Evolution of Air Interface Towards 5G
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Lecture – 04
Evolution of Wireless Communication Standards from 2G to 5G (Part – 3)

Welcome to the lectures on Evolution of Wireless Communication Towards 5G or Evolution of Air Interface Towards 5G. So, far we have been seeing the technical requirements for 2G, 3G some of their solutions. And in the previous lecture, we have also started looking at IMT-advanced that is 4G.

And we have reached the point, where we described the cell spectral efficiency, and have also described the met parametric values, which are the requirements. And then we said that now onwards, we will move forward and discuss about the performance of such systems. So, we will continue with the IMT-advanced in this particular lecture, and then we will move forward to IMT-2020.

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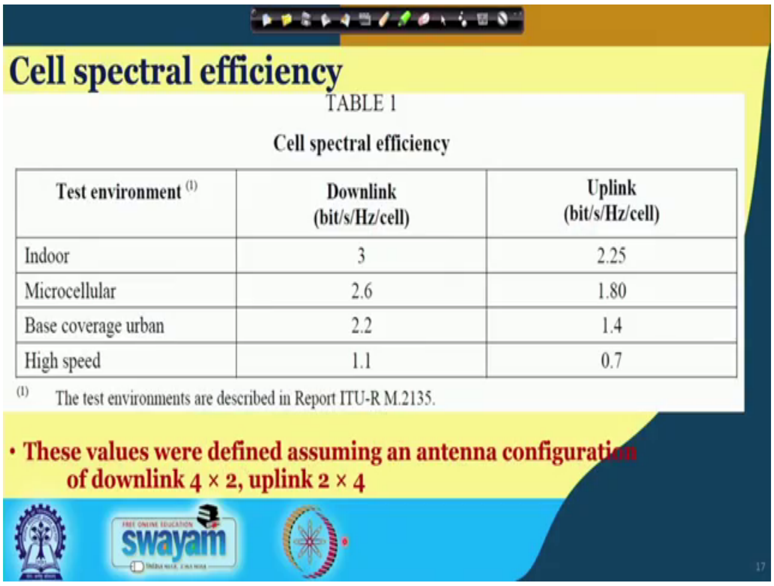

So, in this particular slide that we have we have talked about the cell spectral efficiency, and these numbers that are pointed out over here are basically the downlink cell spectral efficiency as described in bits per second, per hertz of bandwidth, per unit of cell. And this is the same thing, however the requirement is given for the uplink. As you can clearly see, there is distinction between the downlink and uplink for several system configuration related issues.

On the left hand side as we had said, there are different propagation environments which have been classified from indoor to micro cellular to the base coverage urban area, this is rather the urban area, which is more important, and high mobility scenarios. And as said earlier these were defined for different configurations of antennas, we will see the description of these at a later time right.

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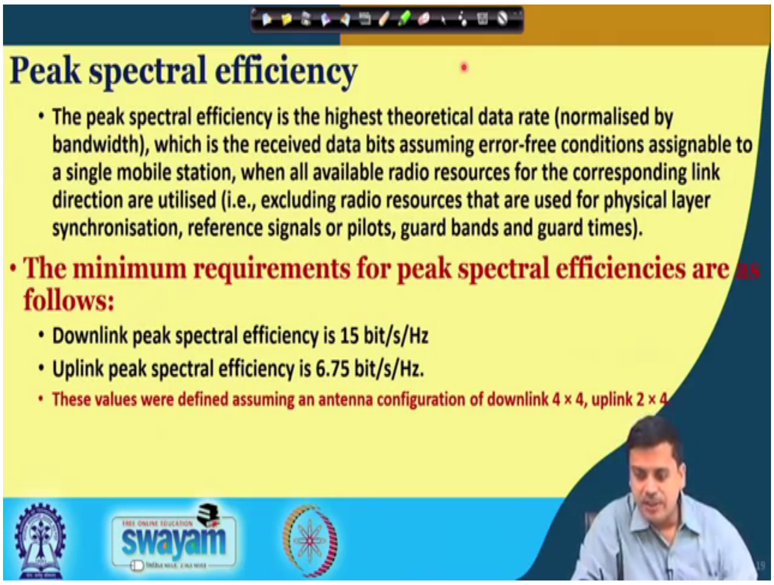

So, the next important metric that we are supposed to see is the peak spectral efficiency. In the peak spectral efficiency, it is defined as the highest theoretical data rate normalized by the bandwidth that means, bits per second per hertz, which is the received bits assuming error-free condition assignable to a single mobile station. When all available resources for the corresponding link direction are utilized, that is excluding radio resources that are used for physical layer synchronization and all those things.

So, effectively what it means, what this description means is that if there is only one user equipment present in the system, as has been described over here single mobile station and all resources diverted to this. However, you are leaving out the headers or additional pilots other things, so that is the reference signal or pilots and guard bands, which are used or necessary in order to make the communication feasible or realizable.

So, in this sense this is the maximum that can be achieved, so this is another important parameter. Usually, you will find that when they say the data rate, usually if nothing is mentioned people talk about the peak data rate, because that is usually an attractive term whereas, what is more important are some other terms, which will come and see like average spectral efficiency. And also the other term, which we had seen in the previous slide that is the per cell that means, overall in an in a cell what is the spectral efficiency.

So, when we look at the downlink peak spectral efficiency that is 15 bits per second per hertz, so this is very very high number. In order to find out that if there was only one user in the system, then and you are mentioned about the bandwidth say there is 20 megahertz of bandwidth. So, if I multiply 15 by 20 megahertz, then we are going to get the maximum bits per second that is possible, then 15 multiplied by 20 into 10 to the power of 6 hertz as cancels out, rest of it is the maximum downlink spectral efficiency. Spectral efficiency is the data rate per unit hertzs of bandwidth. Similarly, in the uplink the number is given over here, which is 6.75 as the required peak spectral efficiency, and again antenna configurations have been mentioned.

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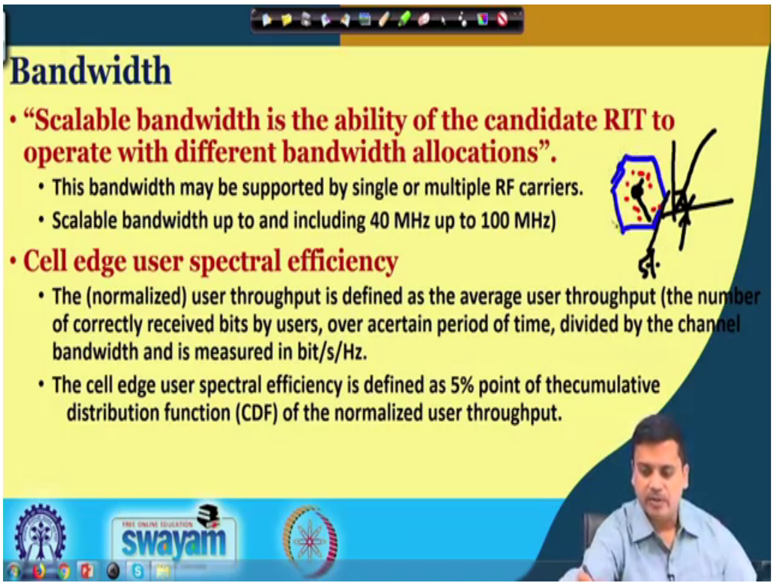

The bandwidth is again obviously a very important parameter. So, scalable bandwidth is available or is the availability or the ability of the candidate radio interface technology to operate with different bandwidth allocation. So, what it means is that the scalable bandwidth is supported by the system, which in other words means that the system should be able to access lower bandwidth as well as larger bandwidth as per necessity or as per allocation. So, systems or the equipment should be capable of accessing different bandwidths as per allocation or as per the situation or controlled by the access point or the base station or the entire network.

Another important term is the cell edge user spectral efficiency, now this is a very very important metric so, although the peak spectral efficiency is very very attractive. But, as we see through the description that the normalized user throughput is defined as the average user throughput ok, the number of correctly received bits by user, over a certain period of time as was discussed earlier divided by the channel bandwidth and is measured in bits per second per hertz. So, this part of the definition is as per the definition of spectral efficiency.

However, the cell edge user spectral efficiency is defined as the 5 percent of the cumulative distribution of the normalized user throughput. So, 5 percent means, the 5 percentile point. So, if we collect the spectral efficiency over the entire cell that means, that each point in the cell, so for example I mean if we take cell ok, so let us say this is an area of a cell as per classical hexagonal layout although things are different nowadays.

So, in this particular setup, if we are taking users in different locations all right, and if suppose the base station is located in the center, so then the user which is close to the base station is going to experience a better SINR compared to the user at the cell edge right. So, if we collect the spectral efficiencies of all the points, and we plot the cumulative distribution function, then the 5 percentile points performance is basically the cell edge spectral efficiency. So, this point is the 5 percent point. So, this is how we define the cell edge spectral efficiency, again we will see these in more details when we see the performance evaluation criteria and other things, there will try to look at how these things are actually done ok.

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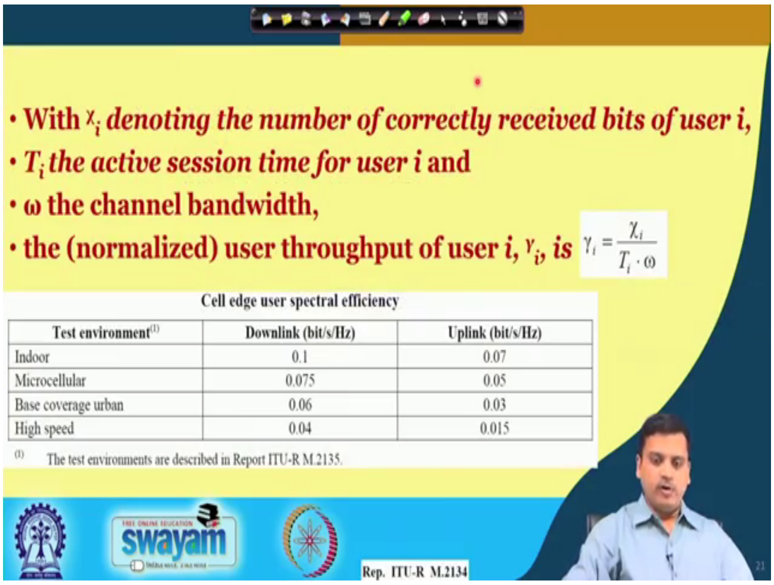

So, moving forward, so in this again if we define x sub i, as the number of correctly received bits of user i. And T i the active session time, because we had divided by time for user i, and w the bandwidth of the channel, then the normalized user throughput is x i that is number of bits received correctly divided by the time and the bandwidth.

So, earlier when we define the cell spectral efficiency, there we had a summation over here. So, in that case we had a summation over here, over the number of users right. So, this is not required over here. You have to only take for a user and ith user so you have to take over all possible users in the entire thing and in entire area plot the CDF, and then take the 5 percentile point right. So, this is how you usually get it. And again if you look at the requirements that have been defined, so what you see is that in indoor condition in downlink it is 0.1 bits per second per hertz, where is an uplink it is 0.07. As usual the downlink is higher than the uplink. And this entire range covers the different propagation environments that have been described in M 2135.

Now, what this essentially says in some other situations, this is also described as the outage spectral efficiency 5 percentile outage spectral efficiency that means 95 percent of the time, the spectral efficiency in the downlink direction in indoor condition would be above this particular number. So, this is kind of the bottom line performance of the system. We had seen the peak; we had also seen the cell spectral efficiency, so these are different metrics, which together describe the performance of such a system. And again these are the requirements that are necessary to be satisfied in order to be called a IMT-advanced or a 4G system ok.

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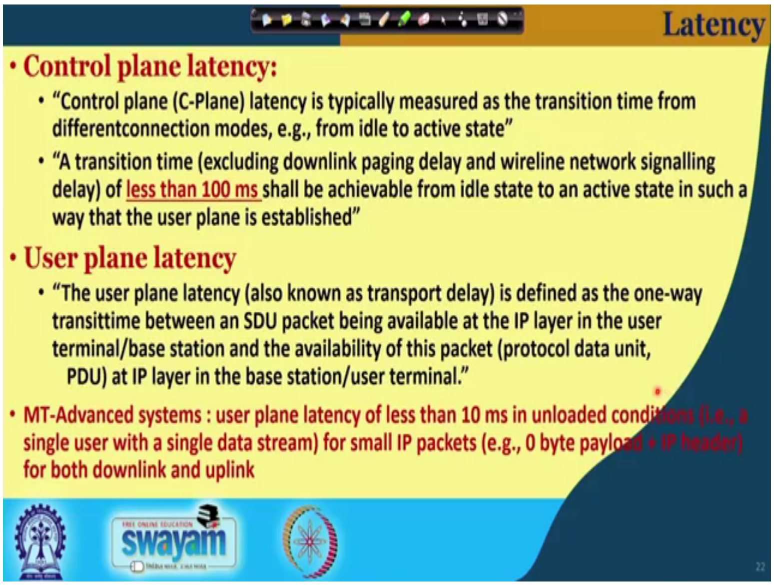

So, then there are some more terms that are again, which come up when we discuss such technologies the control plane latency. I considered it important that we go through these at least once, because whenever you will be going through such documents, you will be coming across control plane latency, user plane latency. And it is important that we read at least for one situation, so that we do not have to get into confusion ever again.

So, here control plane also referred to as the C-plane latency is typically measured as transmission time from different connection modes that is from idle to active state ok. A transition time excluding downlink paging delay and wire-line network signaling delay of less than 100 millisecond shall be achievable from idle state to active state in such a way that user plane is established. So, this clearly defines what is known as the control plane latency. Whenever requirements of control plane latency comes up, you can refer to these particular definitions, which are there in the ITU documents.

The other one is the user plane latency. The user plane latency also known as the transport delay is defined as the one-way transmit time between the SDU packet being available at the IP layer in the user terminal or the base station. So, in whatever direction we are discussing.

So, if it is the uplink, then it is the user terminal; if it is the downlink, it is the base station. And the availability of this packet that is the protocol data unit PDU at the IP layer in the base station. So, when it is the terminal, it is the base station. What is the base station, it is the terminal that means, in the uplink direction the packet from the IP layer of the user to the IP layer of the base station. And in the reverse direction from the IP layer to the base station to the IP layer of the user terminal. So, this is defined as the user plane latency.

So, in IMT-advanced systems the user plane latency of less than 10 milliseconds in unloaded conditions that is the target. So, unloaded condition means a single user with a single data stream for small IP packets like 0 byte payload and so on and so forth. So, these are idealistic conditions, so these set the limit for performance. So, when one specifies or one evaluates the performance, one has to meet the numbers. And the test has to be done as per the description as given over here, and detailed in the ITU documents, which have been referred in this lecture as well as in the earlier lectures. So, it is very important to be aware of this, because whenever performance evaluation has to be done for such things one has to know exactly where to start the measurement, and where to end the measurement.

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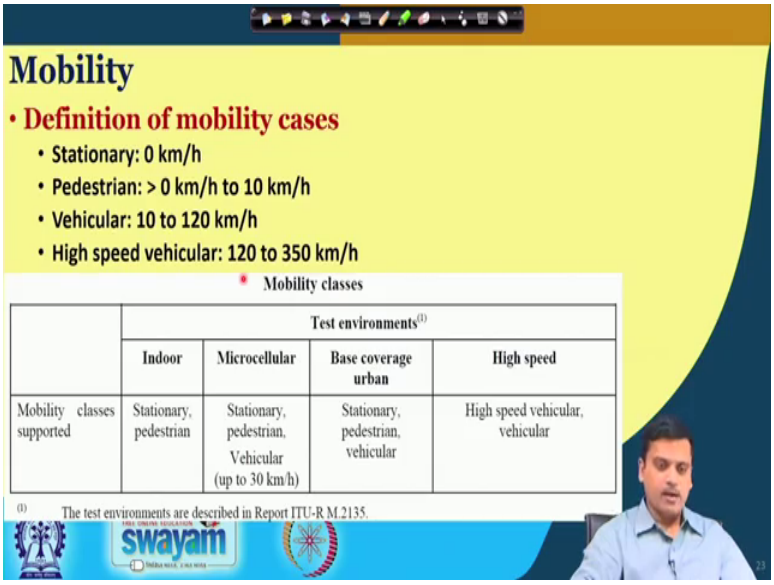

	Test environments(1)			
	Indoor	Microcellular	Base coverage urban	High speed
Mobility classes supported	Stationary, pedestrian	Stationary, pedestrian, Vehicular (up to 30 km/h)	Stationary, pedestrian, vehicular	High speed vehicular, vehicular

Now, comes the mobility we had seen the van diagram so called not the venn diagram. So, here there is definition of mobility, so stationary conditions are of course no mobility that is 0. Pedestrian conditions are when people are walking kind of situation where it is up to 10 kilometers per hour, so like 3, 5, 7 I mean all kinds of values are good enough. And vehicular traffic is like 10 to 120 kilometers per hour again details are described in the document M 2135. And high-speed vehicular is from 120 to 350.

So, I mean high speed vehicular usually is associated as per these documents in the rural environment, but that is specific to one particular evaluation scenario, whereas there could be other rural scenarios, where it is actually reverse. So, I mean rather than classifying as rural and urban, which is mainly to do with the multipath environment. Separately specifying mobility as defined over here is makes things clearer.

So, for example one can have urban while a high mobility, so that could be possible I mean and it may not be high mobility, but it could be like vehicular speeds, where you nowadays have long flyovers running across for maybe 5 to 10 kilometers. So, were probably speeds within this range is highly possible, so I mean it is important that you specify the mobility as well as you specify the multipath propagation environment. And you can club them together to make the description of one complete specific environment.

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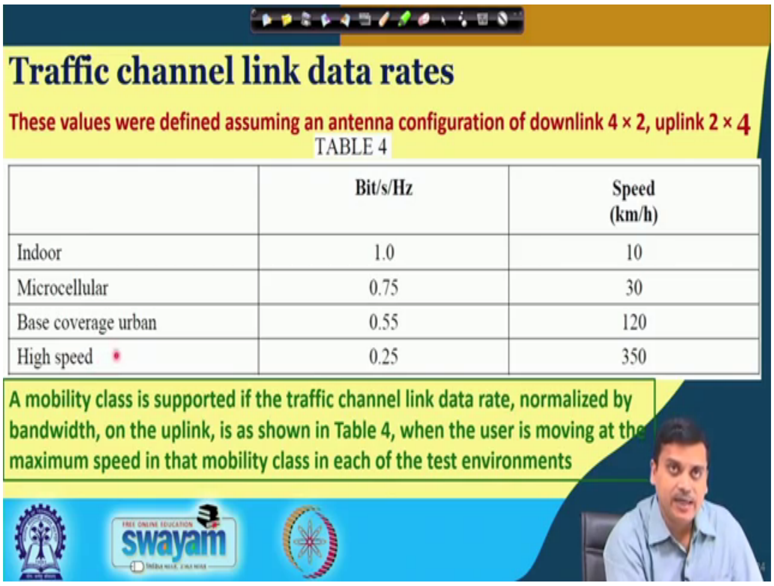

So, in this particular slide, what we see is the traffic channel link rates ok. So, what we see over here is the mobility class is supported if the traffic channel link data rate, normalized by the bandwidth, on uplink is as shown in particular table-4 is in the specific document that is with which we are referring to. So, what it says is that in indoor conditions it is a stationary or mobility, so the test condition says 10 kilometers per hour. So, there this spectral efficiency of 1 bits per second per hertz should be supported.

Now, if this is supported, then we know that this particular mobility class is supported. In high speed, when speed of 350 kilometers per hour is used for developing the test scenario, there the link spectral efficiency should be 0.25. So, if this is achievable, then we know that the high speed mobility case is satisfied, so that is all that is described in this particular text.

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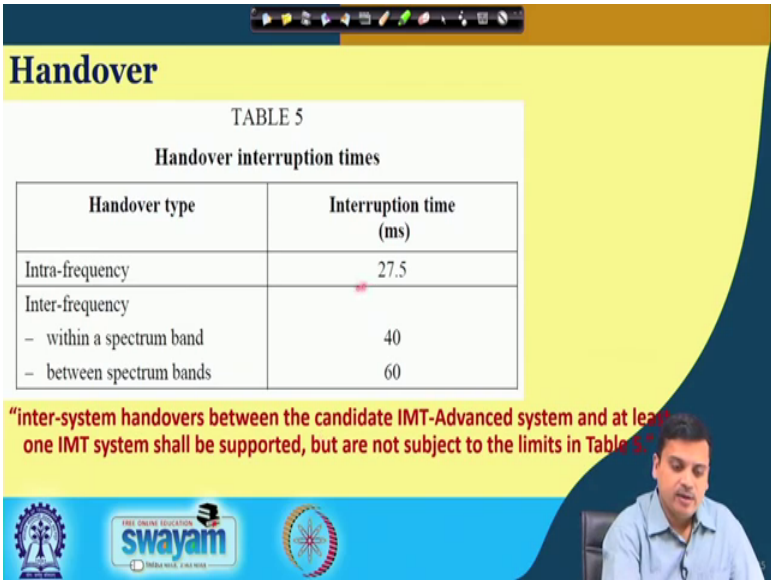

Again handover is a very important thing, when it comes to mobility handover is again naturally comes into play. So, there the inter-frequency handover is defined as around 27.5 milliseconds, and the inter-frequency handover is defined within the spectrum and is 40 and between spectrum bands is 60. So, again these are like numbers, which have to be met and these specific situations have to be tested for.

So, if the protocol, and the framework, and ran architecture supports these numbers which are ITU specified numbers, then you know that case it is an IMT system. So, the importance of discussing these things are again that when you move on to IMT-2020.

Similar, such specifications would come in the numbers are going to change along with it additional requirements would also come into play.

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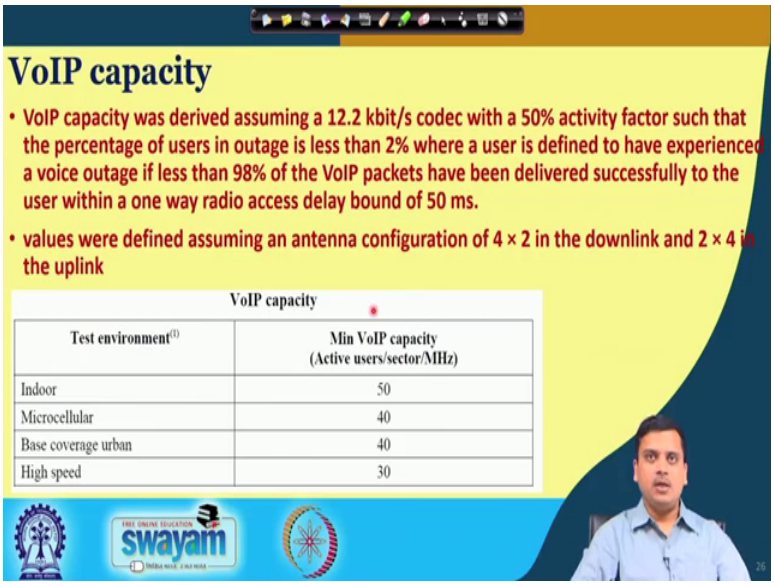

So, now comes the next important thing. So, when we discussed about these 4G systems in our earlier discussion, we had said that this is one such system, which does not provision for circuit switched voice, which is which was still available in the earlier generation. Like the 3G had a circuit switch voice as well as a packet switched data possibility, but here the entire thing is packet switched data.

So, all real time traffic are also available as packet data including voice. Now, although it might appear pretty normal today, but when we look at the transition earlier it was voice, which was circuit switched. And, there was fixed slots at which things were getting transmitted whereas, here there is randomness or a stochastic nature of scheduling which comes into play, which make things very very different.

Further the mobility is also a big factor, which comes into play over here. So, when you combine the mobility which brings in a huge amount of uncertainty because, of the Doppler effects along with the stochastic nature of packet scheduling, then supporting real time traffic such as voice or VoIP is a critical challenge. IMT-advanced has provisions or if the technology satisfies the certain numbers as displayed over here, then it can support the specific activity.

So, there as described over here, what capacity was derived assuming 12.2 kilo bit codec with 50 percent activity factor. So, there is a detailed model, which describes how you generate VoIP traffic in order to be tested for a particular operating environment ok, such that the percentage of users in outage is less than 2 percent ok, so that means, 98 percent of users would be satisfied right. So, how would you define whether a user is satisfied or not? So, there comes a user is defined to have experienced a voice outage if less than 98 percent of the VoIP packets have been delivered successfully or in other words if 98 percent of the packets are delivered successfully, then you would say that user is satisfied, and that to within a delay bound of 50 milliseconds right.

So, these are again defined for certain set of antenna configurations. So, what it says is that under indoor configuration 50 VoIP users per sector, per megahertz to be satisfied right, where is in high speed again the same thing comes up 30 there is a huge drastic difference, again because of the high mobility condition 30 VoIP users, active VoIP users per sector, per megahertz required to be satisfied. So, it clearly brings out the association of mobility with data rate, mobility with number of VoIP users that can be supported in a sector. Now, if this is possible, then you are then the technology under test would be classified as IMT-advanced or 4G. And fortunately most of the technology submitted satisfied these things quite easily. Especially, if we look at LTE and LTE-advanced, they also satisfy these numbers quite comfortably.

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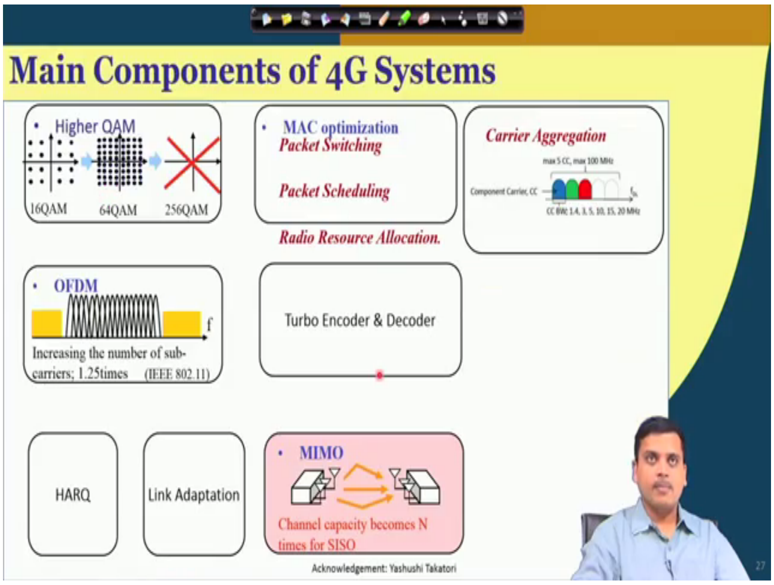

So, with all these requirements in the next particular slide as we have over here, it is a summary of the methods that essentially help achieve these different massive requirements. So, one of the primary changeover is basically the OFDM system, which will find opportunity to discuss, because as we go to 5G there is a variation of OFDM, which comes in this remains as the base layer. Higher order modulation. So, OFDM essentially is an overlapping waveform, whereby you get a huge amount of spectral efficiency.

As we go to higher order modulation, your spectral efficiency increases. Then there is MAC optimization in terms of packet scheduling, radio resource allocation, which further improves the spectral efficiency. Turbo encoder and decoder, improves the reliability. MIMO facilities increase the spectral efficiency n times, so it clearly says n times that oversee so link. So, all these help in increasing the spectral efficiency along with of course link adaptation and HARQ that is hybrid ARQ. Whereas, carrier aggregation provides a huge improvement in the aggregate data rate that is possible. So, when we move on to 5G, quite a few of these things move forward, so MIMO carries on, but there are more enhancements, then these carry on the higher order modulations variation of OFDM carry on.

So, the carrier aggregation carries on, and radio resource allocation again newer methods come into play. So, it is important that we understand the baseline structures that are available in 4G, so that it is easier to move on to the translation or the transition that happens, when one moves from 4G to 5G. So, we will set the background or set up the foundation based on which, we will discuss the enhancements that are present in the 5th generation air interface.

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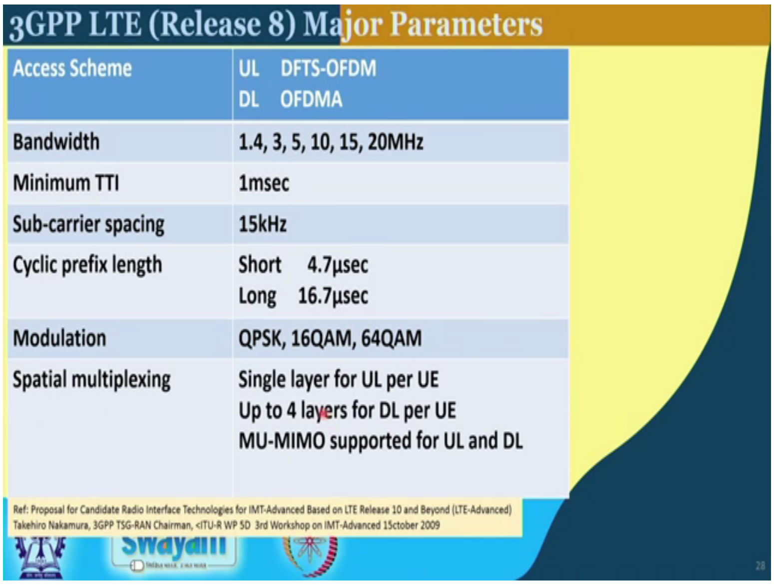

So, as we see the 3GPP is the 3rd generation partnership project, where LTE or release 8, which is kind of near to 4G system. And in this particular slide, we have some of the important parameters. And what we will see very soon is that even LTE, which is not LTE-advanced meets quite a few of the IMT-advanced requirements ok. And what we will see later is the LTE-advanced and meets it meets them comfortably.

So, in LTE we find that there are various scalable band widths, which are supportable. And if you remember, when we discussed earlier that flexible or scalable bandwidth is one of the important things that is required to be supported. The minimum transmit time interval is 1 millisecond, this is an important number, which we will see when we move to the 5th generation system.

Sub-carrier spacing for OFDM is 15 kilo hertz, again we will see a variation when we move to the 5th generation system. The cyclic prefix length when we discuss OFDM in details, these things will become clearer two possible values are available, the short and the long. And we will see why these are used, so 4.7 microsecond and 16.7 microseconds. So, two options are available, in order to take care of different propagation conditions. Modulation as indicated in the previous slide QPSK, 16QAM and 64 QAM are allowed.

Spatial multiplexing or MIMO as we see a single layer MIMO for uplink per user is supported in LTE, and up to 4 layers for downlink per UE, UE is the User Equipment and may MU-MIMO that is multi user MIMO is supported for both uplink and downlink. So, these are some of the important technical parameters you can say, which can be used to describe the LTE air interface.

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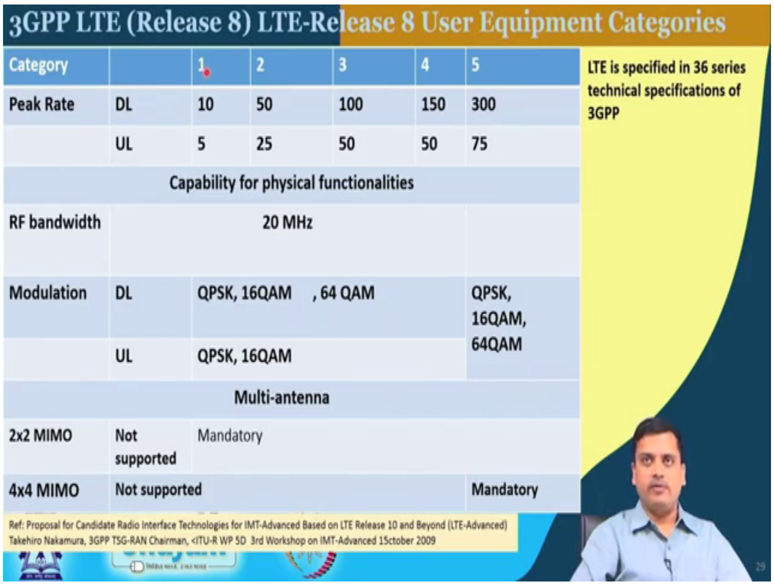

So, in LTE itself the user equipment have several categories as has been in the title of this particular slide. So, there are category 1, 2, 3, 4 and 5, and what differentiates them is the peak data rate. So, what you can see is that as you increase the number, which indexes the category. It basically indicates that the device can support higher and higher data rate ok. In uplink the similar is the picture, but the data rate in uplink is obviously different compared to that in the downlink, which has been consistent with all our previous descriptions.

The RF bandwidth 20 megahertz is supported. Now, in downlink what we see the modulation that is supported in downlink for category 1 to 4, you have all these schemes which are supported, where is an uplink only two modulation formats are supported ok. Whereas, if you go to category five, what you find is all the schemes are supported in both uplink and downlink. So, what it essentially means is that when we take up a higher cap indexed category phone or a smart-phone or a device, it can simply support higher data rate by virtue of providing higher modulation order.

And as we can see the 4 cross 4 MIMO is not supported up to four categories, but in the 5th category it is supported alright. So, what essentially we have is the 5th category equipment is much more complex in terms of signal processing, but at the same time it provides a higher data rate. So, if you are looking for very high data rate, we should go for higher category user equipment. And if you are satisfied with the low data rate, then one can go for a lower category, it depends upon the specific operating requirements of the particular device.

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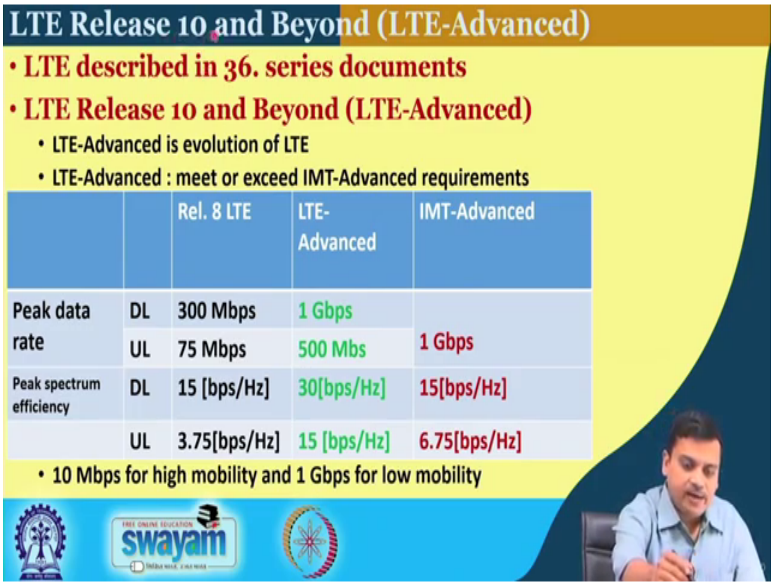

So, LTE release 10, which is beyond LTE it is basically LTE release 10 and beyond, which is the LTE-advanced, which is rather categorized as IMT-advanced. So, what we see is that these specifications are described in the 36 series of documents of the 3GPP organization. So, if you go to the internet and look up the 3GPP website, then there are technical specifications, which describe the different technology that they have released.

So, if we are looking for LTE series of documents, we need to take up the 36 dot something which will be describing different set of requirements, which we will probably see in one of the slides. So, basically if you look up the 36 series of documents you are going to get the technological description of LTE and beyond, and if you evaluate the performance, what we will find is that LTE-advanced.

The peak data rate is 1 Gbps in downlink and 500 Mbps in uplink ok, IMT-advanced also points out the similar thing. And of course, here what you can see is that 10 mbps for high mobility and 1 Gbps for so this has sorry this is 100 Mbps, which was described earlier. So, peak spectral efficiency what you can see is that in downlink there is 15 bits per second per hertz in case of LTE, which satisfies the requirements of IMT-advanced. So, yeah, but LTE-advanced gives you 30 bits per second per hertz, so which is much more than the minimum requirements are specified by ITU.

Even for uplink what we clearly see is that IMT-advance requires a 6.75 bits per second per hertz, which we had seen earlier whereas, LTE-advanced supports 15 bits per second per hertz. So, what we clearly see is that LTE-advanced quite easily satisfies the different requirements of IMT-advanced. And hence it is the actual 4G system, whereas the previous one that is the release 8 and onwards releases 9, they were kind of pre 4G or 3.9G as people have been describing. So, we stopped this particular discussion here, we will move forward with more description about IMT-advanced as well as IMT-2020 in the next lecture.

Thank you.