Evolution of Air Interface Towards 5G
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Lecture – 02
Evolution of Wireless Communication Standards From 2G to 5G (Part – I)

Welcome to the course on Evolution of Air Interface Towards 5G. This is the 2nd lecture and in the previous lecture we have discussed about the Evolution of Wireless Communication, a bit of historical perspective, but sometimes it is important to get back to history for reasons which we have discussed earlier. In today's lecture we will take a brief overview of how the communication standards have evolved.

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So, towards this we will have a structure as presented in this particular slide, where we will initially talk about the standards and the development cycle. Then we look into the ITU R recommendations followed by a summary of GSM and IMT-2000 and then we will take a look at the requirements of IMT advanced. So, with this let us proceed.

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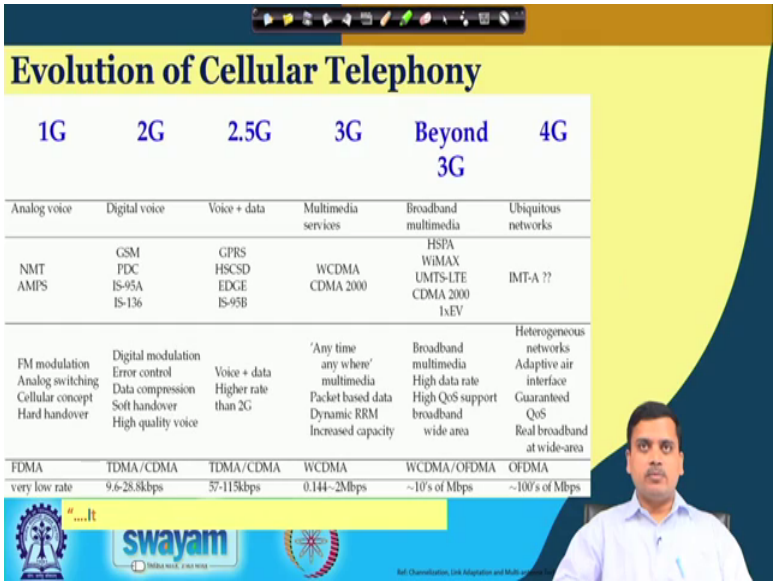

So, we were discussing about the evolution and in this particular picture which we are seeing in the previous discussion that we have summarized the different technologies which have evolved from the first generation to the fourth generation. And, there were different kinds of modulation techniques, different data rates and different kinds of access methodologies that have been summarized. And, what we recall is that a very famous statement that was put that, it is dangerous to put limits on wireless data rates is true and it will even remain true when we will discuss the fifth generation of mobile communication systems.

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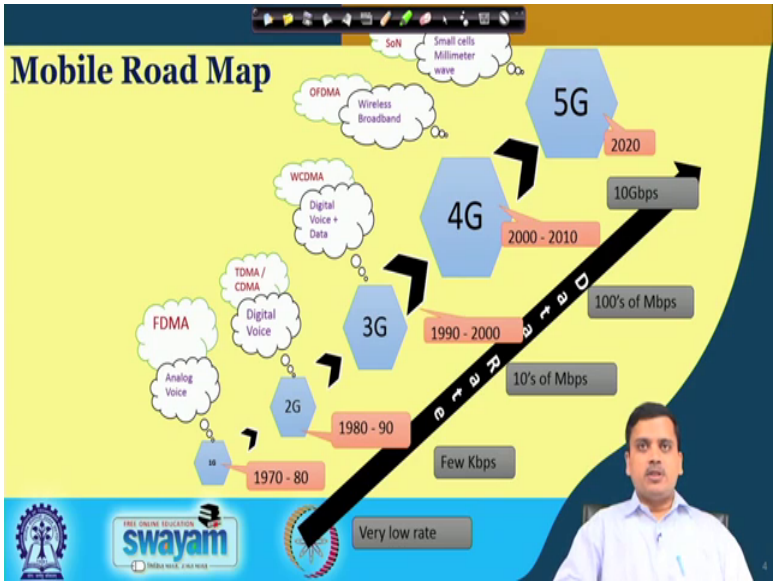

So, in this particular picture what we see is that the first generation communication systems were mainly analog and they were primarily designed to cater for voice communications. The way the channel were multiplexed amongst the different users is essentially frequency division multiple axis. And this particular set of technologies existed before the 1980's which was mainly analog domain communications.

We moved on further and we looked at or we came to the generation of second generation communication system, where the primary change was digital voice compared to what was there in the first generation. Primary methods that were used were time division multiple access and code division multiple access; we will get an opportunity to briefly see them sometime in the lectures. This set of technologies existed from 1980's onwards and even today we have a huge percentage of mobile subscribers who are still connected to the second generation of mobile communication systems. It is one of the most successful mobile communication systems which are in use today and it is expected that 2G will continue for at least a few more years before it becomes obsolete.

Beyond this from 90's the work on third generation system started and the main access technique was WCDMA, that is Wideband Code Division Multiple Access and the primary difference from the previous generation communication systems was not only digital voice, but there was data also which was pre-designed into the system. If we look

at the transition from 2G to 3G, data was slowly brought into the system, but it was essentially into the circuit switch network whereas, as we will see the data was part of the design where packets which data services were brought into the systems.

This started around 1990's and around 2000 we had the third generation systems deployed and then the work on fourth generation system started. And, around 2010 we had the 4G system in place and it was a wireless broadband system. It was one of the first wireless broadband systems as such although 3D 3G was itself a broadband system, but 4G was effectively one of the most efficient broadband systems compared to the previous generations. And, the access technique that was used was Orthogonal Frequency Division Multiple Access and in short it is usually called as OFDMA.

Moving beyond that somewhere after 2010 the work on 5G started and we have one of the preliminary versions of 5G which has been accepted by lot of organizations. It is expected that around 2020 5G will start to get rolling out into the different parts of the world. There have been a lot of changes in the access techniques from fourth generation to fifth generation which we will see in this particular course. What we also see in this particular picture is that from the different generations, first generation was mainly analog voice.

But, leaving that apart from 2G onwards as we move towards the fifth generation one of the common things that have remained is increase in data rate. Whereas, it was only a few kilobits per second most of the users or most of the viewers can easily accept; that the in the fourth generation technology few megabits per second per user is a reality. In fifth generation system amongst many other requirements one of the requirements would be to support even higher data rates compared to the previous generation systems. But, I said and we will see the data rate is only one of the few parameters that have remained in 5G compared to the earlier systems.

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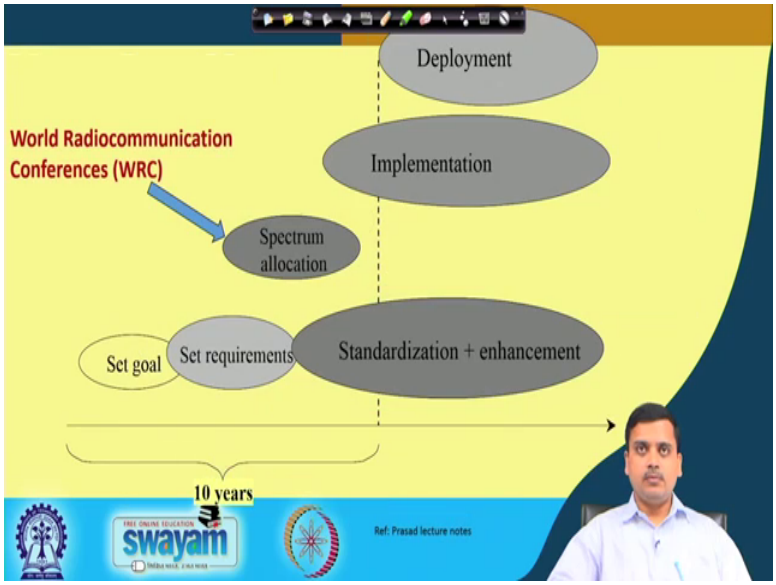

So, what we see from the previous slides is that generally there is a 10 year cycle when one standard evolves into a newer standard. So, this entire process starts with the setting up of goals as depicted in this particular slide. So, initial set of goals are the kind of objectives where, the new set of technology are supposed to meet. And, then this gets translated to a set of requirements which are more of specific requirements in terms of numbers for example, data rates and delays and all other constraints.

Spectrum allocation also happens which is usually discussed in the world radio communication conferences and this plays a vital role in selection of the methods that come into the standards. So, by this time most of the methods or the techniques or new inventions have been discussed thoroughly. And, addition to the spectrum allocation information whichever technology requirements or whichever technology solutions fit into the system are discussed in the standards organizations. And, then around a 10 year cycle from the setting up of the goals the standards gets finalized and implementation and deployment starts.

Thereafter, the standard continues to live and there are further enhancements to the standards while, a new standard starts getting designed from the phase after the 10 years. So, what we essentially have is that while a previous generation standard continues to evolve a new generation standards activity already get started. What you see is that the GSM technology although, it was pretty old it evolved into newer versions where it

would support higher and higher data rates. While, the new generation that is the third generation communication systems started to getting designed.

Even when the 4G system was getting designed 3G system was still evolving and to a certain point it had almost the specifications meeting, that of the 4 generation systems in terms of at least the data rate. Although, the methods the way they are implemented were quite different from each other.

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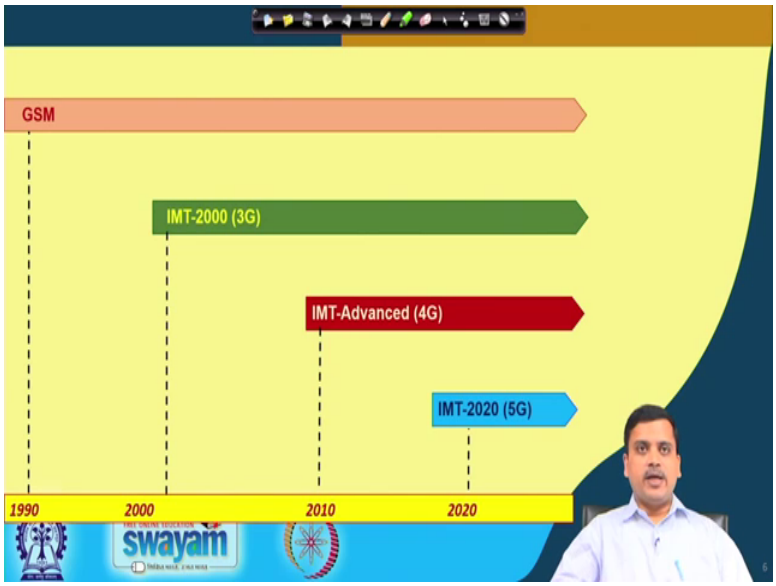

So, this has been summarized and if we look at the dates GSM was around the 1990's, IMT-2000 came into being around 2000, IMT-2000 is also called 3G and 4G which is also called the IMT advanced came into being in around 2010 and IMT-2020 which is 5G will come into being around 2020. So, what we see is that there is roughly a 10 year gap between the deployment of the standards. However, there are contentions that this is not a one step jump from one standard to another. So, there has been continuous evolutions and you may have come across names such as 2.5G 3G 3.5G 3.9G 4G and so on and so forth.

So, there is a gradual change of technological evolution which keeps on happening and it is not a sudden phase change that the industry experiences. Even a sudden phase change is not possible to accept because of several such interconnected devices a huge amount of investment, a huge amount of effort that gets involved. So, it is a natural process that

things evolve slowly from one phase to another, but finally, what we see is when there is a 10 year gap there is a significant amount of difference from one technology to another technology.

And, one of the other aspects is that people to look forward to a feasible set of framework, a platform which is remain valid for a next period of 10 years which can evolve within the framework yet provide sufficient time for the new generation things to be deployed as well as adopted and which gets backward compatible with the earlier generation systems. So, that they can co-exist simultaneously.

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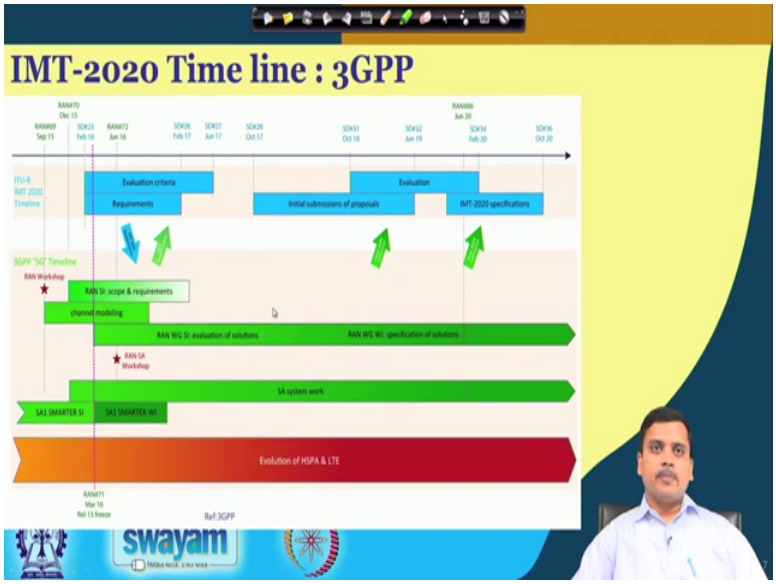

In this picture which we have taken from the 3 GPP information which shows the timeline of development of IMT 2020 which is the fifth generation standards; what we see is while the activity of fifth generation standard carries on there is still evolution of HSPA and LTE that is 3.5G and 3.9G that goes on along with the development of 5G activity. So, these activities continue to a certain point until and unless these are no longer supported by the global community.

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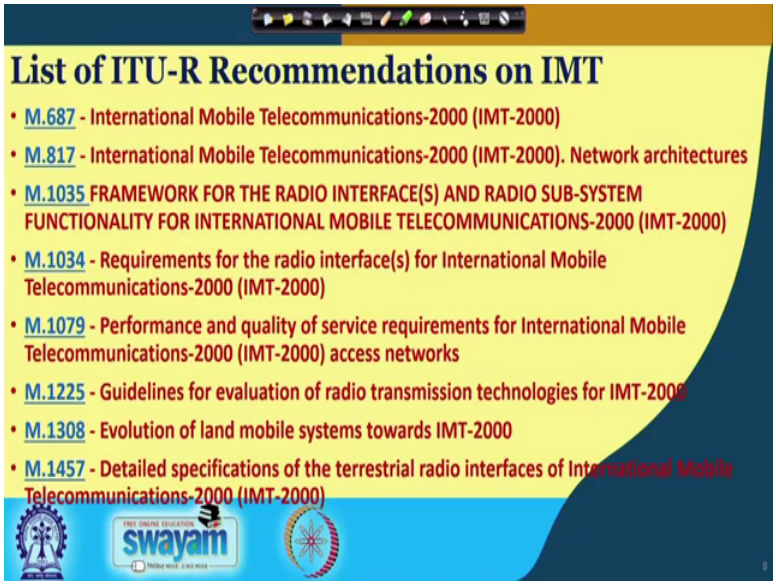

Next we take a look at a series of recommendations. One reason for bringing in this list is so, that those who are interested in finding out the specifications the requirement as given by ITU can easily look into these references and find out the detailed inputs or the material that is present over there. For example, M 687 is the name of a particular document which describes IMT-2000. Then a series of other numerologies are present like M 817 discusses the network architecture of IMT-2000, M 1035 is a framework for the radio interfaces and radio subsystem functionality for IMT-2000 which is the 3G standard.

M 1034 discusses the requirements for radio interfaces for IMT-2000, 1079 discusses the performance and quality of service requirements of IMT-2000. And finally, 1225 represents the guidelines for evaluation of radio transmission technologies for IMT-2000. So, what we see in these few set of documents is the sequence of things as we have seen earlier like there is a set of requirements that get set up, then there is a specification, then there is a performance and quality measure as well as a set of recommendations on evaluating the performance of such systems.

Then we proceed on to the next number 10 1308 which explains the evolution of land mobile systems towards IMT-2000; that means, as they move towards 3G. And 1457 presents the detailed specification of terrestrial radio interfaces of the IMT-2000 standards.

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As we move ahead in the 1645 I mean it is not necessary to remember this, but this particular set of slides can act as a reference for you to look into and get details of the information that you may require. So, the first document talks about the framework and overall objectives of future development of IMT-2000; that means, whatever happens beyond IMT-2000. I mean advancement of IMT-2000 as well as beyond IMT-2000; that means, for evolution of 3G as well as things beyond 3G. 1034 are the requirements of radio interfaces, 2012 are the detailed specification of the radio interfaces of IMT advanced. So, we have now moved to the set of documents which start discussing about IMT advanced which is the fourth generation communication system.

2134 describes the requirements related to the technical performance of IMT advanced radio interfaces which we will see in some of the lectures. In 2370 this is also a very interesting document which talks about the IMT traffic estimates for the years 2020 to 2030. Now, these documents are very interesting and important because, they predict the traffic that is going to be coming into the system and based on the description of the traffic the detailed solution of systems need to be developed.

So, such analysis and predictions are the ground or basis on which new technological solutions come into being. Then the 2410 describes the minimum requirements related to the technical performance of IMT 2020. So; that means, the fifth generation and 2083 it

is the IMT vision or framework for overall objectives of future developments of IMT 2020 and beyond.

So, this talks about 5G and beyond systems and so on and so forth. And along with this the ITU R FAQ that is the Frequently Asked Questions on IMT is also a very interesting document which answers many of the queries which are usually present in our mind. And, I would recommend to the users of this particular course to find some time and get into these documents. These are very well described documents which can provide you with a good background of how things have evolved from earlier generations to the next generations.

This will lay the foundation of how things keep on evolving and at least for the next generation how things have moved on. And, probably the process is going to continue for at least one more generation.

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So, if we check back on GSM which is the second generation communication system a bit of historical aspect, it was the European Conference on Post and Telecommunication Administration or CEPT which was which founded the group specially mobile which talks about the objectives of better and efficient wireless communication than analog.

So, this was one of the objectives and it was established in the GSM standards. And, a very important aspect it is a single standard for all Europe that was the initial objective.

But, what you can see is that it is it was made available across a huge part of the world. India is one such country where GSM is hugely popular and very effectively it helped connect to the remote areas through telecommunication network which was difficult with wireline systems. TDMA was one of the access techniques which was agreed upon by all the groups of members which were part of this community and it is still in use.

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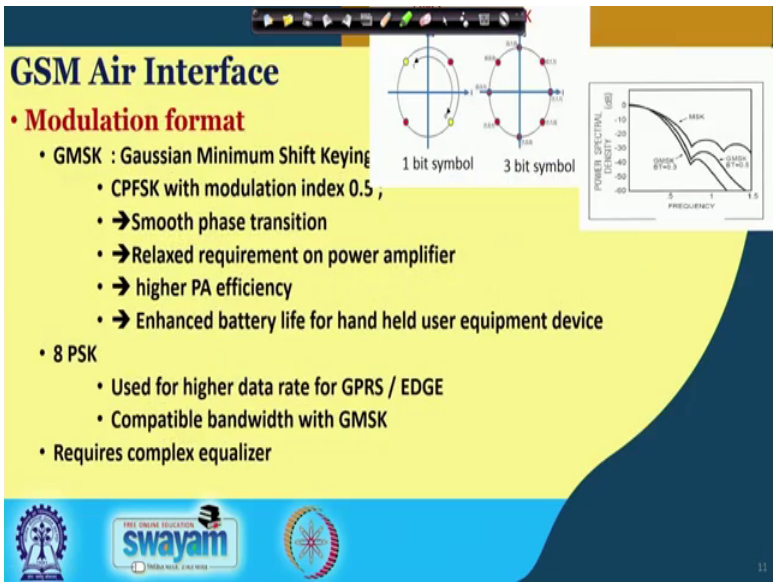

In GSM we may all know, but it is interesting for us to take a look that it uses the Gaussian minimum shift keying as the modulation. And it is a kind of continuous phase frequency shift keying which is very effective in the sense it is smooth transition between symbol to symbol.

So, when the symbol changes which we will discuss at some point that depending upon the pulse shape the spectrum of the signal is formed. So, if we want a signal to be well contained within a certain pulse shape, within a certain bandwidth we require to design a modulating technique by which the bandwidth is well contained. GMSK is one such modulation technique in which the bandwidth is well contained as well as the peak to average power ratio is also limited.

So, if the peak to average power ratio is limited, it helps us in enhancing the battery life because, the power amplifier which is in use is operating at its higher efficiency. And, this helps in providing higher battery life to the handheld devices which is very very

essential for most of the handheld devices that we require and it is still a big challenge as you increase the bandwidth.

For GSM we all know the bandwidth of occupancy is around 200 kilohertz whereas, as we moved beyond to higher systems we have seen earlier and we will see later also the bandwidth has become larger and larger. So, these problems still remain as important problems in next generation systems. And, there have been newer methods which have been there to help contain the signal bandwidth within a certain amount of spectrum as well as reduce PAPR amongst other technological enhancements.

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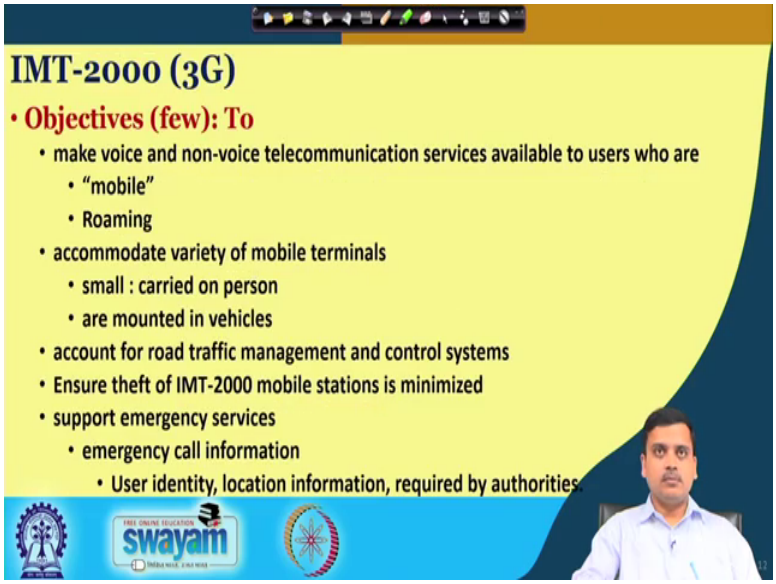

IMT-2000 which is the 3G, it had a set of objectives we will just pick up few of them just to highlight what are the contents of the documents as were listed earlier. So, one of the objective was to make voice and non-voice telecommunication service available to users were mobile and roaming. So, if you see the earlier requirement; early requirement was to make analog communication system to digital and to provide a single communication standard for all Europe. Whereas, here the objective is to make voice as well as non-voice telecommunication services which comes into being as a requirement. So, hence your entire system design starts to be looked at from a different perspective altogether.

So, this is the starting point of the development of a new technology. It is also expected at that time they discussed that it is expected to accommodate a variety of mobile

terminals. So, they had already foreseen a variation or multitude of devices; that means a variety of devices from small devices which could be carried on person as well as devices which could be mounted on vehicles. A small command on this would be if we look at 5G systems which we will see shortly is that this requirement has carried on and in fact, only the variety has become much more than was perceived in those times.

So, as a general objective it still remains to accommodate a heterogeneity of devices into the communication system. It was also foreseen to account for road traffic management and control system. Now, if you look at some of the use case scenarios of 5G this still remains as one of the requirements. But, it is not surprising because at some point of time there is a vision and there is a requirement people find technical solutions, but with time the challenges also evolve. When challenges evolve the overall objective remains the same, but new solution needs to be found for the increase in magnitude of the problems.

So, as we see that overall objectives have continued from 3G to 5G, but newer solutions are required given the magnitude of the problem. Interestingly out of the many many requirements I could pick out one of them which says to ensure minimize the theft of IMT-2000 mobile stations. So, that got built into the standard. So, this kind of requirements are very essential in order to maintain safety; further as you may also see that support for emergency services was also discussed to be brought into this to the standard.

So, as to support emergency situations like in case of emergency, the emergency call information for example, the user identity, the location information which are required by authorities are automatically provided to the network. Because in emergency it is not possible to provide a whole set of information whereas, a simple call to the center of rescue is sufficient to provide huge amount of extra information which can be used immediately for the mission. So, these kind of requirements create a huge impact on the design of the solutions that are looked into by these systems.

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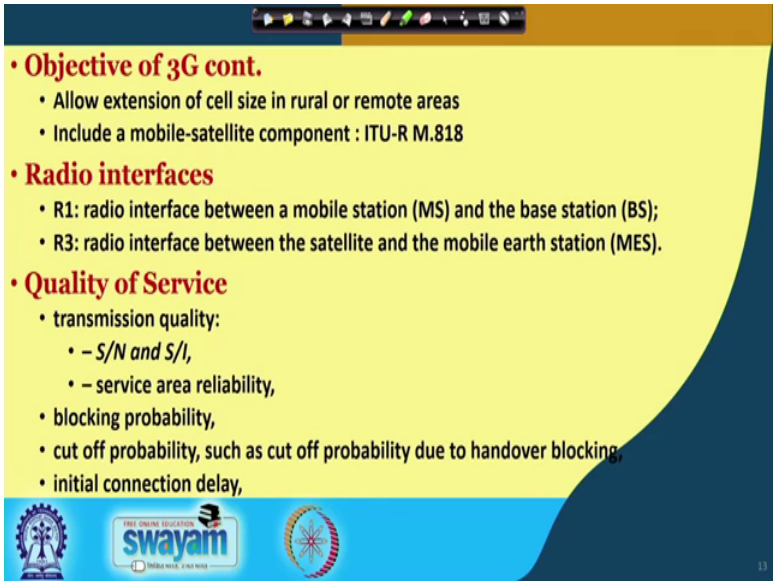

So, if we look at the objectives and carry on with them; one of the objectives was to allow extension of cell site in rural or remote areas. Now, this has even continued to 4G and probably it will continue into 5G as well because, there is still a vast majority of areas where there is scanty population and which is mainly agrarian based. So, in those areas you would like to have cell sizes which are large whereas, if you look at the evolution from 2G to fifth generation systems. the primary cell size have become smaller and smaller.

One of the reasons is to increase the term called area spectral efficiency or bits per second per hertz per meter squared. So, if we have to increase the area spectral efficiency amongst several things, the frequency reuse factor or the cell size needs to be adjusted. The smaller the cell size, the better it is it provides higher efficiency. But, what it states is that the larger cell size should be supported without much modification into the baseline standards because, we would like the same devices to operate in a highly dense scenario as well as in a rural area.

So, the radio interfaces have been defined in several ways and the R 1 and R 3 amongst the many I have just picked up only two of the because, of limitation of space and since this is not our main objective of discussion. But, since it is still important that these are the ways in which radio interfaces between the mobile station and the base station have

been defined in R 1 and the radio interface between the satellite and mobile earth station is defined in R 3.

So, what we see is that the third generation system also had provisions to connect to the satellite communication system and this is also a very important part of 5G. Now why I am bringing this up? So, that you are aware that certain things which may appear as a new requirement which may suddenly appear as a new thing in the fifth generation system is actually not. So, they have been existing since the time of data communication systems. In terms of quality of service the transmission quality is described in terms of signal to noise ratio or signal to interference ratio.

As well as it is also described in terms of service area reliability or the percentage of time over the service area, the services are available. The other parameters of quality of service were blocking probability especially important for voice calls. And cutoff probability such as cutoff probability due to handover blocking; that means, when you are moving from one physical region to another physical region because of handover of call from one base station to another base station there could be called drop. So or there could be the cut off because it the next cell is unable to accept the new connection request.

So, for all these reasons a cut off probability is also taken as one of the important metrics which should be measured. Initial connection delay is also one of the measurements of quality of service. So, what we can see is there is a small list of quality of service from the entire set of list that has been captured over here. And, some of these have continued as quality of service measure in the new system while, some more things have been added as we move to 4G and 5G systems.

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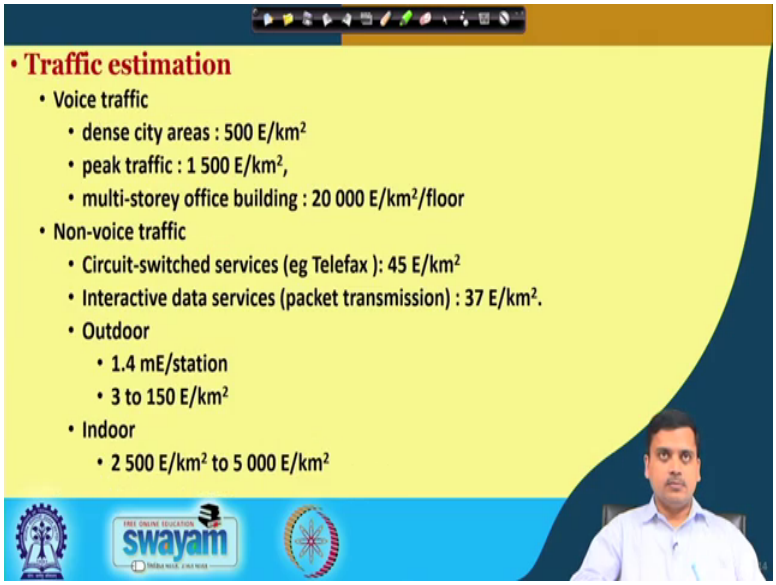

Some measures from the documents which describe the 3G requirement specifications as we can clearly see is that there is a variation of traffic requirement estimates from 500 Erlang's per kilometer squared to 5000 per kilometer squared. So, there is a huge variation of traffic requirement on different scenarios. So, again what I am trying to point out in through these set of numbers is that with 3G onwards, there has been a variation in the requirement or a range of variations that starts to get defined. Instead of just a single requirement that voice needs to be communicated which was the first generation and second generation communication system.

As we move beyond this into the fourth and fifth generation system we will see even a wider variety of description which tells about the requirements. So, there has been more detailed description of requirement and hence we are able to come up with better design to meet better quality of services for the fourth and fifth generation system. We conclude our lecture on the evolution of communication systems, till this point over here in this particular lecture. We will continue in the next lecture to talk more about 3G and 4G communication systems.

Thank you.