Evolution of Air Interface towards 5G
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Lecture – 09
Requirements and Scenarious of 5G (Contd.)

Welcome to the lectures on Evolution of Air Interface Towards 5G. In the previous lectures we have been looking at the different requirements of the earlier generation communication system as well as we were also looking at the differences.

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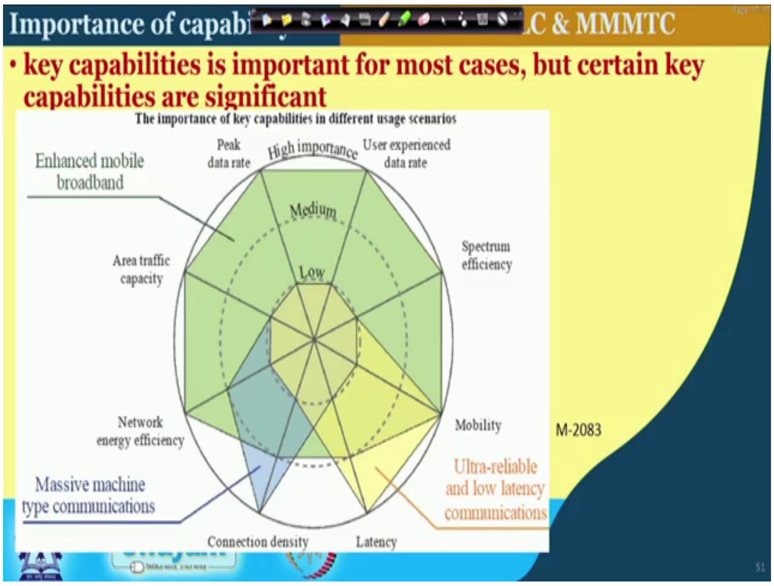

That are expected to come in the next generation and we have also seen how the 5th generation system is getting defined through the description of different scenarios.

And in the previous lecture we have been talking about the different situations that one would like one would encounter summarily the ultra reliable low latency communication as one of the scenarios. Enhanced mobile broadband as one of the scenarios and machine massive machine type as another scenario. And in this particular slide we had highlighted what are the important performance evaluation metrics that are important for each of the different scenarios.

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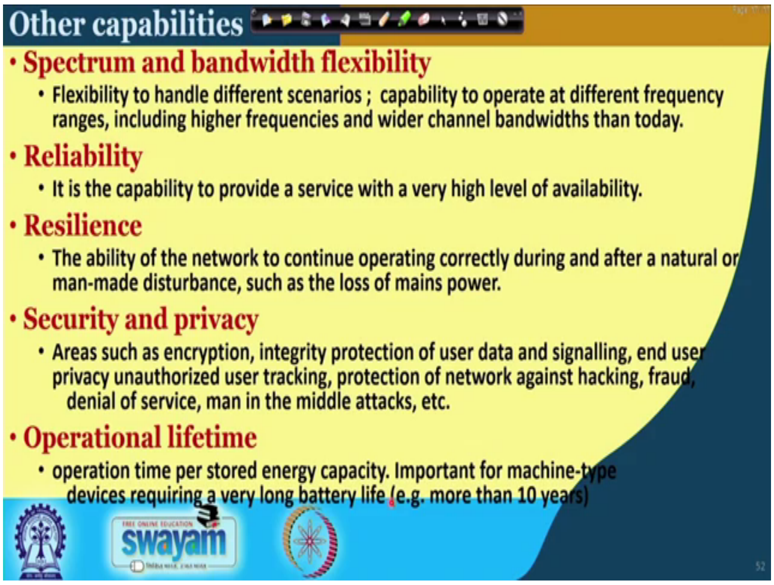

We had also talked about the other capabilities which are also significant for such systems such as flexibility in bandwidth and spectrum. So, that large data rates can be delivered. Reliability of course, is one of the important things that required to be improved. So, is resilience security and operational lifetime.

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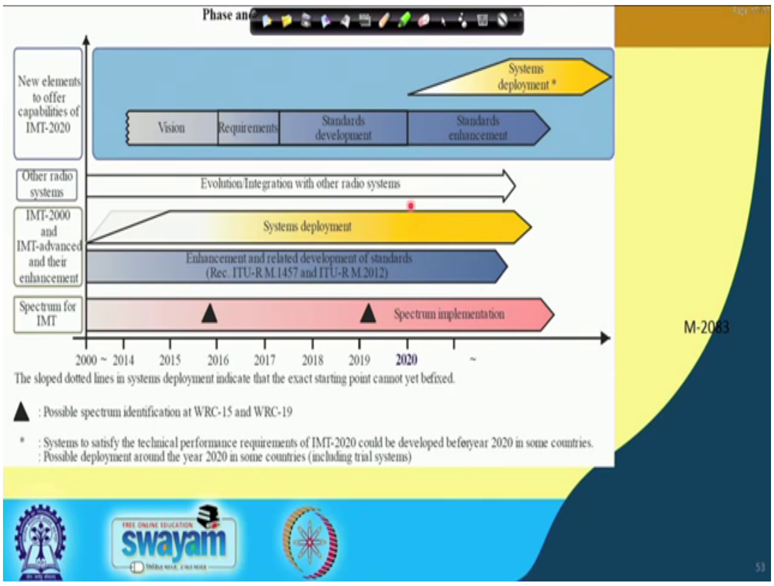

And we were also discussing the timeline of the development of IMT standards. So, again as per the report what we have is a brief summary of how things have been happening from 2002 to the 2020. So, initially there was a issues with spectrum then I am the IMT 2000 finally, came the IMT advanced and then we were talking about IMT 2020.

And the activities started certain somewhere around 2012 2013 14 and we are currently in this phase where the standards development activity is going on release 15 is already done and work is going on towards the next release in terms of 3 GPP. So, it is expected that around 2020 the deployments would slowly start to come in. Although there are claims that there are already existing deployments which are kind of somewhat before 5 G that is release 15 and hence we are almost going to experience 5 G in phases. So, by 2020 its expected the full fledged deployment of 5 G is going to come in.

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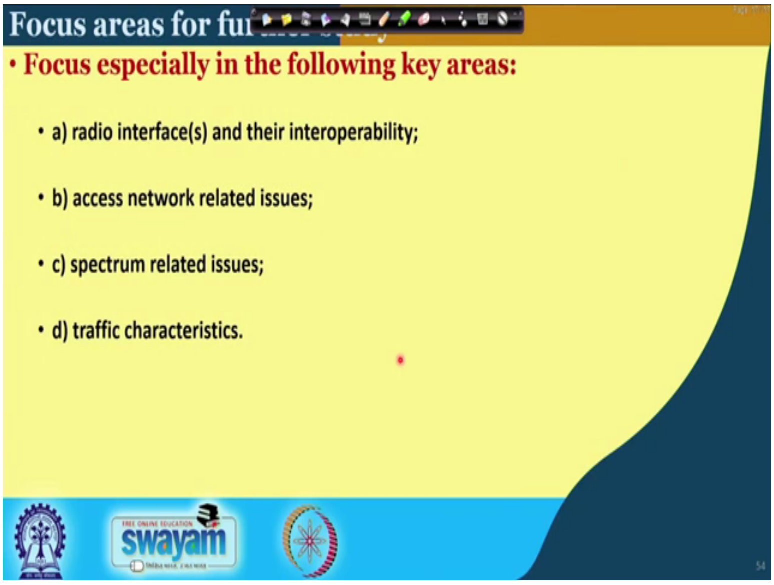

And we have also said some of the focus areas are like radio interface, access network, spectrum and traffic characteristics and we have actually started off with the traffic characteristics. And in the next phase of the discussion or the lectures in this particular course will be interested and will be discussing more about the air interface which this course is particularly designed for and we will also talk about the access network and spectrum related issues which are important for 5 G.

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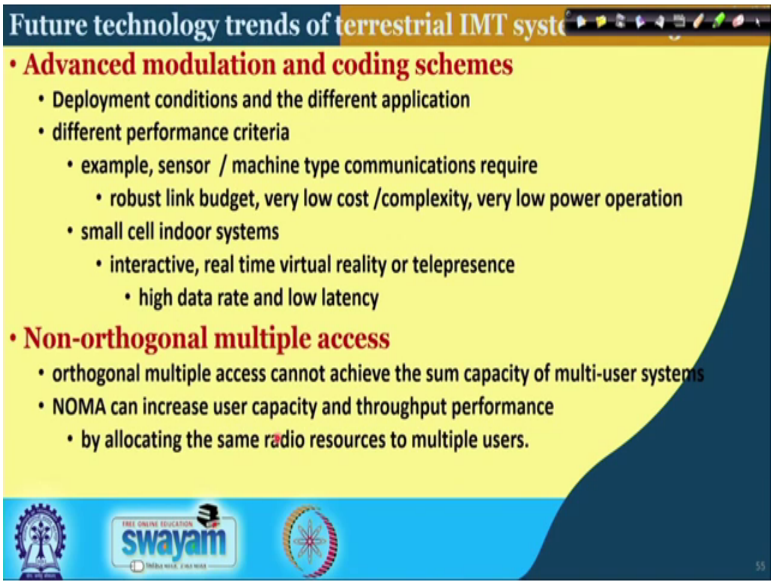

So, we have also briefly talked about the different methods or different principles which would be vital in the previous lectures namely the advanced modulation coding non orthogonal multiple axis we will talk about them. Then the advanced multi antenna techniques we have also discussed this particular issue in the previous class and we will talk in more details about them in subsequent lectures.

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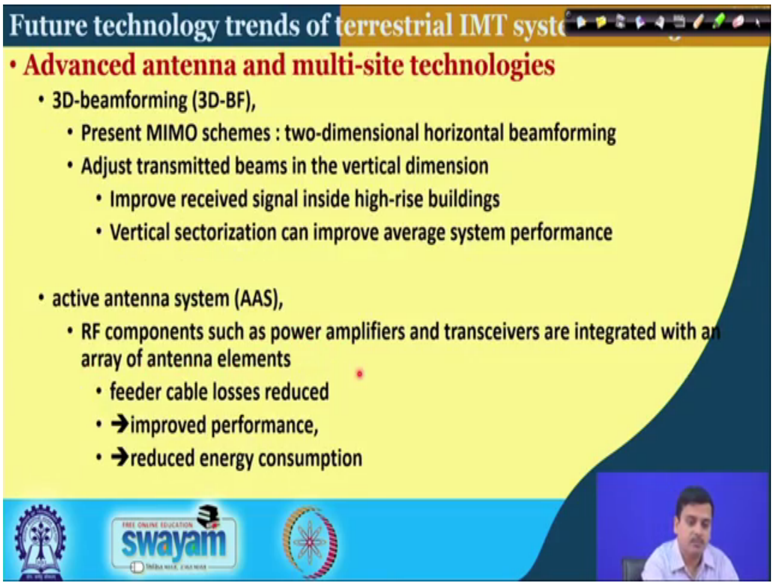

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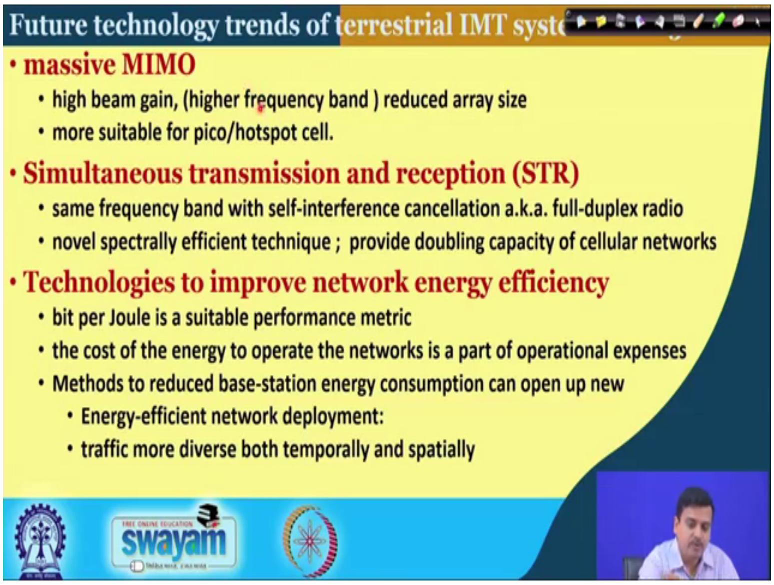

Massive MIMO simultaneous transmission reception and methods for increasing the spectrum efficiency or the energy efficiency is also some of the things as we have said we are going to take up in the future lectures.

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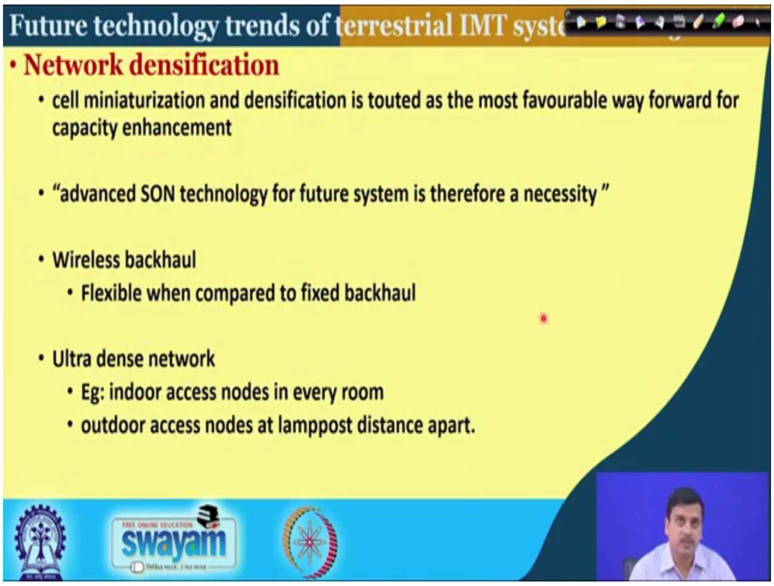

A network densification, when we had a brief discussion about ultra dense networks and so on and again we will get an opportunity to see them in more details in the upcoming lectures.

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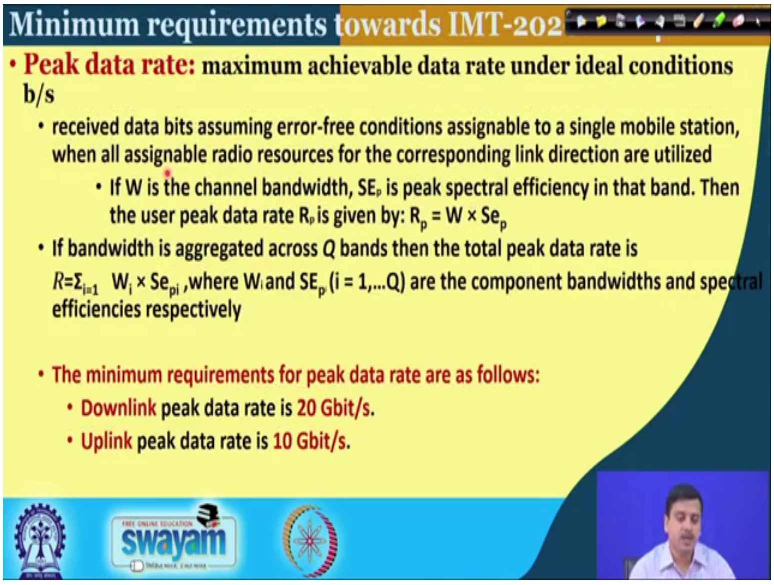

So, now we discuss the minimum requirements for IMT 2020 and these requirements are specified in the document M 2410 as is being highlighted here. So, this is the particular document. So, one particular thing I would like to point out here is I have been referring to several 3 GPP documents and numbers. So, with the prime intention that while going through these slides or going through these video lectures you would get an opportunity to download these freely available reports and go through them for more clarity over and over again.

So, that you are assured and you are yourself assured about what is present in them and could read them in your own convenience. So, let us look at the minimum requirements specified for IMT 2020. So, one of the characteristics is the peak data rate which is minimum requirement. So, it is the maximum achievable data rate under ideal conditions. So, this is very very important and it is measured in bits per second that is pretty normal and it is defined as the received data bits assuming error free condition. So, this is a pretty important.

So, you can almost do this calculations theoretically because, whatever is transmitted assumed to be received without error in this particular case. So, this is the error free data bits. Assignable to a single mobile station so, that means, this is talking about the maximum number of bits that could be given to one user that is a single mobile station there could be restrictions in the amount of bandwidth that is accessible to one user and different other constraints.

So, we must take this word very very in a in a significant manner to find out what is the maximum assignable error free bits to the single user and this will be specified by the details of the radio access technology which will form part of IMT 2020. So, when all the assignable radio resources for the corresponding link direction are utilized. So, this is very very important. So, if I am talking about downlink in that case if all the radio resources are given to a single mobile station then all the bits that could be transmitted and received without error would be the peak data rate.

So, for example, if we have let us say 10 resource elements just for the sake of an example and if we give all these resource elements to this user then the maximum data rate would be attained when the highest modulation is used highest order modulation. So, if it is 256 qm then we are talking about 8 bits per symbol which have to be given to a user and then you multiply that with the number of symbols that can be carried by all the resources that can be assigned to a user. And hence you get the total number of bits. So, if W is the channel bandwidth SE sub p is the peak spectral efficiency.

So, in that band so, this peak spectral efficiency you will get by calculating the maximum number of bits that can be sent per unit of hertz in and this is influenced by MIMO and all other mechanisms that come into play. You would also have to take in the error correction coding so, if you are using rate half encoding. So, 50 percent of the bits are redundant if you are using rate three fourth then one fourth of the bits are redundant. So, if you take that into account in order to calculate the spectral efficiency then the peak user data rate R sub p is given by the bandwidth multiplied by the spectral efficiency.

And if bandwidth is aggregated across Q bands; that means, Q number of bands are put together through carrier aggregation. Then the total peak data rate is the sum over all such bands where Wi and SE sub p i over all the bands are the component bandwidths and spectral efficiencies respectively. Now, if this is kind of generic in the sense that the W i's are flexible in the manner that it need not be the same value. If they were the same value would have simply multiplied by Q over here. Further the spectral efficiency in the different bands may be different by virtue of restriction of the different modes of operation for certain bandwidth because of many other system level constraint.

So, for each band you will calculate the data rate that is as given by this you are doing it for each band and adding it up over the different bands. So, if I have a 20 megahertz and a 10 megahertz and a 5 megahertz I may have different spectral efficiency supported. And if I am aggregating them I have to calculate data rate separately for each of the bands and put them together. So, when you do it the minimum required requirement for peak data rate is for downlink direction it is given as 20 gigabits per second. So, 20 Gbit s and in uplink it is a 10 Gbit s.

So, these are the minimum numbers which are required to be satisfied. So, if the user if the system or the radio access technology is such that you can support these numbers then it will qualify as IMT 2020.

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Next we look at the definition of peak spectral efficiency that was one of the terms in the previous definition. So, peak spectral efficiency is the maximum data rate under ideal condition normalized by the channel bandwidth and here it is the enhanced mobile broadband usage scenario for which it is getting defined. So now, it is kind of an iterative definition that is data rate is in terms of spectral efficiency spectral efficiency in terms of data rate.

So, one could effectively actually calculate the spectral efficiency from which one can calculate the data rate. And spectral efficiency calculations will be based on the modulation the coding rate the MIMo schemes the overhead and everything put together.

So, the minimum requirement for peak spectral efficiency that is the best. So, here you are going to use the maximum possible loading of bits on a resource block and this would entitle one to use the maximum special multiplexing mode as well as the highest order modulation and the least error protection mechanisms.

So, when you put all these things together you can get the highest spectral efficiency in downlink it is 30 bits per second per hertz. Now, if you have a bandwidth of 10 a megahertz you have 300 bits per second. So, if you have a peak data rate of 20 gbps you divide by 30 bits second per hertz you can calculate the maximum aggregate bandwidth that is supported in each of the directions. Here also we are seeing that the uplink and downlink spectral efficiency requirements are different its basically half and that is scaling to these numbers; that means, the data rate requirements are accordingly scaling in a ratio of 1 is to 2.

Now, antenna configurations for these things up to eight spatial streams in the downlink directions and four spatial streams in the uplink direction. Now this way also you can categorize that when you have eight spatial stream it is theoretically you can support twice the data rate or twice the spectral efficiency of the uplink which is a hint towards the numbers which are being reflected over here.

So, essentially its being driven by these parameters which are the pinpoints of control. So, through these parameters we can get these numbers and from these numbers we can get back to these numbers with the appropriate multiplication of the bandwidth factor. And again these are defined for different operating scenarios so, that we must be very very careful and all details are specified in M 2410.

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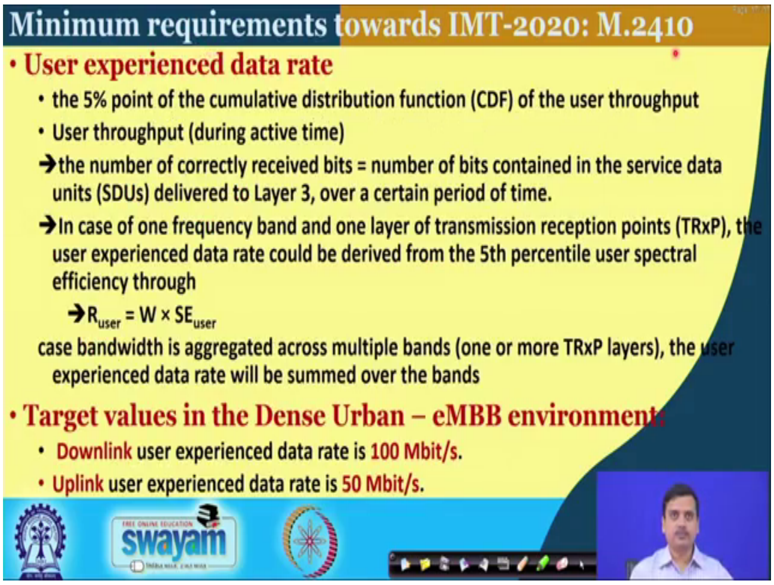

The next important parameter which we are supposed to look at is the user experienced data rate. So, if we look at the definition it is the 5 percentile point of the cumulative distribution function of the user throughput when user throughput during active time is defined as the number of correctly received bits which is equal to the number of bits contained in the service data units which is usually referred to as the SDU deliver to layer 3, over a certain period of time ok.

So, what it effectively means is that again we are talking about the number of correctly received bits. So, essentially we can say that the number of bits that can be sent and one can assume that these bits are received error free and so, you can calculate the users throughput and then you would find the 5 percentile point on the cumulative distribution function of the user throughput during the active time.

So, if you would connect all possible data rates that is achievable by the user and then plot the cumulative distribution function and then take the 5 percentile point. So, roughly speaking.

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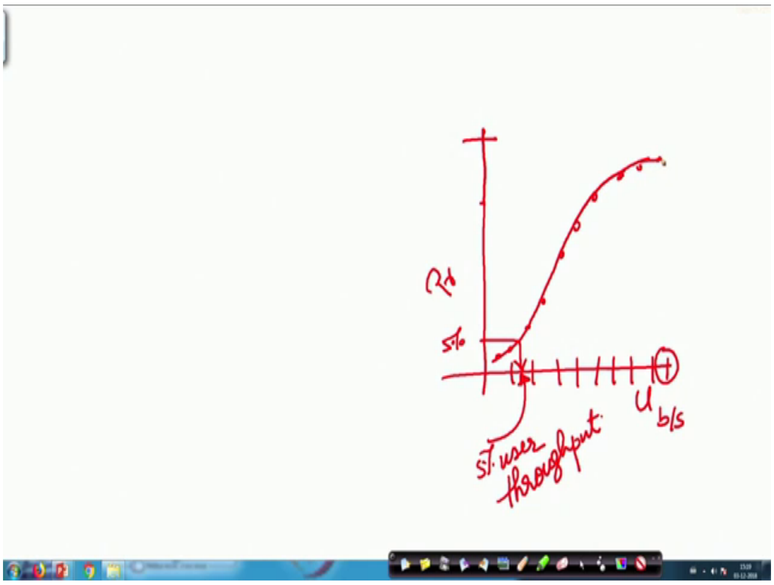

If let us say this is the user data rates in bits per second and in this side if you have probability that the data rate is less than the abscissa. So, generally we have curves which appear to look in this manner and here this particular line it extends to 1 or 100 percent that is the maximum. And here you have different values of user throughput and at a certain point you have the peak value of user throughput which is here.

So, if we look at the 5 percentile point and read this number you get the 5 percentile user throughput ok. So, that is how one calculates the user throughput and you get all these different points by a large number of simulations over the service area. So, once you collect all those data you can go back so, that is how you calculate the user throughput.

Now in case of one frequency band and one layer transmission one layer means like SISO reception points. That means, transmits interception point the user experience data rate could derived from the fifth percentile of user spectral efficiency through this naturally this is again the same kind of definition we are seeing before. So, you have the user spectral efficiency multiplied by the bandwidth and you get the user.

So, if there are multiple layers you again multiply this by the number of layers and each layer would provide a certain data rate and then it is the aggregate data rate in that case. Now in case of bandwidth is aggregated across multiple bands; that means, one or more and one or more transmit layers the user experience data rate will be summed over all the bands. So, that is as defined in the previous case. And the target value in the dense urban eMBB environment eMBB is enhanced mobile broadband environment.

The downlink user experience data rate is supposed to be 100 Mbits and in uplink which is 50 Mbits; now these are pretty large numbers compared to what were available in the previous generation systems. And clearly if you compare these spectral efficiencies in IMT advanced you would remember that peak download spectral efficiency was 15 and uplink was 6.75. Whereas, here if both the numbers have become almost double and also at the same time we would we may recall that LTE advanced was supporting these figures.

So, in some manner its kind of LTE advanced is pretty much equipped to provide these kind of a spectral efficiency values. So, the newer generation 3 GPP technologies and other technologies may be expected to far exceed these numbers which are provided by ITU. So, these numbers are kind of already achievable within the technologies that are available in present day.

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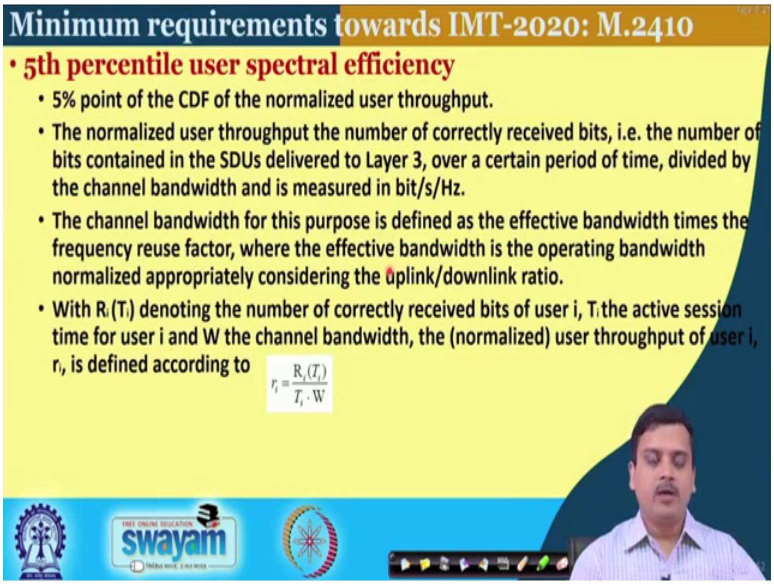

So, moving on and further so, in the previous this definition we had referred to the 5th percentile user spectral efficiency. So, as was given over here in case of one frequency band and or dot the user experience data rate could be derived from the 5th percentile use a spectral efficiency.

So, let us look at that particular definition. So, rather this is more fundamental definition the 5th percentile point of the CDF of the normalized use a throughput. So, let us look at that the normalized user throughput the number of is basically the number of connected correctly received bits that is the number of bits contained in the SDU there is a service data units which have been defined before deliver to layer 3, over a certain period of time.

So, you are taking time into account divided by the channel bandwidth and is measured in bits per second per hertz. So, the channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor where the effective bandwidth is the operating bandwidth normalized appropriately considering uplink down link ratio. So, if we take everything into account.

So, if there is a certain bandwidth and you are sharing it for a certain fraction of uplink and certain fraction for downlink then that must be taken into account with our sub id T sub i denoting the number of characteristic bits per user i and T i is the active session times; that means, that is the duration over which it transmits for user i and W is the channel bandwidth then the normalized user throughput of the user i that is r sub i is defined according to r sub i is equal to this capital Ri over T i divided by T i that is bits per second this is the bits per second per hertz.

So, if we collect all these numbers over the entire coverage region and plot the cumulative distribution function and then take the 5th percentile point we are going to get the 5th percentile spectra efficiency.

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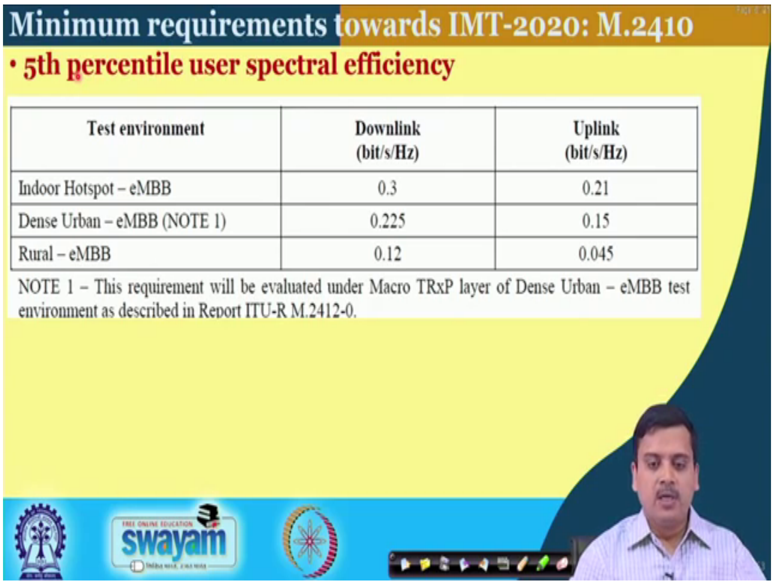

Test environment	Downlink (bit/s/Hz)	Uplink (bit/s/Hz)
Indoor Hotspot – eMBB	0.3	0.21
Dense Urban – eMBB (NOTE 1)	0.225	0.15
Rural – eMBB	0.12	0.045

So, moving further the minimum requirement towards IMT 2020 and the 5th percentile user spectral efficiency are given in this particular chart and that is again in M 2410. So, what we see is that in the indoor hotspot enhanced mobile broadband the downlink 5th percentile spectral efficiency is given as 0.3 and uplink it is 0.21 I mean these are not very small numbers because this is the 5th percentile spectral efficiency number. Dense Urban eMBB is a 0.225 and rural it is 0.12 and these numbers also scale down accordingly.

So, what we see is that in the rural scenario the number is the lowest where is an indoor it is the highest and urban dense urban is somewhere in between; now there could be several reasons for these things which will become clearer. So, in indoor situation you are very strong desired link and the interference is relatively less when you go to dense urban you have a strong interfering link, but there are a lot of interference. Whereas, in rural the signal power is less because the distance between the transmitter and receiver is pretty large the cells are expected to be larger in size.

So, its not possible to provide very high signal strength in such situations because smaller number of cells are expected to cover a larger area and hence the outage or the 5 percentile spectral efficiency is having a smaller value. And these requirements as given in this particular note will be evaluated under the macro transmits transmit received point layers of the dense urban eMBB test environment defined in 2412.

So, when we look at M 2412 it describes in details how do you create the environment over which you test these things and there these definitions will become even more clearer. And once you set up the environment run your system get these numbers then we should match with these and if it satisfies these numbers then again you can claim the technology to be IMT 2020 compliant.

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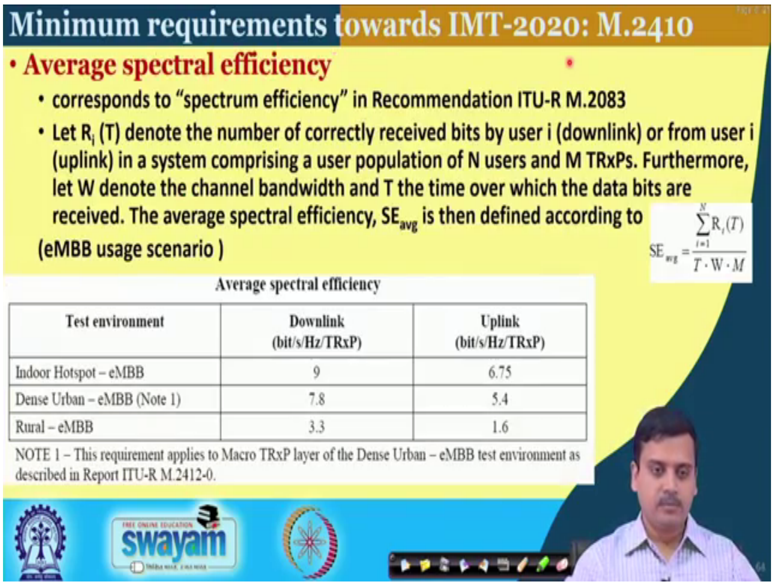

Then the next important term is the average spectral efficiency. So, this average spectral efficiency corresponds to the definition of spectrum efficiency within quotes as it has been given over here in M 2083. So, you could refer to M 2083 and see the definition of spectrum efficiency and which is basically the one which is the average spectral efficiency in this case. So, if R i R sub i T denotes the number of characteristic bits for user i which is in the sub index from user i in downlink I mean received by user i in downlink and from user on uplink in the system comprising of user population of N users.

So, you have a environment where there are N users i is one of the users and there are M transmit receive points. Furthermore let W denote the channel bandwidth and T the time over which the data bits are received the average spectral efficiency SE sub average is defined as you sum over the data rates of all the N users and divide by the T which is the time of transmission W the bandwidth and M TRx P s. So, then you get the average spectral efficiency. So, effectively what you are seeing is that your averaging it over the different users that are present in the system.

So, different test environments are described in 2412 M 2412 is the document which describes the way to evaluate these things and 2410 basically tells you what is the minimum numbers, which these should be satisfying. So, in the indoor hotspot what we are seeing is the average spectral efficiency in downlink should be 9. Whereas, we had seen the peak spectral efficiency numbers earlier it was 30 bits per second per hertz right and we have also seen that in indoor hotspot the downlink 5th percentile user spectral efficiency is 0.3.

So, here what we are saying is the average is 9 in rural the average is 3.3 and in dense urban it is 7.8 for all reasons which we have discussed earlier and in uplink it is 6.75. So, what we are seeing is that on an average 6.75 bits per second per hertz is required to be supported by IMT 2020 whereas, this was the peak spectral efficiency for the previous generation system and again everything is described in 2412.

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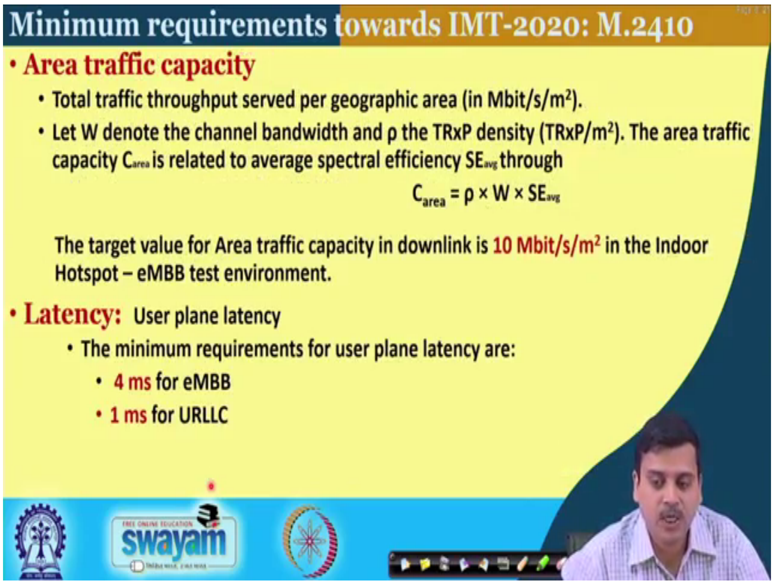

Then we look at the next important metric according to which things have to be evaluated and one of them is the area traffic capacity. So, area traffic capacity is described as the total traffic throughput served per geographic area in megabits per second per meter square.

So, what you are seeing is that the meter squared comes into play. So, over a certain area whatever throughput is getting served you divide it by the total area. So, per bits per second per meter square; that means, over every unit of area how much is traffic is flowing through. So, if W denotes the channel bandwidth and rho the transmit receive density; that means, so many transmit receive points per meter square the area traffic capacity that is C sub area is related to the average spectral efficiency which you have defined before as the area as se area that is the traffic for the area is the density of TR xP multiplied by the bandwidth multiplied by the spectral efficiency.

So, this is the spectral efficiency you multiplied by the bandwidth you get the data rate; that means, you get bits per second and then you multiply by the density of the transmitter points per meter squared and then you get bits per second per meter square. The target value of the area traffic capacity and downlink is 10 megabits per second per meter squared; that means, roughly speaking if you are taking indoor environment for every meter squared you can expect 10 megabits per second it roughly translate to that.

So, over an area that is the kind of traffic it should be able to support that is kind of a another definition which was not much prevalent in earlier generation systems. In terms of latency the user plane latency we have defined the control plane latency end user plane latency earlier the minimum requirement for user plane latency are 4 millisecond in enhanced mobile broadband scenario and one millisecond in the ultra reliable low latency communication scenario.

So, what we are saying is that in the low latency communication scenario the latency requirement is 1 millisecond which is very very stringent requirement and in the mobile broadband requirement it is around 4 millisecond, which is not that stringent but still these numbers are much lower than the latency requirements in the previous generation system. So, with one millisecond latency constraint one should be able to control a lot of industrial applications to a great extent.

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So, control plane latency is again defined over here as the transition time from the state of idle to the state of active we have discussed this earlier and the minimum requirement is 20 millisecond which is also much reduced from the from the earlier generations. And it is also saying that the technologies should be able to or may be supporting even lower number that is always welcome. Connection density is something which we have seen before in the graphs is the total number of devices fulfilling a specific quality of service.

So, it is not just the number of devices the devices which satisfy the QoS per unit area. So, whenever we give these numbers the QoS support is always to be taken into account and QS is to support delivery of message of a certain size within a certain time and with up to a certain success probability again these are defined in 2412. So, this defines the specific method or the way of calculating QoS and the minimum requirement for connection density is 1 million device per kilometer square.

So, it is kilo meter squared. So, now essentially you are seeing that if we have smaller and smaller cells with cell radius of a few 10's of meters it probably becomes more feasible to support such things where these kind of situations are expected to be encountered in massive machine type communications.

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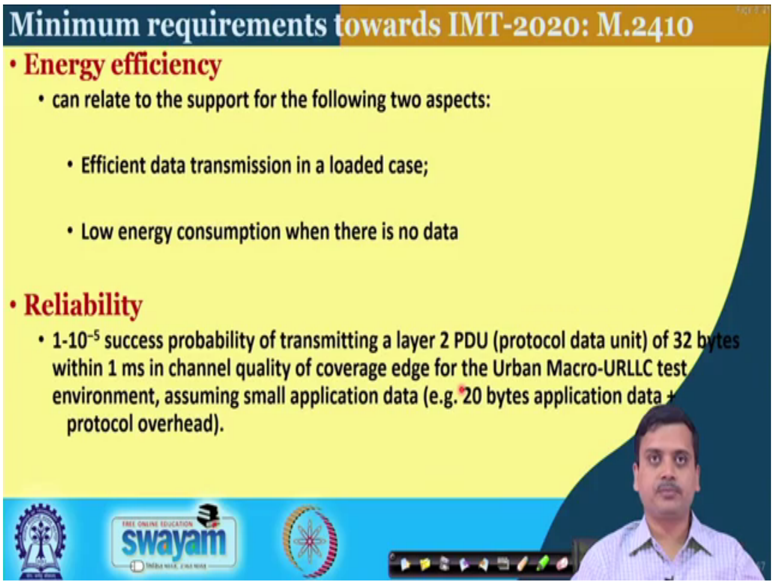

So, there are energy efficiency requirements reliability requirements are also there in terms of mobility requirement.

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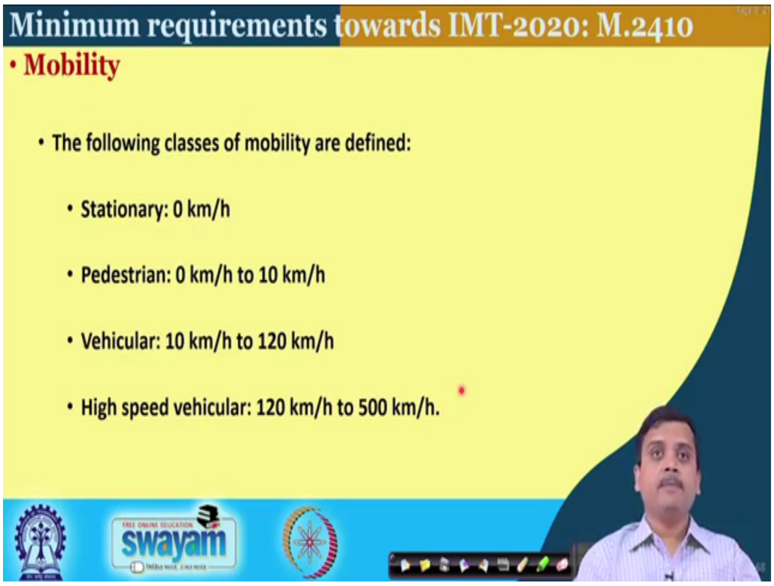

Now, what we see is that even higher speeds are required to be supported. So, we will see a few more of these in the next lecture and then begin our discussion on the waveforms which is one of the first most important thing that we are supposed to see in the next generation systems. And we will begin with a discussion of the earlier generation system because there lies the foundation of some of the important things which have come up later and which will also come up in the systems which go beyond the 5th generation communication system.

Thank you.