Wireless Communications

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Lecture No. # 01

Motivation and Introduction

We will start our course on wireless communications. I am Ranjan Bose, Department of Electrical Engineering. Here is a breakup of all the lectures.

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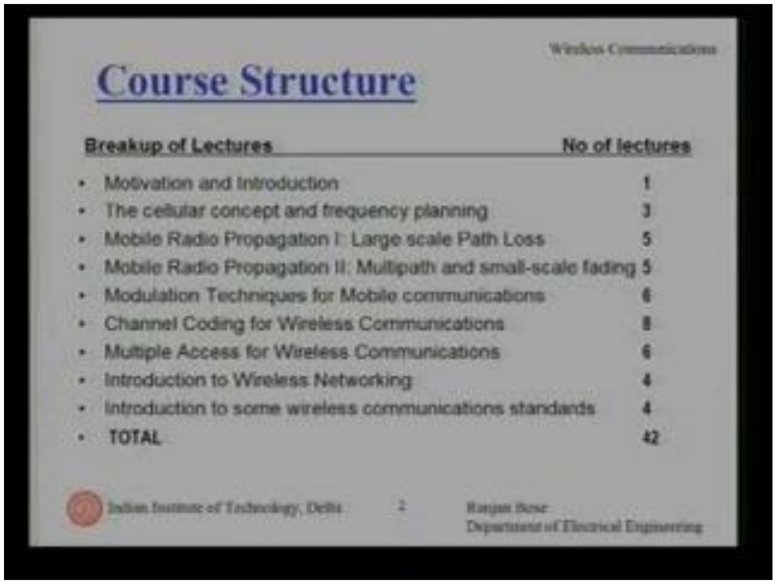

We'll start with the motivation and introduction. We will then follow with the cellular concept and the frequency planning which is a part of most wireless communication systems. Then we will go on and study mobile radio propagations. Fading which is an integral impediment in most wireless communication systems will be tackled. We will look at the large scale path loss and then the multipath small scale fading. Then will look at the modulation techniques for mobile communications followed by certain channel coding for wireless communications. We will then look at multiple access.

Finally introduction to wireless networking and if time permits, we look at certain wireless communication standards. The whole series consists of 42 lectures. These are the three suggested reading (Refer Slide Time: 02:31). Of course a lot of material will be taken from the various standards and hopefully we will have1 running example, maybe the GSM phones or the CDMA 2000 1X phones for various aspects of wireless communications.

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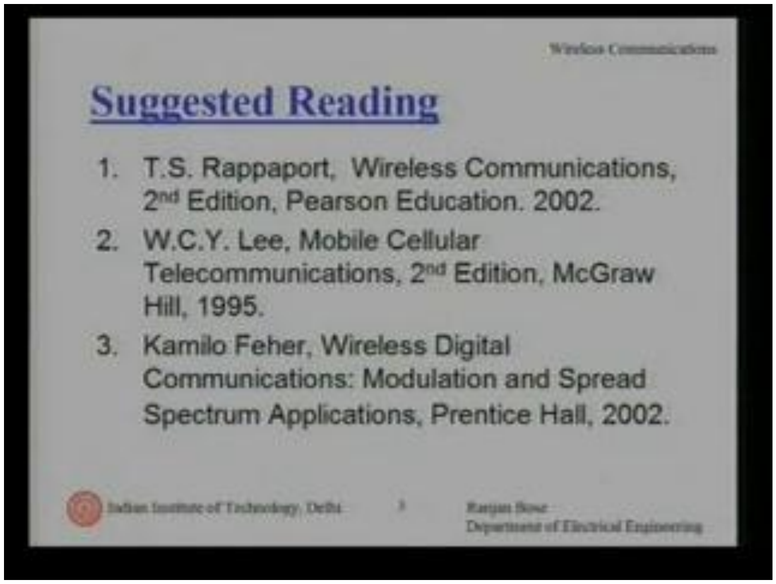

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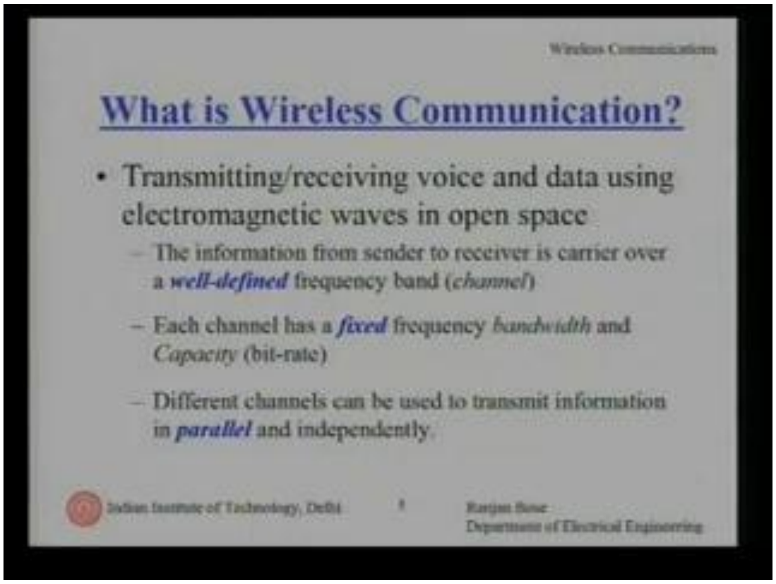

We will start with the most fundamental question: what is wireless communications? So as we all know, wireless communication is basically transmitting and receiving voice and data using electromagnetic waves in open space. They are basically free from wires. Please note the emphasis is not only on voice but also on data. So today we see people talking on the cell phones but at the same time the mobile phones are also used to check their emails, get the stock codes, and find the cricket updates and many other things.

We will soon see that the data traffic is not only giving tough competition to voice traffic but also exceeding the voice traffic. The information from the sender to the receiver is usually carried down over a well-defined frequency band. We will soon see this frequency band also known as the bandwidth allocated for wireless communication is one of the most prized commodities and is usually auctioned. Then different channels can be formed because today, wireless communication is not between one person and the base station but it is the multiple access scenario. It’s a multiuser system. So we need to somehow wisely allocate the frequency channel so that can we accommodate more than1 users. In fact most of the mobile phone companies are making money because there were very big customer base. We will look at various multiple access methods as we go along the course. Let’s look at a simple example.

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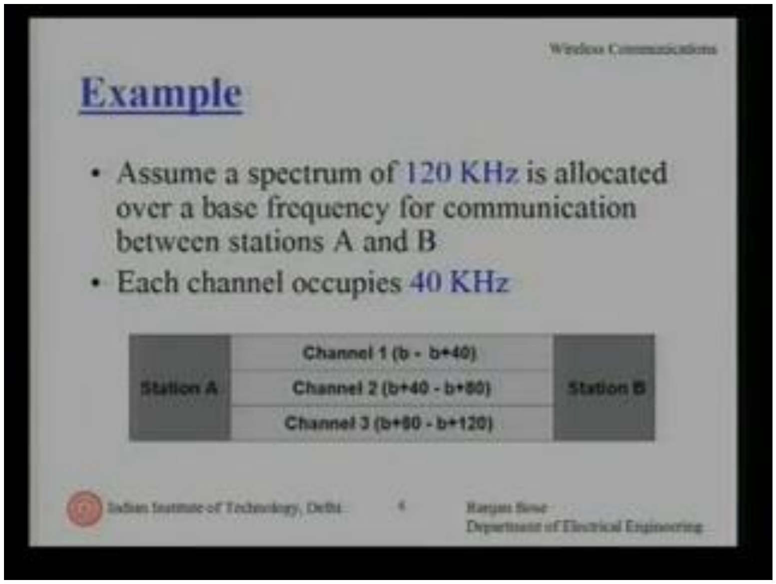

Suppose, we have an allocation of about 120 KHz of bandwidth and we require to communicate from station A to station B, a very simple way is to divide the entire bandwidth into 3 sub bands. Each one is known as a channel. Channel 1, channel 2 and channel 3 share about 40 KHz of bandwidth. Clearly this is idealized because we do not have the luxury to neatly partition the bandwidth. What determines that we can have sharp cut offs? Well, there will be a receiver with a filter. The filter characteristics will be imparted determining what kind of channel bandwidths are being actually used. So there is a difference between what you allocate and what you end up using. So what will happen in a real life scenario is a lot of frequency overlap that might take place because1 of the bands trespasses on the other band. So you can have an interference. We look at these interference issues as we go along the course. In this idealized situation, station A can communicate through this three channels without the fear of interference.

Conversation between professor and student: you have a question?

Student: shouldn't we allocate a guard band?

Professor- that's right! So a good way to overcome the simple problem is to allocate some space between the frequency allocations which are known as the guard bands. For example, channel 1 and channel 2 are not just adjacent to each other but they have a small guard band, let's suppose a 200 Hz of guard band in a40 KHz band. We will come across the term guard bands not only for frequencies but also time guard bands when we use another technique called TDMA- Time Division Multiple Access. Here, we are actually looking at an example of FDMA - Frequency Division Multiple Access provided, 3 users are using the 3 channels.

Student: how do we determine the width of the guard band?

One of the ways to do it is to figure out how sharp is the role of factors of your filters. So if you have very sharp filters, you are actually throwing out all the unwanted frequencies which are not in your domain. However, if your filters and not so sharp, that is, you have put in less money to design the filters, then you need bigger, broader, guard bands. So it is a tradeoff between the money you want to spend designing your hardware and making your hardware versus the cost of the bandwidth because the guard band is actually not being used to send any data or voice. Student: can i know more than one type of guard bands within one?

Professor: One clear example is a frequency guard band as mentioned here. The other one could be the time guard band. Suppose different users are using different time slots for communicating, what we can do is make one user stop transmitting and start the next user begin a transmission. But we can have a short time gap between the 2 time slots. That is the time guard band. Frequency and time are the 2 most frequently used methodologies of communication.

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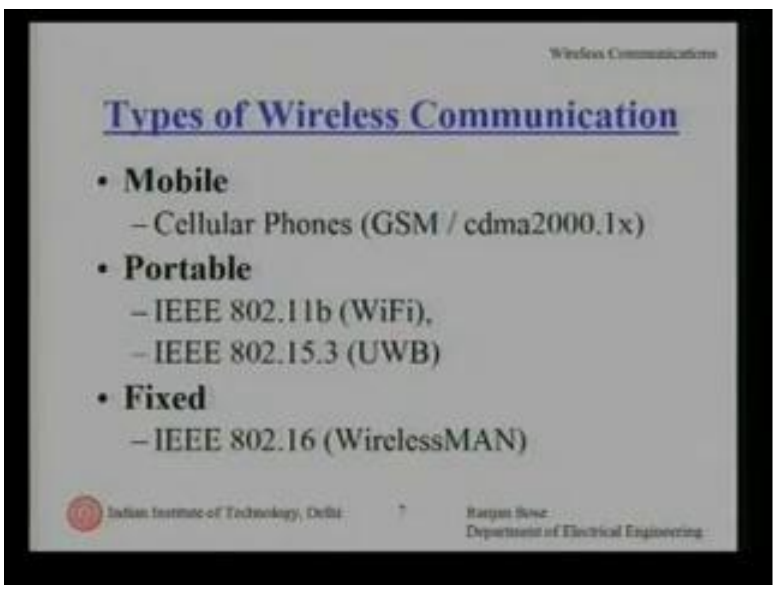

Now let's look at the basic broad level classification of wireless communications. Today, the ubiquitous wireless communication is the mobile phones. You have the mobile but that is not the only way we communicate using wireless. The other way is to have a portability. There is a difference between mobile and portable. Mobile is complete freedom to move around, talk or communicate data on the run. However portability is slightly different. For example, a laptop connected to a wireless local area network is said to be a portable wireless device. You can pick it up. Don't worry about the wires. Take it to the other part of the room and set up. So it's portable. However, that’s different from being completely mobile. The third and not-so-popularly discussed is the fixed wireless communications.

There is always an ongoing debate between fixed wireless and wire line. The major objection is if you have fixed wireless communications, why not just put a wire and make it much more robust? What is the need for having a fixed wireless? We thought wireless is supposed to be mobile. However, there clear-cut advantages that fixed wireless systems have. These advantages are the basic advantages that any wireless systems have. The first is freedom from wires. Less installation time and cost. If you have wires, you have to install them. You have to either dig up the road or put up towers or you have to carry them on poles.

But wireless means you do not have any of these problems. In fact, one of the evolving standards is the IEEE 802.16, the wireless metropolitan area network standard, the wireless MAN standard. It is being ratified and this is important because this is one of the first IEEE standards which will be first tested in a Southeast Asian country. Most of the IEEE standards which have been launched so far are either first tested in the US or in the Europe. For the first time, 802.16 prototypes will be tested in South Korea early this year 2005. So we will also have a little bit of focus on fixed wireless access. The next thing we have to look at is the typical frequencies and how the frequency domain acquisitions work.

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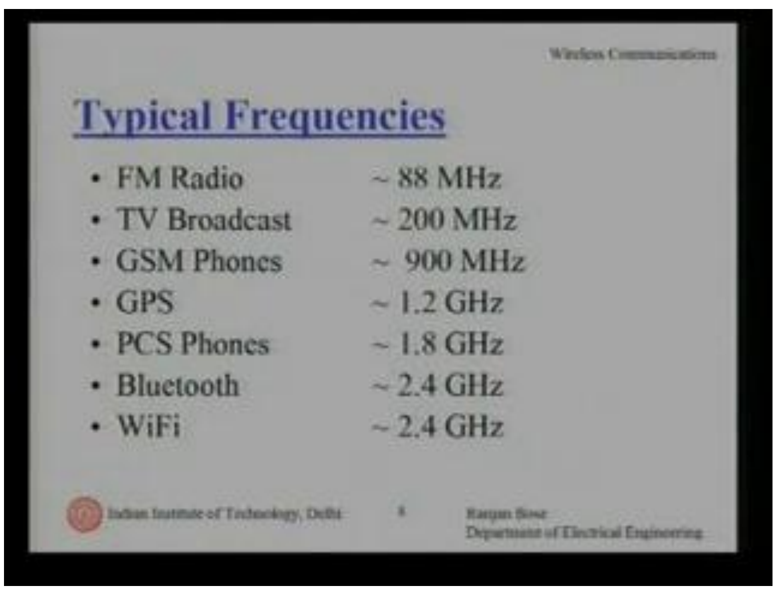

For example, FM radio which we all listen to these days work around 80 MHz. the TV broadcast is at 200MHz. the GSM phones work at 900 and 1800 MHz. so the dual band phones work at 2 frequencies. So we are touching the GHz range. the GPS, Global Positioning Systems work at 1.2 GHz. PCS phones work at 1.8 GHz, the Bluetooth the poor cousin of the ultra-wideband technology which we will also discuss in this course also works at 2.4 GHz. WiFi, the 802.11 B works at 2.4 GHz. 2.4 GHz has been a favorite band recently because it is a free band. It is also known as the ISM band. It's given to the medical industry, institutions & scientific establishments to experiment with. A lot of useful appliances have come out on this frequency band.

We have wireless lab here where most of the experiments have also been designed around the 2 point four GHz simply because we did not have to take any license. So it's a license free band. Please note i have put in numbers here, 2.4. It doesn't mean that is the only frequency that it works at. It's a frequency band all the time. However, let's not be limited by this 2.4 GHz. we have frequencies working at 28 GHz. we have frequencies working 42 GHz, 60 GHz and trial runs are being made at 100 GHz. So a lot of frequencies are being experimented with. This is our favorite electromagnetic spectrum.

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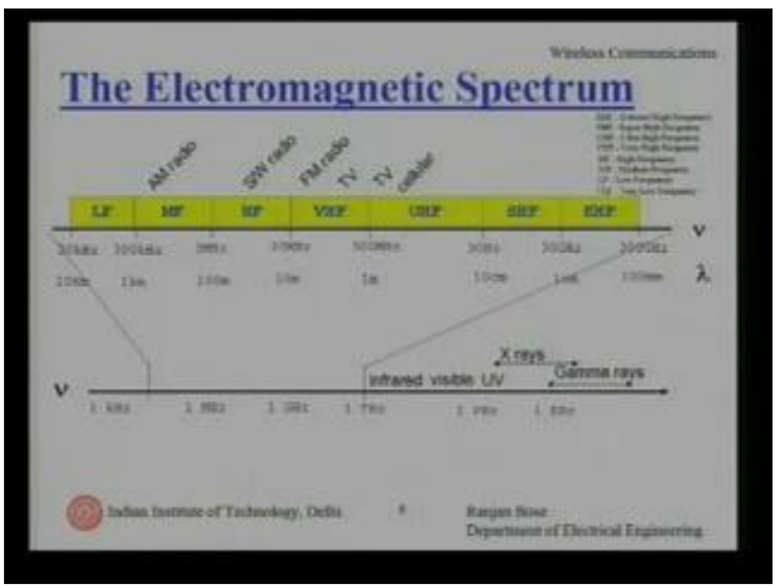

This tells us where we are and how much more we can exploit. This yellow strip translates to a lot of rupees for the government because it gets a lot of money by licensing the spectrum. There is a telecom regulatory authority of India, TRAI which works on this area. Here, if you see, I have started off from1 KHz up to gamma rays. Of course, we cannot use all of them because there are frequency related issues. The most important thing that we need to know is that different frequencies get attenuated differently by air. So air is a frequency selective channel in the sense of attenuation later on we will also see other frequencies selective properties of the channel. So far the wireless communication, air is the channel. However, if we pump in, say1mW of power at 20 KHz. it might go to a certain distance before getting attenuated beyond the receiver sensitivity. So wireless communication has to work between stations A and B which are not collocated. Otherwise there is no need for a communication. However, we need to communicate over large distances. So, one way is to increase the power. but any increase in the power comes at 2 specific causes. One is clearly the money. If you are radiating more power, your equipment is more power hungry and causes more money to operate. The other more important thing today is the radiation hazard. For example, the mobile phone that I am using today must comply to a certain maximum radiated power constraint.

There is a peak power and there is average power. We cannot just keep on increasing the power of radiation to cover more distances. Because the friends and people nearby will get effected. Certain frequencies for example, in 900 MHz travels to quite a distance. Lower frequencies also travel large distances. Therefore TV tower and radio tower can cover areas up to 5-10 km, if not more. A typical 900 MHz base station which communicates with our mobile phones can work easily up to 5 km radius for the given power. But for the same power, if we increase the frequency, say we go to 2.4 GHz; the electromagnetic radiations will get attenuated much more. That is, our coverage area will get reduced.

Let’s go to still high frequencies. for example, 28 GHz. there also our range comes to about 2 km. then there is another factor which are rain, dust, fog, etc. the higher the frequency, smaller the wavelength. In fact, at 30 GHz, we touch the mm wave. as the whole range of communication products today which work in the mm range. Now the mm long wavelengths, the size of the wavelengths is of the size of a rain drop. This starts interacting. There is a fog or rain or big dust particles, these rays would get greatly attenuated. Hence result in smaller coverage areas. So on this yellow strip, it is important to know where we operate also from the point of view is how far can you send the rays.

Microwave lengths have been traditionally used to communicate data over tens of kilometers. But those are point to point wireless lengths. Those are again examples of fixed wireless communications. Since we are looking at the electromagnetic spectrum, another way to do wireless communication is light. We can use simple visible light or in fact, infrared to do communications. We will also see how these things come into picture. All of this is indeed wireless communications. We do not need wires for any of them. So as a part of this course, we will look at parts of infrared, not so optics but primarily radio waves.

Student: sir, why do we go to such a higher frequency for wireless communication which results in such a large percent of attenuation. Why don’t we go for lower frequencies?

Professor: the question being asked is: what is the need to go to such high frequencies? Clearly, high frequencies not only get attenuated but the other thing that I didn’t mention is designing high frequencies circuits itself is a challenge. This is more expensive. So why do we at all need to go to high frequencies? The answer is that today we are getting into more bandwidth hungry applications. Multimedia is a part of any application today. We not only want an SMS but also want an MMS today.

We want to send video clips. All this require a larger bandwidth. To go to a larger bandwidth, we have to translate ourselves upwards to higher frequencies. So there is a center frequency and then there is a frequency band associated with that. That frequency band is your bandwidth which will allow you in the high data rates. A higher bandwidth will give you a larger data rate. It depends on the modulation scheme that you use. We will talk about the modulation schemes later on. Until the time that we were using electromagnetic spectrum only for voice communications, lower frequencies were okay. They would travel long distances and the bandwidth requirement was not much. It was 4 KHz voice and it was analog. The moment I need to check my e mail or try to do some data download on my mobile phone or by a PDA, I would like to have a little bit more bandwidth. If I am going to have a wireless in the local loop and support digital video and demand, then i definitely need to have a much higher spectrum. Therefore, for example, the wireless MAN, the metropolitan area network is going to solve the last mile problem. What is the last mile problem? The last mile problem is you can take the fiber to the curve. But still taking the fiber to every home is not the reality. It is still expensive.

More than big expensive, it is too much of an effort to take a fiber optic cable to every home. But if we need broad band, we need to have something like a fiber optic connectivity to the home. What people do is take the fiber to the curve and put up a tower and solve the last mile wiring problem using of wireless. So this concept has been used in the wireless in the local loop scenario where over short distances. We can have large bandwidths for transmission. So here if you see I have highlighted propagation characteristic are very different. Each of different frequency bands. Not to mention the hardware design issues.

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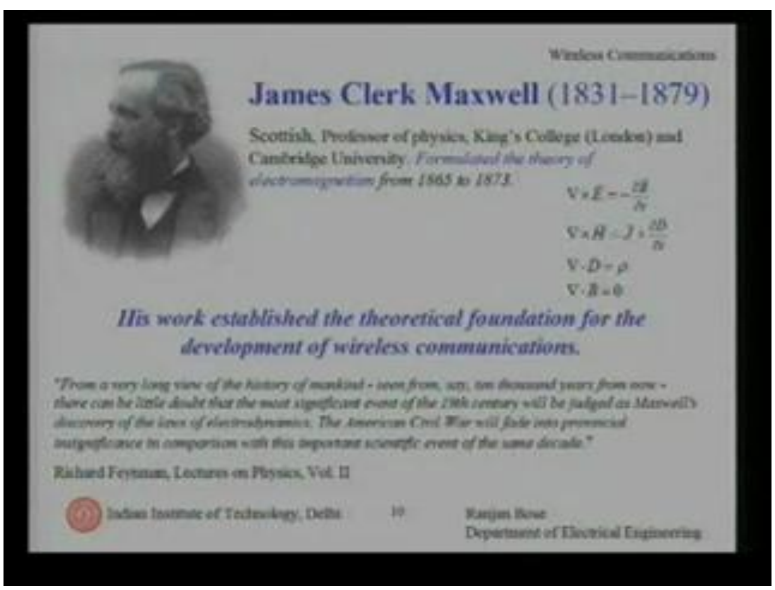

a brief history: this is the guy who started it all, “James Maxwell” and these are the four fundamental equations which the well-known Maxwell’s equations (Refer Slide Time: 24:24) which proved that” yes. Magic can happen”. So when he proposed this it was a theoretical result and it would take several decades for experimental physicists to prove the existence of electromagnetic waves and what you can do with it.

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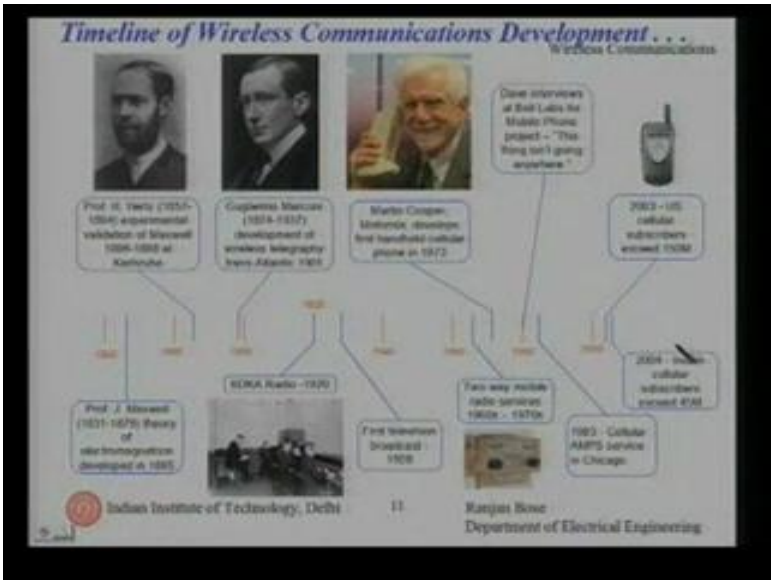

So if you look at the timeline, after Maxwell proposed his theory, Hertz was the first guy who validated the theory. Then Marconi developed the first telegraphic instrument. However, J.C. Bose actually did the experiments in Calcutta and published the results. The credit goes to Marconi as being the discoverer of the wireless communication equipment. But J.C. Bose was the first guy who actually demonstrated it. What he did was he could remotely turn off a light or fire a gun powder using electromagnetic radiations to demonstrate the proof of concept. It was magic because you sit at one corner of the room and you press a button and an explosive will go off at the other part of the room. This was the experiment he did.

Unfortunately we were not good at marketing. Then of course, initial radios were established in the 1920's. The first TV broadcast took place in 1928. This is wireless. Then in 1973, the first handheld cellular phone was unveiled. Mobile phones came into the picture in the early 80's. It started with the first generation mobile phones which were analog. Then the second generation mobile phones which was still analog and then the 3G phones which get into the digital domain. In 1983, cellular amps service was unveiled. It was a purely analog system. In 2003, the cellular subscribers in the US exceeded 150 million. In November 2004 in India, the cellular subscribers exceeded 45 million. This 45 million has another very interesting connotation which is: we exceeded the number of fixed lines phones. So for the first time in India, the number of fixed line phones were outnumbered by the number of mobile phones. It gives us and a perspective as to how important this wireless technology is.

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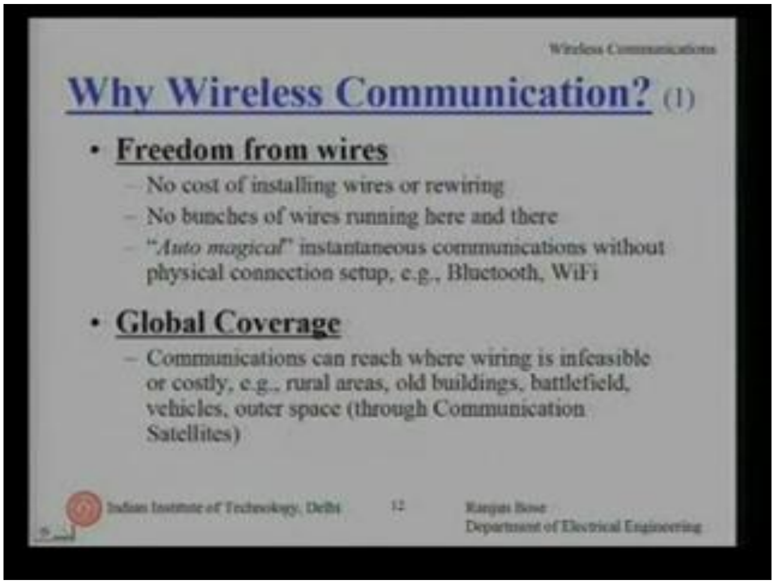

So let's look at the reasons. These are very fundamental reasons. They may be obvious but that makes the cash registers reign today. First of all, freedom from wires translates to less installation fee, no rewiring, no stolen wires, no bunch of wires running here and there. In fact this basic reason is driving the next communication standards. The 802.15.3, the ultra-wide band communications which will also promise a wireless desktop. Today, why should my PC be linked to my printer through a wire? Sometime back, people used infrared connectivity for printers. But you had to have a line of sight. Today what we are working at is complete freedom without the constraint of line of sight. The next is global coverage. rural areas, old buildings, buildings which are not wired, battle fields etc. Again this second point is very important in driving the wireless communication industry. Rural areas are particularly significant for India.

Today our teledensity is very low. Close to 4 per 100 on an average. So I am talking about the rural teledensity. What is happening is the way to take advantage of this technology is to have a wireless coverage. In the later part of this lecture, I will give you brief perspective how wireless communication is going to affect the Indian scenario. More importantly the battle fields scenario. Today we are talking about wireless ad hoc networks. It is the buzzword because these are reconfigurable and self-configurable wireless networks which can be quickly set up for sending data or communicating between the notes.

Vehicular communication, for example, each time I go to a toll road, I have to stop, take out cash, pay and go. The car behind me also has to do the same thing. Wouldn't it be great if i just go across the toll gate, and a wireless reader will just read up and deduct from my account, the electronic cash and pay the toll for me? It can avoid so many traffic jams near the toll road. That will be great. RFID's - the Radio Frequency ID's. It's the next big thing in the markets today. That's going to replace bar codes.

Today, most of the equipments which have bar codes have to be read out. But they are passive devices. RFID's are also passive devices but they can be read from a distance and they can have a little bit more smartness built into that. For example, if all my medicines on the shelf or equipped within RFID, then automatically if any medicine is nearing an expiration, i will have an update on my PC that says, "Okay. Look! That bunch of medicines have to be replaced soon". Or if some medicines are selling faster than others, I can generate more revenue by ordering them on time and host of other applications. So these are some of the applications which are revolutionizing the wireless communication industry. So the point that I am trying to make is wireless communications is not just talking on your mobile phone. It's way more than that.

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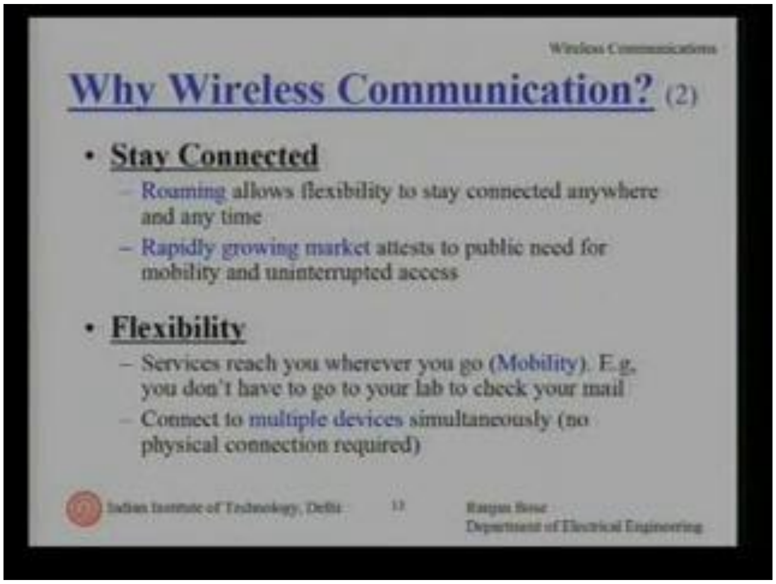

Now, why do we need wireless communication? The first point is, stay connected. Basically, roaming. Today, when I go and switch on my phone in Mumbai and I am ready to talk, absolutely no problem. Secondly, flexibility to connect several devices at the same time, Bluetooth protocol. Today, for example, I reach out for my wallet and give you my business card. The next best thing would be, I take my mobile phone and take it close within a hand shaking distance to my customer. The phones communicate and send my business card electronically. There is no need for them to retain my card because he will lose it anyway. It's much simpler to give information. These are the businesses which are driving the force.

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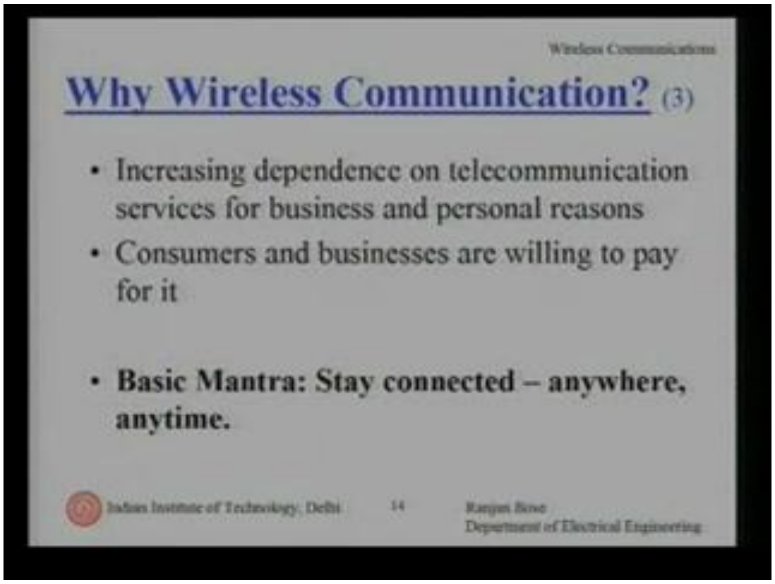

So the basic mantra is: stay connected anywhere-anytime. Of course, to make this mantra realizable, a lot of other things must work. The next big thing which has coming to the picture is broadband connectivity. So all these businesses are interlinked. Of course, most of the advantages are coming from solving certain kinds of challenges.

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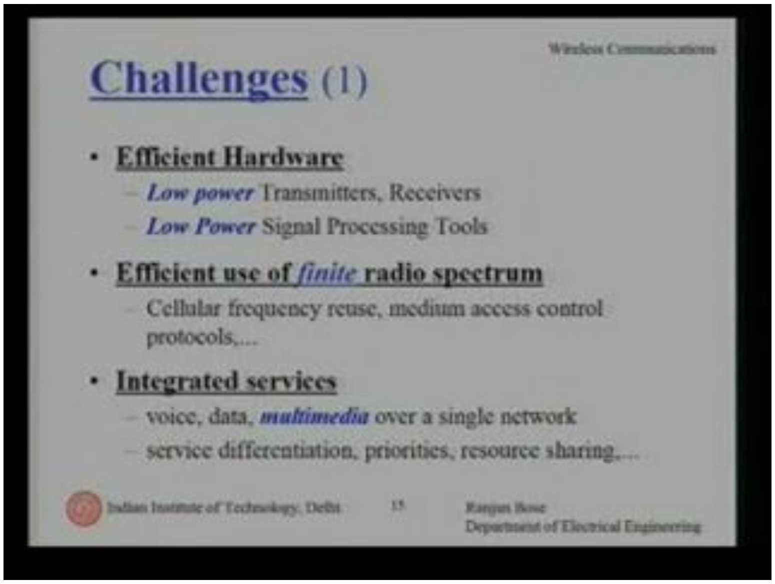

So in the next couple of slides, let’s look at what are the important challenges to be sorted out. The first and the most important thing is low power design. As I mentioned before, low power is important for 2 things. The first thing is, it should consume less power to make your battery lost longer. When you sell a mobile phone today, you say: talk time -so many hours and standby time- so many hours. If my competitor wants to sell more, he will increase the talk time but the standard battery remains the same. The only way the person can do it is to make the hardware less power hungry. But there is a conflicting requirement.

Today, when we are sending an MMS or trying to download the stock codes or doing some kind of other multimedia application, automatically I consume more power. So a lot of research is being done to figure out ways and means to reduce power consumption. The second important way to reduce power consumption is to have certain signal processing tools to ensure that I only expand power when required. I do not waste power. I can have a sleep mode. My phone should radiate only when i am talking. Part of the circuit should be shut down. There are several other techniques to go around. The other challenge is to squeeze out maximum from the spectrum. So if we have the finite bandwidth requirement, there is pre-decided capacity relations which tells us how much we can go. If you have so many spectrums, you can only send so many bits per second provided the signal to noise ratio is so much. So the question is how can we better use it? So people thought and came up with a very simple solution. Why have only 1 transmitter antenna and 1 receiver antenna? Why don’t you have multiple input - multiple output systems, the MIMO? So recently the MIMO systems have come in vogue.

We are using the same bandwidth and squeezing much more out of it by using the multiple inputs- multiple output systems. The other challenge is coming from the consumers. We have voice, data, and multimedia. All have to be packed in. the circuits must perform, please remember low power requirements & low bandwidth requirements. The more number of users are there, the smaller share of the fire brigade. If we cut off the bandwidth, as we looked at in the first example, the more number of users, the smaller is the share. So given a limited frequency band per user, we have to extract the maximum. Again we will look at the techniques to do so. Then of course, we have to obey certain human requirements. For example, if we are talking on the phone, the delay should not be greater than a certain amount.

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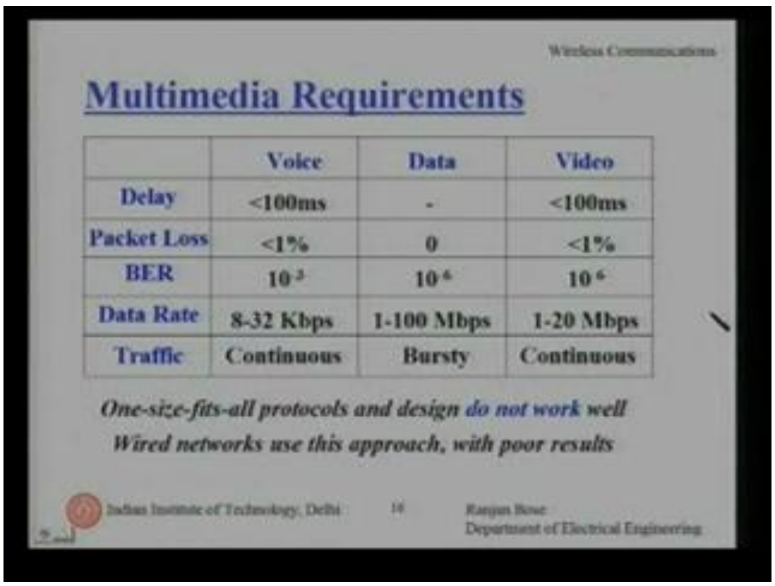

Take for example, the voice over IP. It's not clearly wireless but today, a part of the voice traffic that we send also goes over IP networks. So today IP networks, the internet protocol networks also are a part of the large wireless networks. Most of the voice over IP applications make sure that the overall delay do not exceed a certain value. Packet loss will directly translate to the quality of sound that you hear. Or if you are doing a stock code update on your mobile phone, then again the bit rate and the packet loss rate will play a significant role. I do not want to sell a stock because I got a wrong data.

Data rates are very important if I am streaming a video. I would like to have a certain kind of data rate requirements. Then traffic can be classified as continuous out bursty. These are the different problems that have to be tackled. A bursty traffic has to be tackled in a different manner than the continuous traffic. So these challenges can also be used to your advantage. For example, if you have a bursty traffic, so I type in "Hello! How are you?" in my internet e mail and then I think for a while and then type in my next set of the sentences. So the traffic is not continuous. It goes as bursts. Even if I am speaking on the mobile phone I say hello and pause and i thing and i then san my second word or sequence of sentences. In the silence period, may be somebody else can fit in their data traffic. Today voice, data, and multimedia everything is going as bits. It's digital communications today. So the challenge of continuous versus bursty can also be used to your advantage. So the conclusion from this light is one- size-fits-all protocol does not work. You have to work for different protocols differently. Wired networks use this approach because they only one kind of instrument and they didn't succeed very much.

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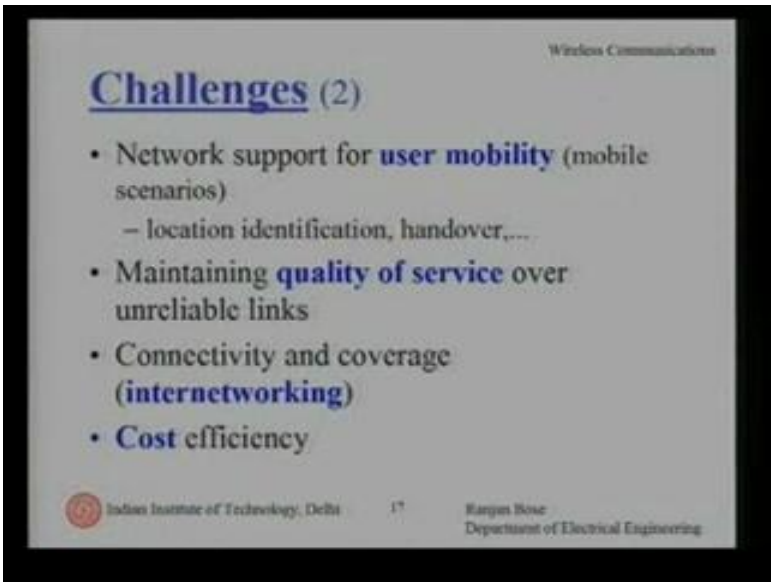

Let's look at the other set of challenges. Network support for user mobility. We have to give them enough mobility. So if person is travelling in a car at 50 km/hr and it moves from one cell to another cell, then the hand over must take place. That is, one base station must handover the call to the next best station. We will talk about these issues in greater details when we look at the cellular concept and handover issues. But these are challenges. Because if I am not going at 50km/hr but at 100 km/hr, I might just drop the call. Quality of service. This is again a big buzzword. Quality of service means different things to different users. The quality of service for a rich customer is different from a poor customer.

Quality of service is different for different applications. But in general, we have to maintain a set of parameters. It could be the number of packet loss, the delay, the bit rate, the noise, the background noise and so many other things which will constitute the quality of service. The next is connectivity and coverage. Today, if a new internet service provider comes in or a new mobile phones service provider comes in and says: "I can give only coverage to 80% of the city". He cannot say. He has to give 99 % coverage. Even if he has to give a coverage over the hilly regions of Uttaranchal, he has to set up wireless communication systems and then give the coverage. Coverage is a big issue. Next comes the cost efficiency. So today a handset costs Rs.2500/-. It should go down to Rs.1500/- tomorrow. Only then you can make money out of the business.

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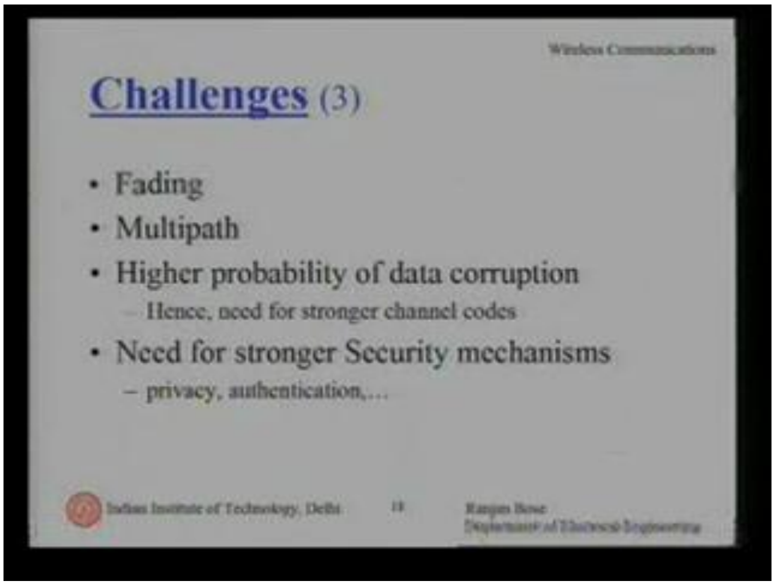

The third set of challenges are non-business issues. They are more technical challenges. Those are the issues which we will look at as part of this course. The first and foremost is fading. What is fading? Fading comes usually from multipath. Because when you have a transmitter and a receiver, the rays travel not directly but comes through several reflections. So the rays have the luxury to travel from the transmitter to the receiver through multiple paths. Hence multipath. But when they reach the receiver, they superimpose. The simple superposition must work. Because how do I pick up signals at my receiver? There is an antenna and any radiation that strikes the antenna generates an electric current.

But if more than one radiation comes delayed but at the same time from different transmissions, then they superimpose. If they constructively add up, you get something different. If the destructively add up, you get something different. In a sense, what you receive is very different from what you set. This would not have been the case if it was a clear line of sight communication without multiple rays. So the multipath is the culprit. This effect is called "fading". Because sometimes if you look at the signal or if you hear the voice, the voice goes up and down. Just like when you look at or hear the short wave radio, you would hear the voice waxing and waning.

The intensity goes up and goes down. Just like fading. So this is one of the most difficult challenges to take care of. In a room environment, suppose I am going to have wireless local area network set up, I will have a much severe path because there are so many wall reflections, reflections through various walls, different room scenarios, through the tables, chairs and other equipments that the multipath effect is even worse. So then we look at for example, 802.11 B, we will definitely consider the fading scenarios. I have already motioned multipath. Then probability of data corruption because wireless communication are not robust unless you add in error correcting techniques. We will look at this error correcting techniques also in this course. The biggest problem is security. Anybody can put up an antenna and listen to what you are saying. So today most of the mobile phones have in-built security systems. But for every lock that (Refer Slide Time: 45:58) somebody will make a key. This is an ever evolving research area for privacy for authentication.

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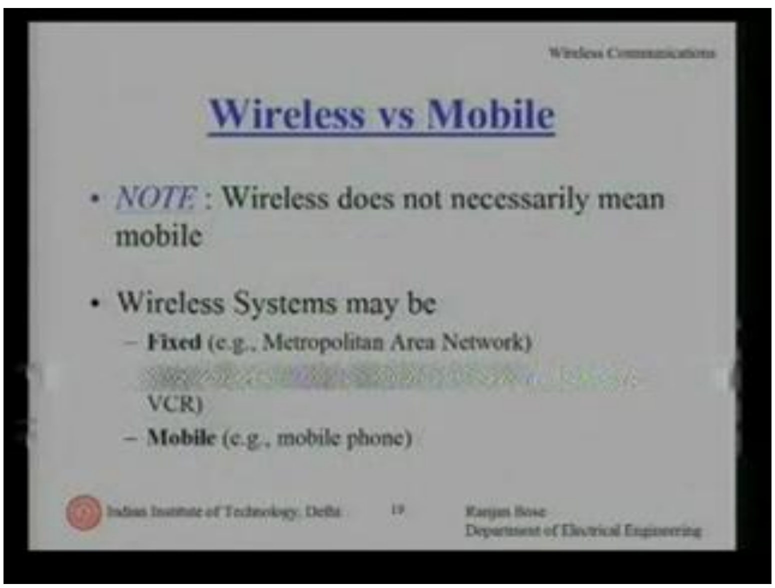

So wireless verses mobile, just to emphasize the point as it doesn't necessarily mean mobile. Wireless system can be fixed supportive mobile. So we should make a difference and treat them differently. So fading for example, will not be so severe for the case of fixed broadband wireless access as opposed to mobile. As we move along, we have different paths of reflections. The reflections scenario changes and the fading also changes. But somebody observed the way things are progressing. When initially TV was invented, most of the transmission was through air. You had a TV tower and you had an antenna on your TV and you got a TV reception by air. When telephone was invented, you had a telephone wire coming to your home. Today the TV is through cables. All the TV channels are coming through wires and the phone through air. So today the phone is wireless and TV is wired. (Refer Slide Time: 47:35 to 47:40- missing video). So now we will conclude the first session and the types of wireless communications will be the first slide in the next series of lectures.