can use a GPS connectivity and it'll fax you or it will send you the coordinates of your location, instant news updates, lot of entertainment facilities.

Speeds are better, download speeds it can go up to 144 kilobits per second provided you are sitting fairly close to the base station with the clear line of sight. If you compare with the last mobile handset if you want to download a song which is 4 minute long in the MP 3 compressed format it will take to 7 to 12 minutes to download the song it's getting better but still a lot of it is to come, we desire lot more. Now when you move to the next generation handsets so what is being emphasized in these slides is it is not only the technology in terms of the base station upgrade or the wireless network upgrade but the bottom line is that the services that can be provided will actually drive the sales.

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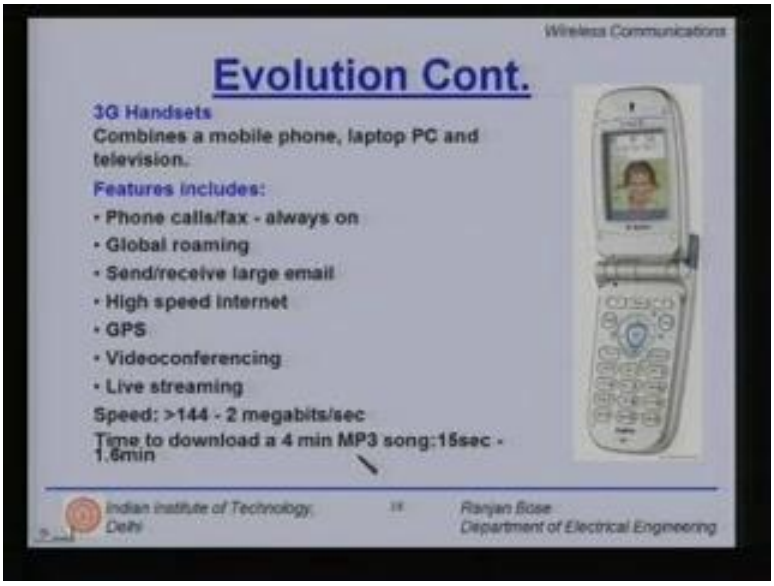

If you look at the 3 G handsets it is supposed to combine a mobile phone with a laptop PC, television, PDA and whatever you can think of. Some people are also promising this to be a remote wherein your TV channels can be changed and also a power point presentation may be conducted using the key pads on your mobile phone. So the features include phone calls, fax has to be there, global roaming no questions asked, send receive large emails, high speed internet so you can check your stock codes or cricket updates, GPS services you can start doing video conferencing so a lot of this is not there already but this is the promise of 3 G handsets because when my network is upgraded to a 3 G network the data rates can be provided such that I can do a video conferencing live my handsets must also evolve to handle those applications therefore they need to evolve handsets.

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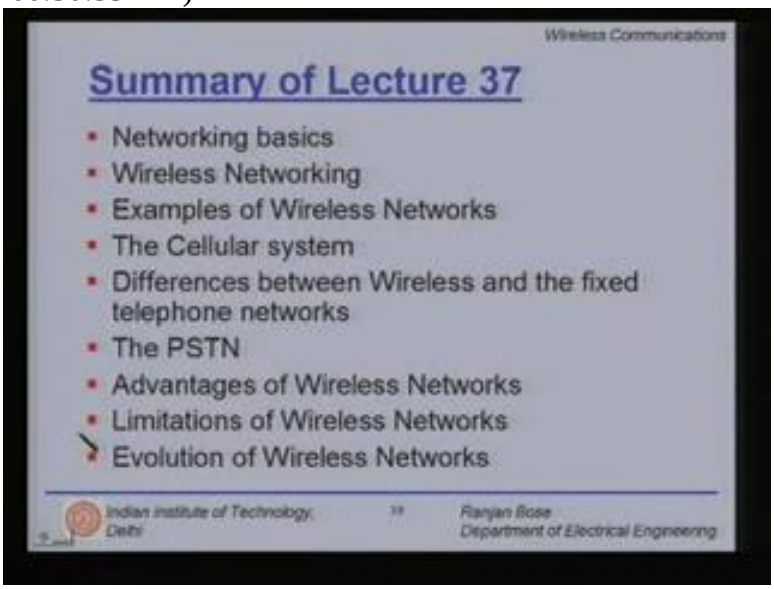

Live video streaming, the speeds are phenomenal greater than 144 kilobits per second going up to 2 mbps so now if you want to download the same 4 minute MP 3 song it'll take you just half a second or one and a half minutes to download the same song. Now we are within the reasonable domain for true multimedia activities. So now we can summarize what we have learnt so far. We started off with networking basics we then specifically talked about wireless networks followed by some simple examples of wireless networks. We saw that the cellular system is an excellent useful proven example of a wireless network, we then focused our attention on the differences between wireless and fixed telephone networks followed by a few slides on the PSTN the public switch telephone network.

Then we looked at the advantages of wireless networks and also the limitation of wireless networks. Finally we spent some time looking at the evolution of wireless networks and also the evolution of wireless handsets. We have now built enough background to look at certain specific wireless standards, in the subsequent lectures we will talk about the GSM standard and the CDMA standard that will include concepts of frequency planning, frequency reuse, modulation techniques, coding techniques, interleaving wireless networking. So all the concepts that has been picked up will now be realized in a certain standard and we will see how the different pieces of the jigsaw fits in. we will conclude our lecture here.