Evolution of Air Interface Towards 5G
Prof. Suvra Sekhar Das
G. S. Sanyal School of Telecommunications
Indian Institute of Technology, Kharagpur

Lecture – 03
Evolution of Wireless Communication Standards from 2G to 5G (Part – 2)

Welcome to the course on Evolution of Air Interface Towards 5G. So, in the previous two lectures, we have been seeing the development of wireless communication a little bit of historic perspective. And then we started to look at the GSM communication, which is the 2nd generation system, and which translated from analog to digital. So, we carry on with our journey and start taking look at the 3rd generation systems also known as IMT-2000s. And then we will move forward slowly towards the development of IMT as things have followed.

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So, in this particular lecture, we are going to cover the topics IMT-2000, requirements of IMT-advanced, LTE, and LTE-advanced, and how they fare against each other and where do they stand. And then we will move forward to the IMT-2020 or which is the five 5th generation of wireless communication systems.

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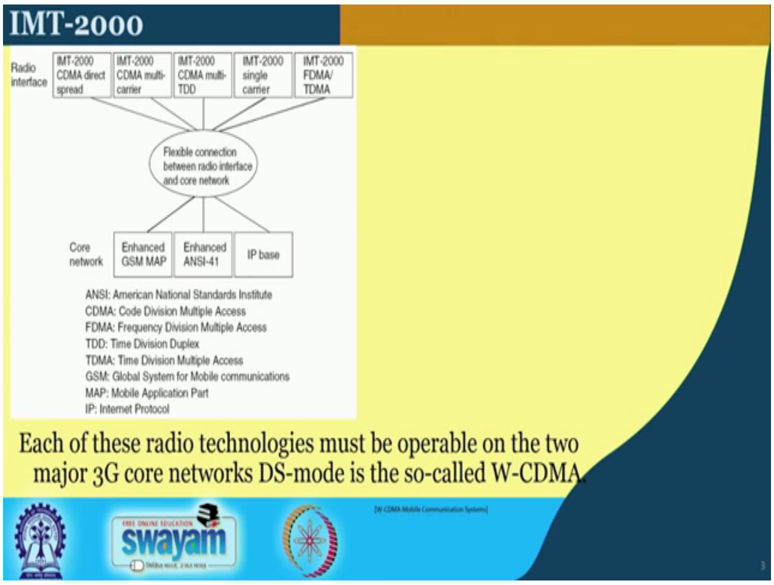

So, what we see in this particular picture of the IMT-2000 is that on the radio interface side, there has been multiple technologies, which could meet the specifications of IMT-2000 whereas, on the core network side, they were again multiple methodologies or techniques or technologies, which could support them. And as has been clearly mentioned that each of these radio technologies must be operable on two major 3G core networks that is the DS-mode is the so called W-CDMA mode.

So that means, there are multitude of technologies, so although there had been some agreement that there should be a common technology, but interoperability and things have been tried to be maintained. But, end of the day there were multiple technologies, which satisfied the requirements and they were labeled as IMT-2000, and that you can clearly see as has been described in this particular picture.

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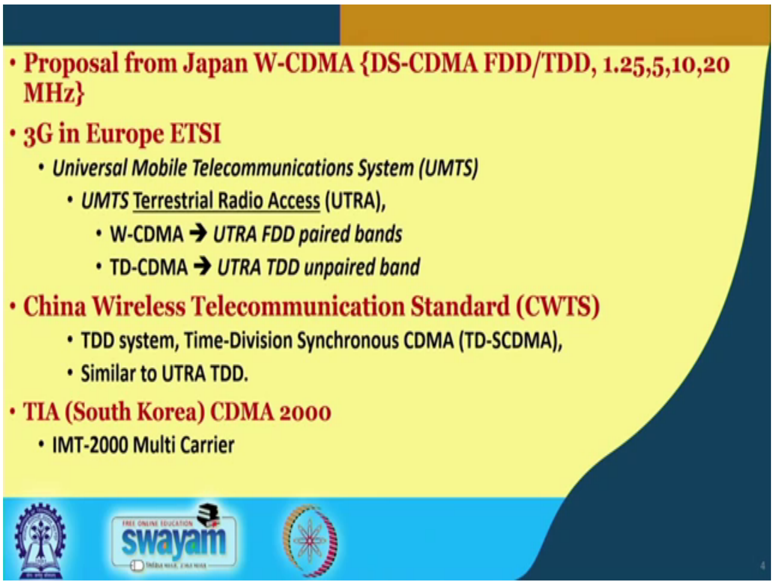

Moving ahead what we take a look at is that the W-CDMA proposal, which was from Japan had a bandwidth of 1.25 megahertz, 5 megahertz and so on and so forth. In Europe, it was ETSI, which presented the UMTS or Universal Mobile Telecommunications System. And it was known as the UMTS terrestrial radio access also usually referred to as the UTRA or U T R A, and it had W-CDMA which is FDD paired, and it had TD-Time Division CDMA.

China had proposed the Time-Division synchronous CDMA, which is similar to the UTRA TDD. While from Korea, there was multi carrier IMT-2000. So, if you look back at some of the publications, there have been huge amount of comparison of the different technologies their benefits, and their disadvantages. And then you could see that how different technologies pair against each other, how do they perform against each other, and there are different reasons for selecting different technologies in different regions.

End of the day, what we take a message from this is that there could be multiple different technologies, which could meet the specifications of a particular generation of communication standard, and a brief summary of its genesis has been given in this particular slide.

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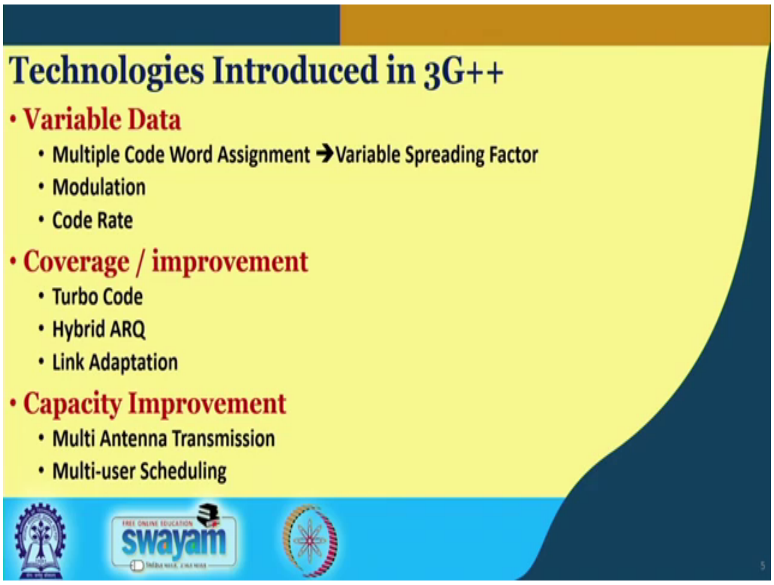

As we move ahead. So, beyond 3G that means, 3G plus plus as I have mentioned over here though there is nothing called a 3G plus plus, but there are like 3.5G and 3.9G some of the important things that came into play were variable data rates, which were supported by means of multiple code word assignments or a variable spreading factor that means, since CDMA technology, which uses spreading mechanism.

So, one could allocate multiple code words to a user or one could use a variable spreading factor. So, as you are spreading factor changes the data rate supported would also change, so thereby a variable data rate was supported. Modulation and code rate were also made flexible. Flexible in the sense multiple options were available. So, different modulations like BPSK and QPSK and 16 qualm were also brought into picture, different code rates not only a fixed rate half, but other code rates were also available.

And the mechanism of error correction codes such as turbo codes and other techniques were brought into play, which improved the error probability and hence the coverage. The method of hybrid ARQ; ARQ is the Automatic Repeat Request, which enhances the performance of a communication system was also brought into this particular series of standards. The hybrid ARQ which if time permits, we will discuss at some point, not only does automatic repeat transmission, but it also has a mechanism to adapt every repeated transmission based on the previous link that means, it could change the data rate in the next transmission or it could save the previous samples of the data, and could combine together in order to improve the performance or reduce the number of ARQ transmissions.

Link adaptations are also great mechanisms, which were brought into the system, which could be used in order to cancel or take care of the fluctuations of the wireless channel links. We will discuss about the fluctuations of the wireless channel links at some point of time. Now, while these were going on the second generation system also evolved, and there the link adaptation methods were also brought into play. So, it is not as we have discussed earlier that is not necessary that when a new standard and new methods come in the previous generation standard stands still, and does no improvement. So, what we see is that as new technology improves, the previous version also keeps on becoming better and better and better.

The capacity improvement was brought into by use of multiple antennas. So, again at a later time we will discuss about the multiple antennas. So, what happens essentially in multiple antennas primarily two important gains come in though there are many more gains that come in at this level, we just say that by means of having multiple antennas. We in turn increase the effective aperture of the system in a virtual sense what does this do, essentially it captures a larger amount of energy. And when you have a larger amount of energy, your signal to noise ratio becomes better, and hence it improves the capacity of the system.

The other way multiple antenna performs more than a single antenna system is that when there are multiple links available, then usually by virtue of the propagation mechanism the link conditions on the two different spatial antennas are not necessarily same. So, there is a lot of de correlation, which is present. And this is exploited in order to make better performing systems in terms of error probability. So, when we use the multiple antennas as a diversity mechanism, the error probability improves.

Then there were mechanisms of multi-user scheduling, which were also brought into play. So, by means of multi-user scheduling, we will again a get an opportunity to see this what is meant is that. In earlier systems multi-user scheduling was there, but it was kind of a fixed process. For example, in time division multiple access, you would assign users in a round-robin fashion that means, the 1st user, then the 2nd user, then the 3rd user and so on and again it repeats the entire cycle from 1st user, 2nd user, 3rd user and so on and so forth.

In case of frequency division multiple access, you allocate different frequencies to different users and so on and so forth. But, here what happens is the data was one of the important traffic. And the basic nature of data is that it is bursty that means, that there is a sudden requirement of data, and the requirement time is not known a priori. So, there is a randomness in demand of a link.

Whereas, on the other hand there is a randomness in the fluctuation of the link conditions; so, what this multi-user scheduling does is it takes inputs from multiple users simultaneously, compares the link conditions as well as takes a look at the data rate requirements and does a mapping, so that the sum rate is maximized. We will again get an opportunity later on to look into the details of such mechanisms, which are again extended further in the new generation communication systems.

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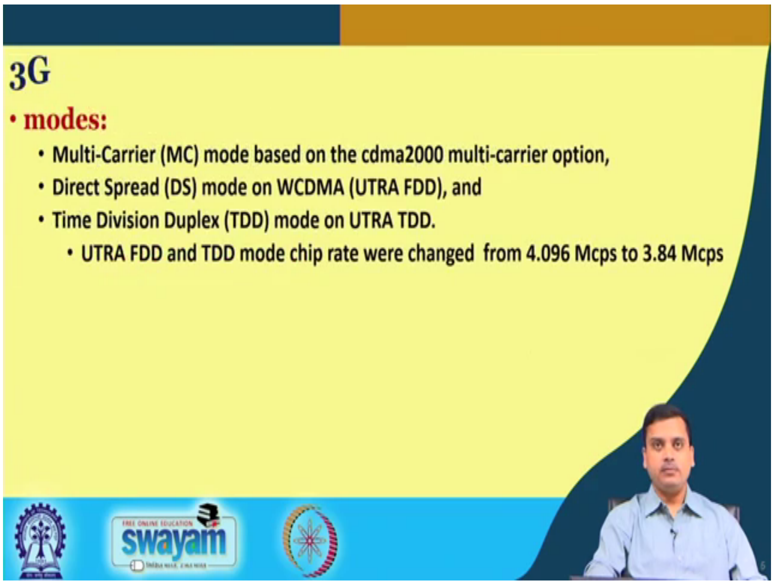

In 3G as we have said earlier there are multi-carrier modes as well as there is the direct spectrum mode, and there is the TDD mode. So, there are multiple modes and we will not discuss the details of this, but again there are different forms, which existed simultaneously. And in these modes they were the chip rates, which is essentially needed to describe the system so around 3.8 mega chips per second is one of the important parameters, which define the 3rd generation systems.

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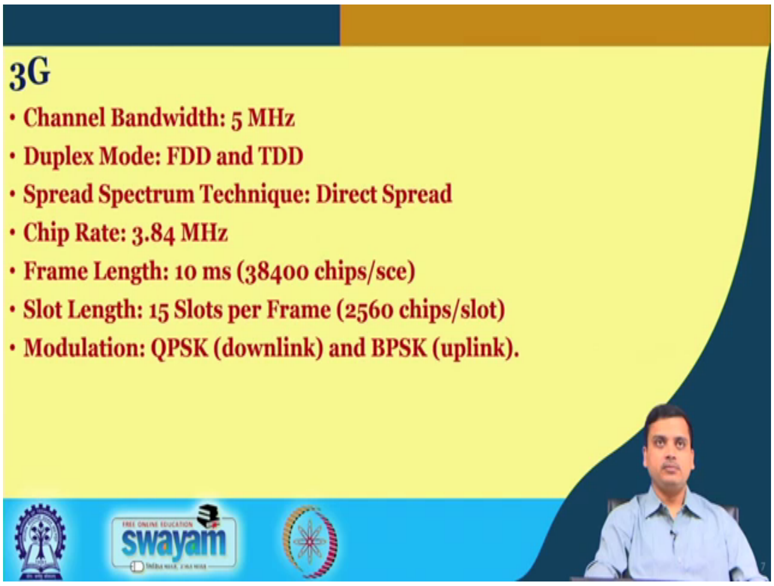

The 3rd generation systems were drastically different than the previous generation system; in the form that the channel bandwidth was much larger than the previous generation system. In the GSM, it was 200 kilo hertz allocated to one user, whereas in 3G 5-megahertz channel bandwidth was available. Duplexing mode as said earlier supports FDD and TDD. Direct sequence spread spectrum was possible. Chip rate as just mentioned is 3.84 Megahertz. Frame length is 10 milliseconds. And slot lengths are 15 slots per frame. Modulation QPSK and BPSK later on things were improved to 16 qualm.

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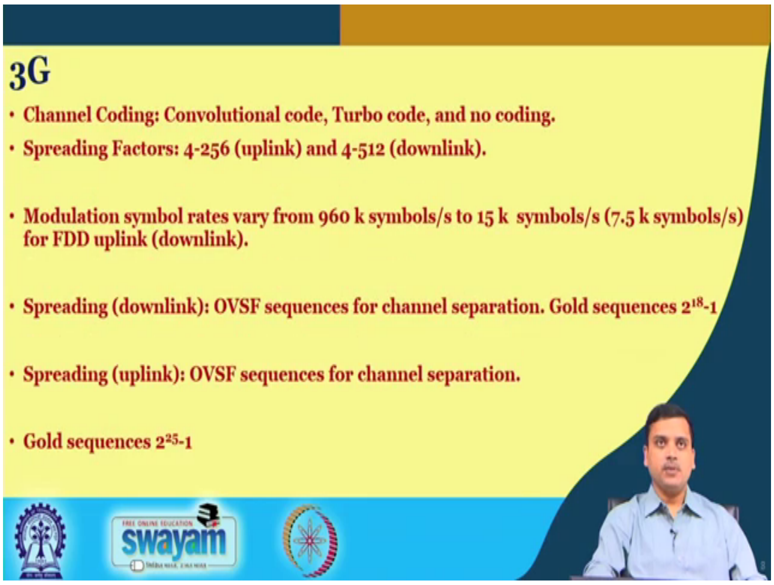

So, the channel coding, it supported convolutional code, turbo code as well as no coding depending upon the link condition. Spreading factors were variable from 4 to 256 and five 4 to 512. So, as you increase the spreading factor, your effective data rate decreases and as you decrease the spreading factor, your data rate increases right. So, when the link conditions are good or when there is interference is less than one can think of using a smaller spreading factor, thereby increasing the data rate.

Whereas, in adverse situation when there is heavy amount of interference or when the link conditions are really bad, then larger spreading factors could be used, and as can be clearly seen from the specification the uplink and downlink spreading factors were different because of several technical reasons. So, there were different sequences that were available for use while spreading these symbols, and the different symbol rates were also possible to implement.

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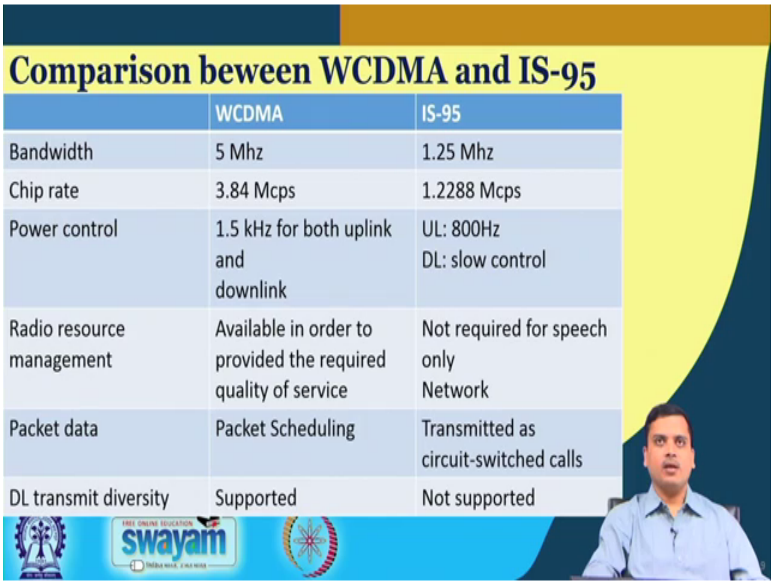

So, if we compare between WCDMA and IS-95, which is also a CDMA technique, and it was an earlier generation system what we find is that the bandwidth increased from 1.25 Megahertz to 5 Megahertz, accordingly chip rate has also increased, and power control has also changed between both the systems. And then if we look at the radio resource management method, so in the IS-95 it was since only for speech networks that was not much necessary, whereas WCDMA which was also going to support data, it was important to have radio resource management methods. So, it was introduced in such systems.

Packet data scheduling as has been mentioned before scheduling is an important part, whenever you have packet data. So, packet data scheduling came into play where whereby you could schedule the packets and different times, whereas in the previous system it was circuits-switched calls and this the time slots available you could use them for transmitting data. Transmit diversity was supported in the new system, whereas it was not supported in the previous generation system.

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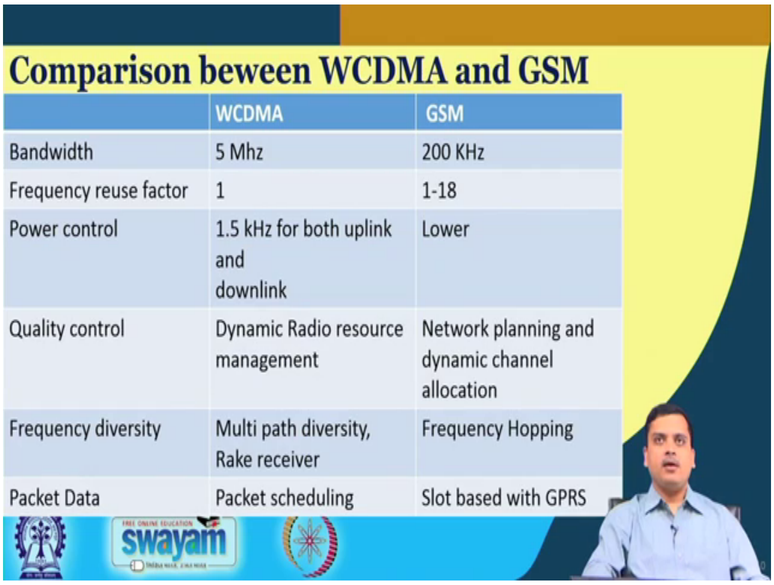

Then we get into the other important technology that is this WCDMA and GSM, which is more popular at least in this part of the world. The bandwidth comparison we have said before is directly available. The other important change, which happened from GSM to WCDMA is that the frequency reuse factor. So, in GSM systems, which use the TDM, FDM kind of an approach. There two neighboring base stations were allocated different center frequencies or different bands of operation. This was simply because in order to reduce the interference. So, the concept of frequency reuse came in, because without frequency reuse, you cannot support a huge number of uses.

So, what is done in such systems is with the distance of a certain factor n counted in terms of number of consecutive cells or consecutive base stations. The frequency of one base station is used in another base station, which is at a certain distance from one of the base stations, whereas neighboring base stations would use different carrier frequencies. So, as given over there that the reuse factor was varying between 1 to 18, it is possible in GSM.

So, as you increase the reuse factor, the interference term decreases. This gives rise to better signal to noise ratio or better link quality, whereas since you are using the frequency less often, so the overall capacity supported by such networks was limited. Whereas, when you moved to WCDMA system, the frequency reuse factor was one. So, it could be a natural question that how come it performs well, even if there is frequency use factor of one.

The main idea is the use of codes, which were designed in such a manner that they could cancel the co-channel interference, so that one could get back to use the same frequency amongst the neighboring base stations. By allocating proper codes to users and by using mechanisms of canceling interference a frequency reuse factor of one was feasible, thereby allowing a larger capacity to be deployed in the system by the 3rd generation or WCDMA systems.

The quality control was possible in WCDMA by means of dynamic radio resource management, whereas in GSM primarily it had to be a prior frequency reuse plan, a location wise deployment of base stations, so there is to be a lot of planning beforehand, whereas in WCDMA systems it could do a dynamic resource management, thereby reducing amount of effort that required in the network planning.

However, in GSM systems or in the advanced version, there was possibility to do dynamic channel allocation also. So, the dynamic channel allocation would help in accepting the change in capacity. For example, if there are a lot of cells next to each other, whereas you have allocated a predefined set of bands and frequencies to each of these cells. But, the user distribution has changed from the time you have planned the network.

So, then suppose most of the users have gathered in one of the cell for a situation let us say a particular sporting event or there could be some particular situation happening let us say a political meeting or some kind of a situation. So, there a huge crowd would gather in one cell, where are they would be lesser number of crowds in the other cells.

So, whereas in the neighboring cells you need to support lesser number of calls, but in the desired cell that is a denser cell, you need to support more number of calls or support more traffic. So, there was a concept of frequency borrowing by means of which you could borrow frequencies from the neighboring cells, and allocate for a certain duration of time. And once the traffic has dispersed, and it has changed over you could again give back the borrowed frequencies to their original base station. So, there were some improvements that were brought into the system whereas, in WCDMA it was already implicit inherent into the system from the basic design itself.

In terms of frequency diversity GSM, there is frequency hopping technique that means, during a call the slot that is allocated to a user, jumps over different frequencies. Now, you may know or we will discuss at some point that the wireless channel is such that the signals keep on fluctuating, and there is a certain rate of fluctuation. So, if the user is moving slowly or there is less Doppler, then once a signal is in fading condition, it would remain in that condition. Whereas, if the channel allocated to the user would hop from one frequency to another frequency, then on an average the user may experience a better channel condition. So, this is one mechanism of frequency hopping, which is used in GSM in order to provide a better link condition, which averages out the fading effect.

Whereas, in WCDMA the multipath diversity, so whenever you have multipath in other words you have a frequency selective channel generally that is the case. So, one can use rake receivers through which the rake fingers can collect the signal power from the different multi-paths combine them together thereby achieving multipath diversity, which can also be viewed in another way of collecting energies from the different frequency bands and combining them together, so thereby it combines the frequency diversity and enhances the signal strength, whereas in the other one it averages out the signal strength. So, they could be different algorithms, which would run while you combine the signals over the different bands.

In case of packet data packet scheduling as has been mentioned is already part of WCDMA, whereas in the previous system it was slot based GPRS, so GPRS came in when data was supported. So, within slots which was allocated for voice, you could give data. And when GPRS and edge came in, you could accumulate a larger number of slots dynamically, and you could allocate to users thereby providing a variable data rate.

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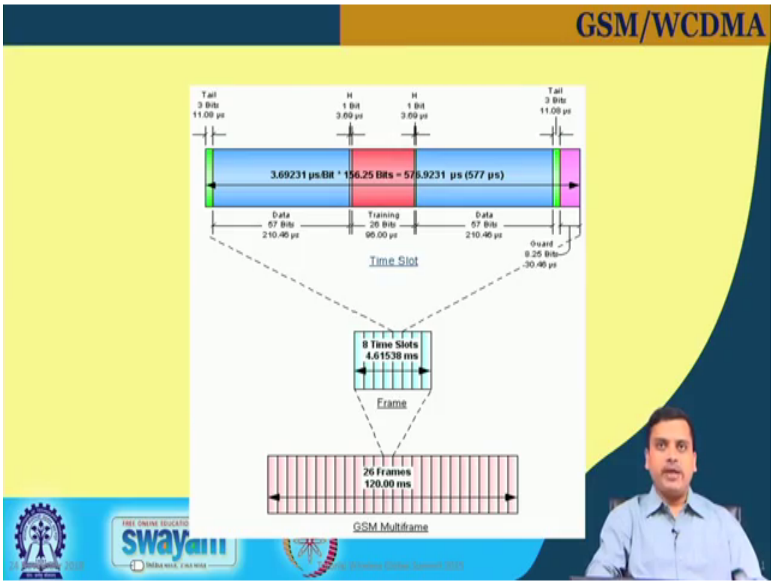

So, roughly one way of comparing GSM and CDMA is that this is a typical frame structure of GSM.

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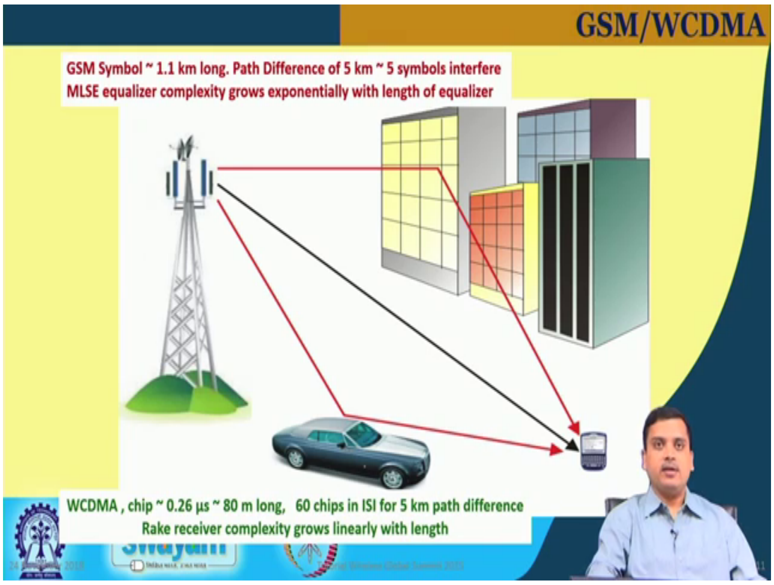

And what why one would see is that in large cells the GSM symbol duration would span around 1.1 kilometers taking into account the speed of electromagnetic wave propagation. And a path difference of 5 kilometers would account for 5 symbol inter symbol interference ISI. So, MLSE equalizer is required, and MLSE equalizer the complexity grows exponentially. Whereas, in WCDMA systems although there is larger high sigh coming into play, but by virtue of using rake receivers you can handle things to a certain rate. So, the complexity would go grow linearly in such systems.

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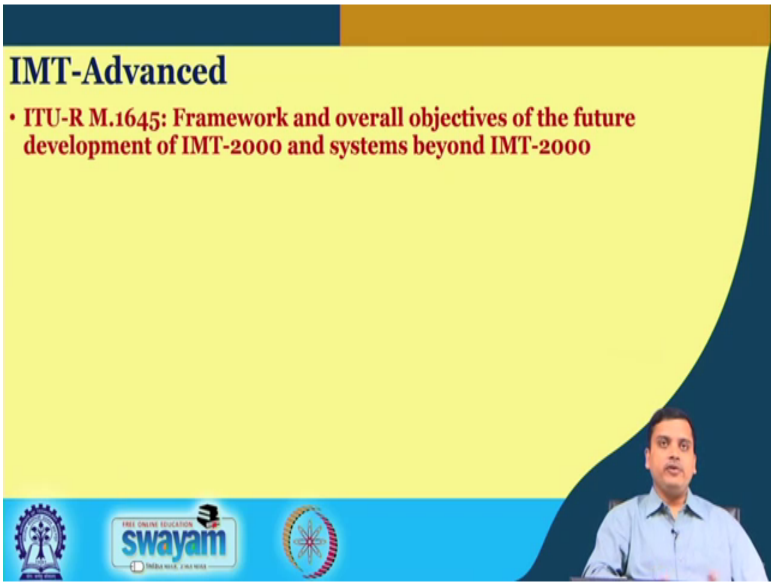

So, then after reviewing the 2nd and 3rd generation system, we move towards the next generation or the 4G systems and as per ITU this is termed as IMT advanced. So, IMT we have described before, it stands for International Mobile Telephony Telecommunications. So, in that the ITU-R, which is a recommendation from ITU. And the report number M dot 1645 describes the framework and overall objectives of future developments of IMT-2000 that is 3G, and systems beyond 3G. So, if you have to look at IMT advanced, you have to start from the ITU-R M 1645 document, which provides a lot of information about such systems.

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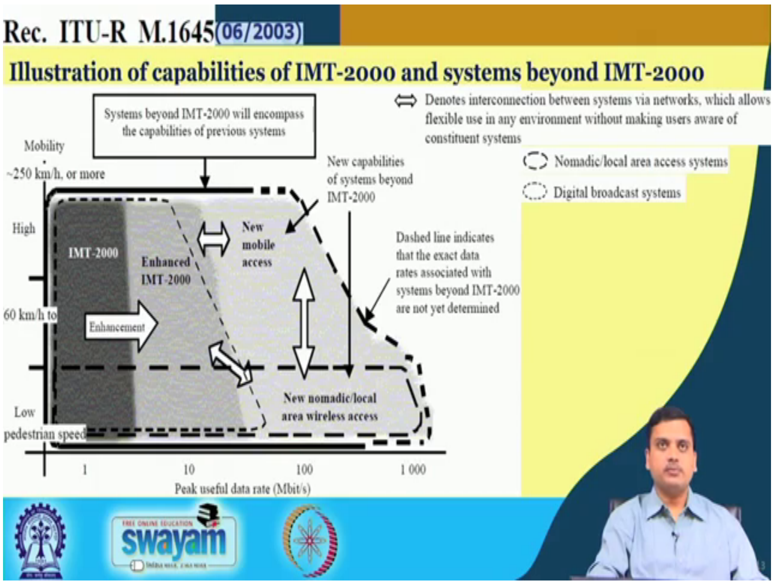

So, in this particular document that means, ITU-R M 1645. There is an illustration of the capabilities of IMT-2000 and systems beyond IMT-2000. So, this diagram has been well labeled, it has been taken directly from that particular document. So, what we see on the X-axis or the horizontal axis, there is the peak useful data rate given in Mbps, whereas on the Y-axis we see the mobility. So, we see mobility becoming an important factor. And it has been described, when we are discussing earlier in terms of requirements. So, what we see is that IMT-2000 is designed to support high mobility situations, and whereas the data rate is not really that high few Mbps.

And the enhancement as we can see over here, in this particular arrow as we can see here; so, this particular enhancement is indicating the development of IMT-2000 of 3G towards advanced systems. So, amongst the various things it requires the data rate support to be increased while the mobility support remains intact. However, as you can see described by this particular dashed line is that at very high mobility, the maximum data rate supported is require the requirement is lesser compared to the maximum data rate supported at lower mobility conditions or sports pedestrian speeds.

Now, this comes because of the effects that mobility brings into play. So, depending upon how we go we will plan a short session on the effect of Doppler, on the error performance. So, usually what happens is as your Doppler increases or as your mobility increases, the Doppler frequency increases. So, as your Doppler frequency increases usually there are many effects amongst which the frame error rate increases. So, you would like to have specific numbers defining certain systems, and which is possible if a good model and understanding of the propagation effects are available.

Beyond those systems there was also expectation of newer schemes, which would have even higher mobility even at high mobility, it would support higher data rates. And this particular diagram as you can see is very commonly and popularly referred to as the VAN diagram, it looks like a VAN. And this has been clearly explained over here the dashed line indicates that the exact data rates associated with the systems beyond IMT-2000 not a determined, so when this particular document was made that was around 2003 right. So, these numbers were yet to be determined, but yes the numbers were something around these and clearly at different mobility conditions different data rates were designed to be supported.

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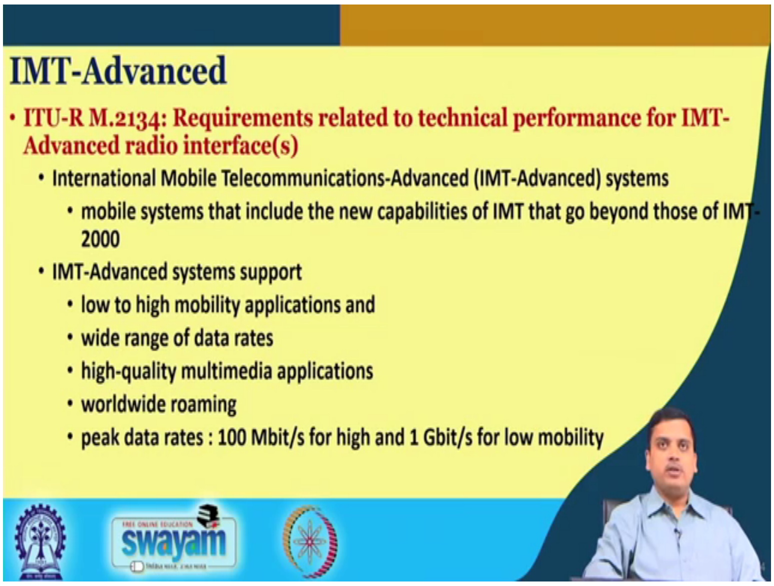

So, IMT-advanced as we are discussing the recommendation document M dot 2134 talks about the requirements related to the technical performance of IMT-advanced radio interface. So, the International Mobile Telecommunication-Advanced or IMT-advanced systems are the ones, which is basically the 4th generation communication system and which we are experiencing right now.

So, what it says is that mobile systems that include new capabilities of IMT that go beyond IMT-2000. So, there is an development in terms of IMT generalogy that means, IMT systems, IMT-2000, IMT-advanced and then you have IMT-2020, so whatever is there before there is usually a specification, which goes beyond that and there is a reference to the previous systems.

So, as has been mentioned that IMT-advanced system, it supports all mobility conditions, a wide range of data rates, high-quality multimedia applications, worldwide roaming. So, you may recall that at some point when GSM systems were discussed, it was talking about roaming in Europe, but now things have moved beyond to worldwide roaming. Peak data rates of 100 Mbps for high-mobility and 1 Gbps for low-mobility. So, this is the top level requirements for IMT-advanced or 4G. And then we will see that how does 4G has performed, when things finally got designed and deployed.

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So, there are minimum set of requirements. So, the intent of these requirements have taken in verbatim from the document is to ensure that IMT-advanced technologies are able to fulfill the objectives of IMT-advanced, so IMT-advanced is the particular standard.

And these are the different technologies as we had seen in when 3G was discussed there is proposal of technologies, so which should meet the requirements. And minimum requirements essentially mean, the minimum set of performance, but this does not restrict the new technologies to go beyond the minimum performance. And generally that has been the case, and as we shall see that the numbers which these technologies meet are quite and much more than the numbers, which are usually prescribed by the requirements of the IMT-advanced systems.

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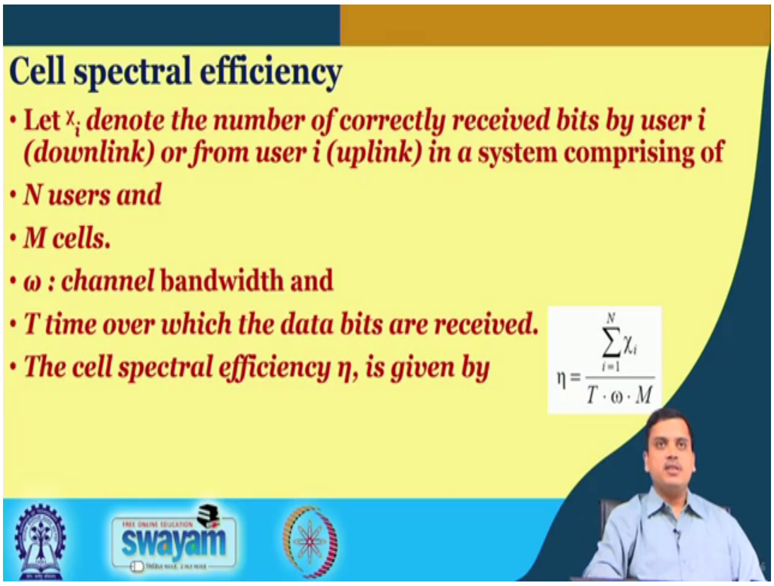

And then when we compare such systems, we need to look at a few definitions amongst the few definitions one of them is the cell spectral efficiency. So, this is a very important term, which comes into play when we discuss such system. So, I think it is important that we see it if x i x sub i denote the number of correctly received bits by user, i in downlink or from user i in uplink direction in a system comprising of n users.

So, there is a cell, cell is a base station and there are n users within that base station. And x i denotes the number of correctly received bits ok. And there are m cells and the channel bandwidth is w w hertz, and the T is the time over which the data bits have been received. So, cell spectral efficiency is defined as the sum of the bits divided by the time. So, bits per second by the bandwidth, so bits per second per hertz and the number of cells. So, it is basically bits per second per hertz per cell.

So, for every cell, so you added over the n number of users in the system. So, they usually specify in the test conditions that how many uses to be taken during the test, and how many uses supported by the system. So, the system might support a certain number less say 100 or 1000, so that has to be taken into account over here. So, the unit is bits per second per hertz per cell, which is a very important metric, when comparing the performance of such systems.

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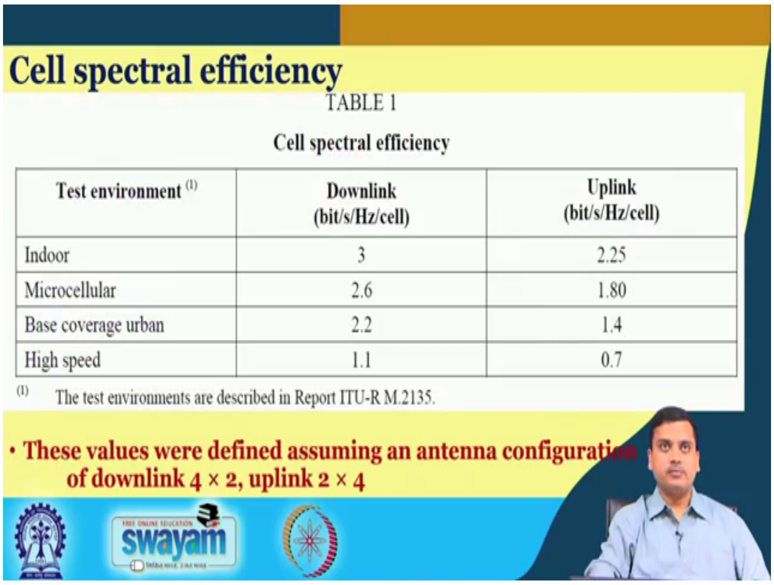

So, if we look at this the cell spectral efficiency, as has been defined for different test environments, test environments like indoor test environments. And these test environments has specified over here are described again in the ITU report M 2135. So, if you take a look at M 2135, detailed description about simulating these conditions have been well explained in that particular document.

So, what it says is that bits per second that is the time per hertz that is the w, and cell is m is given over here, so for indoor it is 3 and for high speed condition it is 1.1 and all numbers in between. In uplink there is again a different set of numbers, and these have been defined for different antenna configurations. So, with the definition of cell spectral efficiency and the numbers, what we now have to see whether the IMT-advanced systems meet the specifications. So, with this base and background we should be able to discuss the IMT-2020 or IMT or five 5th generation wireless communication systems in the upcoming lectures.

Thank you.