Evolution of Air Interface Towards 5G

Prof. Suvra Sekhar Das
G. S. Sanyal School of Telecommunications
Indian Institute of Technology, Kharagpur

Lecture – 01
Evolution of Wireless Communication

Welcome to the course on Evolution of Air Interface Towards 5G. This is the first introductory lecture, so our main focus would be to lay the ground and discuss how the course has been arranged. So that, you can prepare as well as revise some of the basic concepts and we will acquainted it what is expected from the course.

Although, there has been introductory material lecture which provides the motivation for the course, but since it is the first lecture ah; it is necessary that we discuss the overall layout as well as get into some of the historical aspects which lays the ground for the entire course that we are going to take its of 20 hour course that has already been announced and 40 lectures.

So, we have quite a bit many lectures to discuss, but at the same time we have quite a few many different technologies to be addressed in this particular course. So, it is a great opportunity to discuss this particular course pertaining to 5G, because 5G is almost knocking at the door and this gives us the right opportunity and gives us time enough to prepare when 5G is just launched in about a years time.

This particular course as has been said before is particularly suited for the advanced engineers; especially for the research scholars pursuing a research career in the domain of wireless communications. It is also suited for the graduate level wireless communication students; it is also suited for the practicing engineers especially for wireless communications.

So, as we are iterating wireless communications the name repeatedly; as we will go through the over overall layout of the particular course we will see what all things that need to be prepared as we go slowly inside the details of the course curriculum. In general this particular course requires you to have a prior knowledge about digital communications and overview about wireless communications would also definitely be of help.

Although, we will discuss some of the basic essentials of wireless communications that are needed to understand some of the things. For example, the propagation which we will discuss slowly ah; we will also require to have some knowledge about MIMO, but that is not necessary we will discuss the preliminaries before we get into the nitty-gritties of the details.

5G as this course is supposed to be is going to be very different from its earlier proceed criticizers the earlier generations when it moved from 2G to 3G to 4G. And finally, moving towards 5G until the previous generation it was primarily about data rates as well as spectral efficiency. Most of the technologies on air interface were designed to provide higher and higher data rate as well as to provide better spectral efficiency.

Whereas when we take a look at 5G; we find myriads of different technologies that are required to come together at various levels from the physical layer, from the access layer as well as in the network layer which are supposed to work together. There are different scenarios and a huge variety of requirements as well as a wide variety of devices and applications which are required to be served simultaneously by one single network which is completely different compared to what happened in all the previous generations.

This is given rise to the development of various different technologies which need to work together. Our aim in this particular course is to take a look at the fundamentals which will make 5G run. We will not specifically look at the exact standard specification, but we will follow them as well as describe the details of how the different fundamentals of technologies make such a huge standard come into being.

We have already said before that this particular course has already been written down in form of a book. And we have given you the link before; I would simply like to show a particular copy of the book which is already available and the soft version or the E-book is also available.

(Refer Slide Time: 04:43)

So, most of the material that we will discuss in this particular course is already provided in E-books it is already available in the internet; so if you just look for it will be available. However, whatever lecture we discuss in this particular course would be also made available through the slides and whatever material we would be able to share with you.

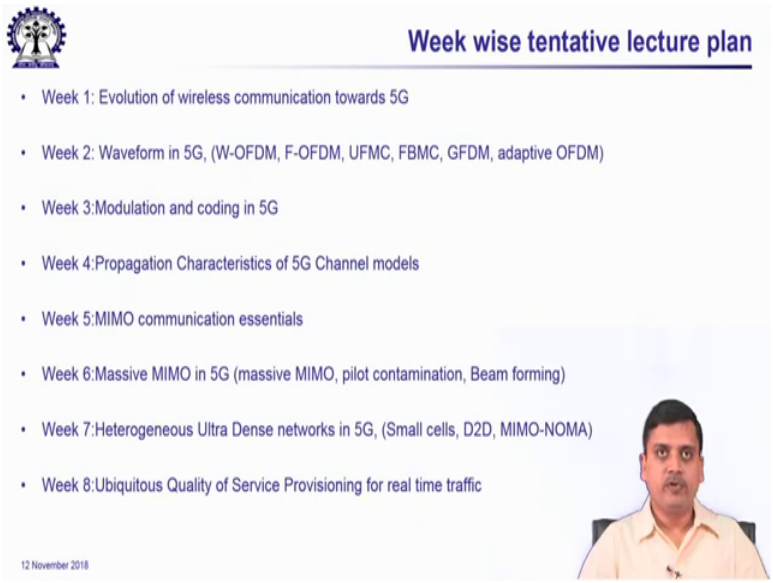
So, 5G is supposed to come around 20 it is not far away and already one of the versions of technological specification has already been prepared and while we go through the course. We will visit it time and time again, so that we can check about the latest developments as well as about the fundamentals that are making those realizations happen.

So, at this point let us look at the course outline. So that we can see what all things we need to prepare and how we will go through this particular course.

(Refer Slide Time: 05:49)

So, we will of course, view the evolution of wireless communications in a few minutes from now.

(Refer Slide Time: 05:55)



But before we go into it lets look at the week wise layout of the course; we will talk about the evolution of wireless communication towards 5G initially. So, there it is not in details with the fundamentals of signal processing and so on but; however, it lays the ground and the motivation for the 5G so that all the things that follow after this particular

week we know why we are doing each particular thing. How the requirements have been set up and how the solutions are arriving based on the initial objective that has been set.

Then we will move on to the waveforms usually this is termed as the new radio in 5G, but will not restrict ourselves to whatever is in the current version of the release 15 or the new radio that has been described in 5G. But we will also go beyond that and discuss some of the contending technologies which have been there in the scene. And however, for some reason they were not accepted for the present version, but however they have enough technical competence and capabilities to be considered for future generations of communication systems.

With that I will move ahead with the modulation formats; we will then look at the propagation characteristics that are very important. Because when we look into 5G it is not just a single spectrum band, it is not just one single technology. So, it is important to understand the propagation characteristics that influence the technologies that are being proposed as well as their performance.

It is very important to understand how the signal propagates through the air medium in the different scenarios, because the air medium presents the challenges which are overcome by the different solutions as will be discussed in this particular course. There are several other courses which detail the wireless communication aspects. However, it is always important to remember that it is the propagation characteristics which influence the design of the solutions which are aimed towards overcoming the challenges has thrown by the of wireless propagation characteristics of the particular medium.

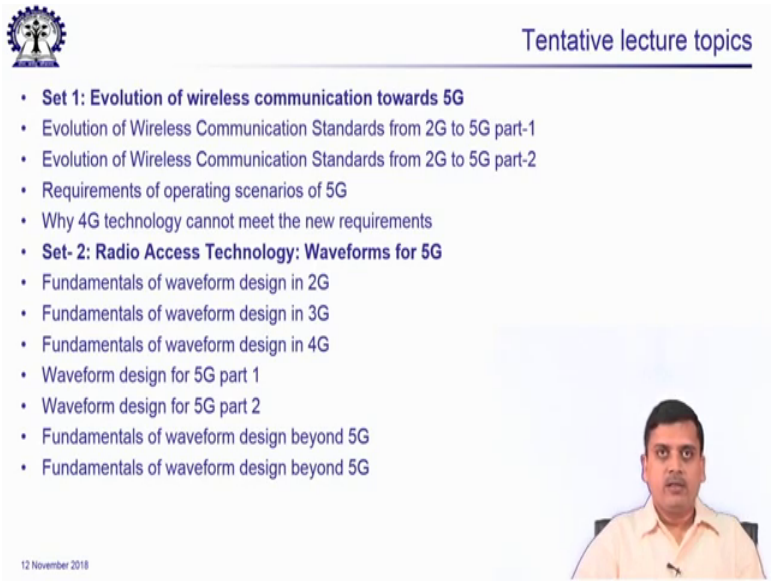
5G is especially going to be different compared to other previous technologies because in 5G we are going to see the new millimeter range of spectrum which will be used in the terrestrial communication system. So, this particular range of frequencies has certain special characteristics which has been studied before, but when it will be used in the terrestrial communications there are certain disadvantages and there are certain advantages which will be considered in details.

And as a consequence you will be easily able to understand how the different solutions have been arrived at, and how the different solutions work together take advantage of the situation rather than seeing the entire propagation characteristics as a challenge. Another important aspect of 5G is MIMO communications, advanced level of MIMO

communications, MIMO communications have been present in the previous generations, but there are certain special aspects especially like massive MIMO and beamforming. We will spend a considerable amount of time in providing the basis for MIMO communications, the fundamentals so that those who are not well equipped with the understanding of MIMO should be able to catch up with the advanced concepts. And then we will move on to some of the important aspects which are going to drive 5G.

Thereafter, we will look at certain system level aspects that is the heterogeneous networks because it will be a system where multiple kinds of transmitters and receivers are going to work together and the RANN architecture is not going to be homogeneous then with various layers of operation. So, we will be detailing the issues that are involved in such a system. Thereafter finally, we aim to touch upon the quality of service the energy aspects as we will see slowly and how to evaluate performance of systems under such situations.

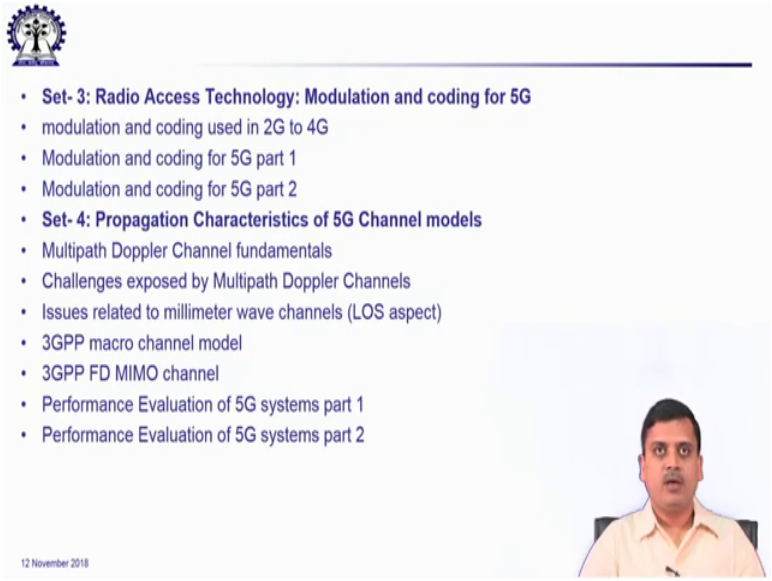
(Refer Slide Time: 10:15)



If we take a look at the details of how we have planned the entire course the initial few lectures would be on the standards, how things have evolved. So, that we get to set ourselves on how the commercial domain of things are moving and how technology has been changing and has been accepted by the industry. So that we are equipped with the mode of thinking and we design our solutions future solutions in a similar line.

We will discuss the radio access technology especially the waveform part which we have considered a number of lectures.

(Refer Slide Time: 10:49)



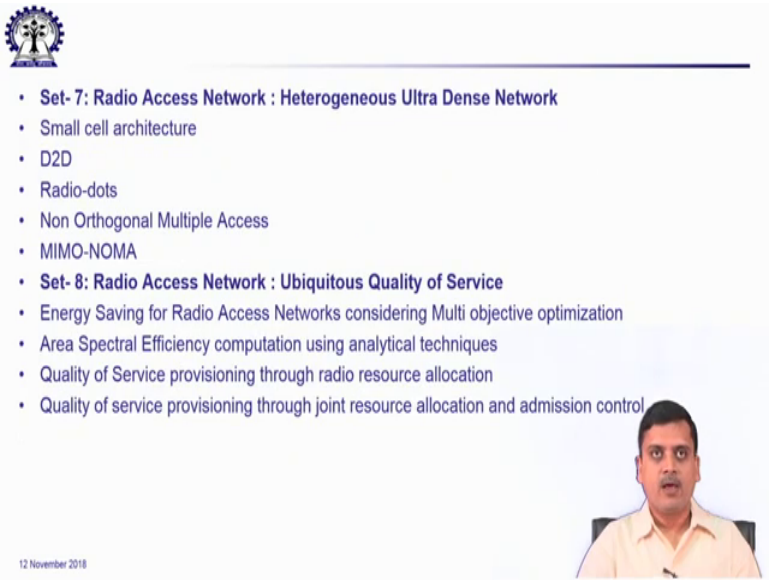
Then we look into the access part where there are different kinds of new access technologies that are coming into play. We will talk about the channel models as has been listed there we will especially look at the third generation partnership project based models. Because, those are some of the models which have been well accepted and used for performance evaluation of the 5th generation communication techniques.

So, it is essential that we understand the commercially usable or the models which are more popular towards realization of practical systems. We will also discuss the performance evaluation methodologies and what principles are followed, how things have to be done so that the results that we get are usable by others. It can be reusable reconstructed and the results can be used for exchange between the different groups so that it is well accepted.

(Refer Slide Time: 11:45)

We move beyond this with the different MIMO technologies as has been said earlier. We will talk about the fundamentals. Then we will move on to the details of massive MIMO and beam space and some of the other advanced concepts which are expected to be vital for 5G communications.

(Refer Slide Time: 12:03)



Then as said about the heterogeneous networks we intend to discuss small cell architecture. We intend to discuss the non orthogonal multiple axis as well as how would MIMO interact with non orthogonal multiple axis.

Finally, we will get into the energy savings mode with multi objective optimization. Because whenever we have systems into play there are various different objectives where the whole network is supposed to meet and you have a set of parameters which you can control in order to meet the different objectives. Now when you have all these objectives coming together simultaneously; how does the system evaluation work out and what all details happen, how does one objective play with the other we will try to look at that.

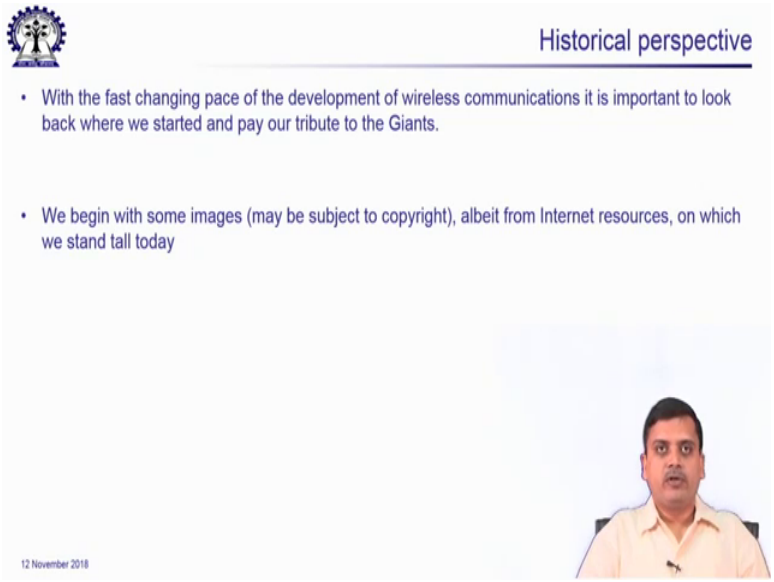
We will also look at techniques for computing the area spectral efficiency which is a very important aspect. Because when we are working with such technologies as 4G or 5G; it is very important to analyze the area spectral efficiency because users are distributed over the area ah. Whereas, the link spectral efficiency is also important, but finally, what plays a major role is when multiple users come together; how do you analyze the spectral efficiency of systems analytically?

So, we will discuss some of the methods which are vital in doing this analysis. The importance of looking at analytical methods is that it helps us to create a framework through which we can get results quicker; than typical simulation procedures. The simulation procedures are of course essential, because the models which are used for performance analysis are usually from measurements and they are usually not mathematically tractable.

But when we look at analytical approaches we look at methods and tools as well as models which are more analytically tractable, but then there is a difference from the measurement models. So, we will try to present some of the ways in which these analytical models could be used to provide results which are quite acceptable or as good as the simulation results; thus only helping us to save a lot of simulation time.

We will move beyond this and discuss about some of the quality of service aspects because essentially the quality of service for real time traffic classically has been provided through circuits which network. Whereas, the modern networks are providing these real time services such as voice and video through packet based services. Now, how do we look at or how do we measure the quality of circuits of such systems. And if we apply the admission control, how does it fit into? What are the metrics that needs to be looked at? So, this overall aspect of the link level as well as system level will be discussed in this particular course.

(Refer Slide Time: 15:05)

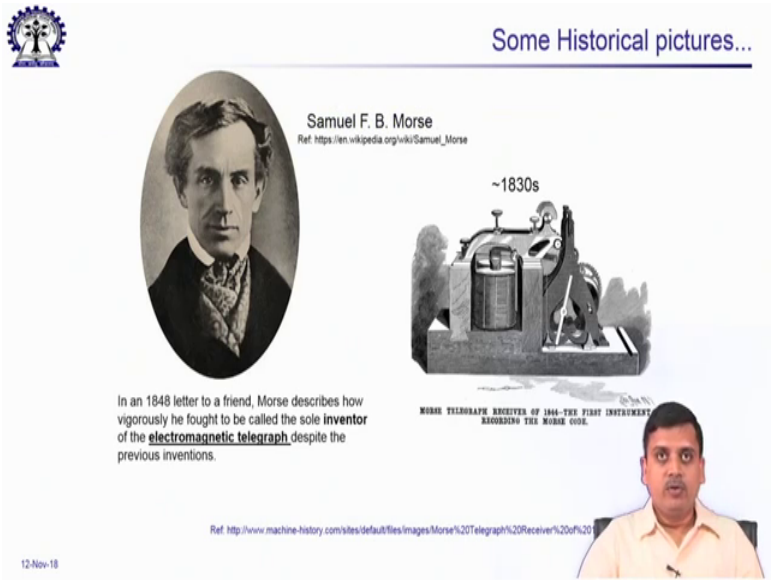


So, moving beyond whatever we said it is very important that we look at from where we started. Because, when we look at today we are standing at the door of 5G things have changed really very very fast over the past few decades.

Today the new generation is almost not aware of how things have started, but I find it very important to look back into the past at least for the initial few minutes. So, that at least we get back to the basics whenever it is necessary and its very important, I consider once again that we find out if there is anything from the past which is still influencing our 5G technologies which will soon be able to find out.

So, at this point we will try to look at some of the historical aspects; although it is quite well known that most of you know about these, but I find that it is very important that we pay our tribute to the great founders of wireless communication technology on whose shoulders we stand. And maybe some of the facts that we discuss could be new to some of us. So, with this lets get into some of the facts that we already know or maybe new to some of us.

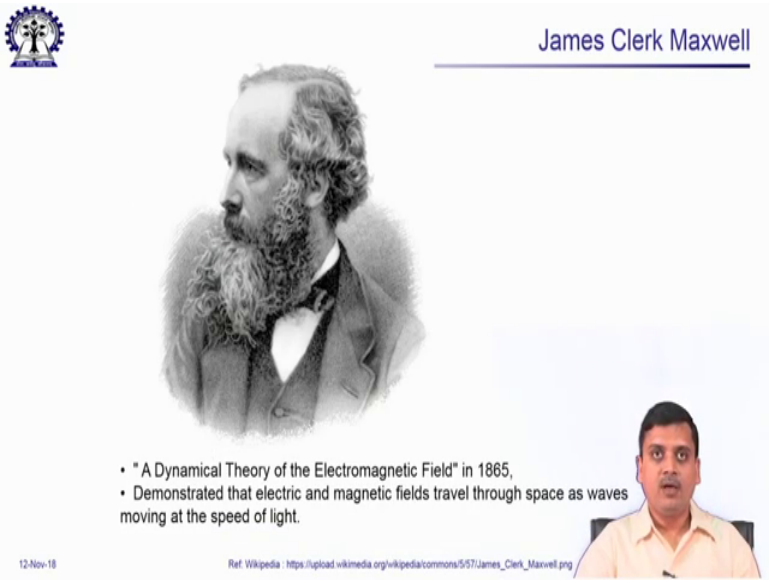
(Refer Slide Time: 16:29)



So, we know that Morse developed the telegraph system and which is one of the very early communication systems, but an important fact. Again most of the things are from internet resources some of the references are given here. Again a fact in wiki which I found very interesting at this point of time is what Morse wrote a letter to a friend as has been there in this particular slide, where he describes that even he had to fight in those years to be established as the sole inventor of electromagnetic telegraph.

So, what it clearly means is that whenever an invention happens simultaneously many people across the world work on some of the things and there has been always a war a fight on claiming the first. Although, that is not the main message, but this is also an important message which I consider and I wish to share with all the researchers of wireless communications of the future.

(Refer Slide Time: 17:25)

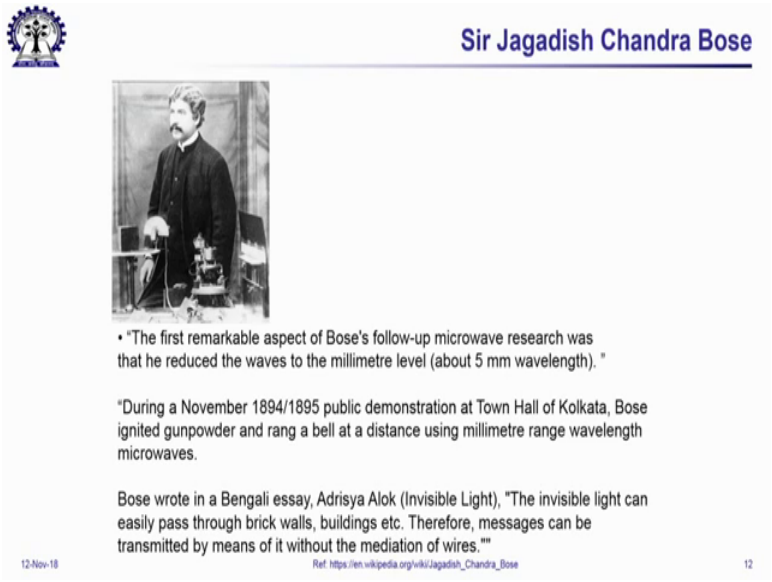


Next, we all know the famous Maxwell equations and this was the genesis of wireless communication. So, whenever we think of wireless communications we can never start without paying a tribute to the great Maxwell because of whom we are finally, seeing there in the entire set of developments of wireless communications.

(Refer Slide Time: 17:47)

The next important stage as you all know was due to Hertz who demonstrated the existence of electromagnetic waves. And then started a flurry of demonstrations of wireless communications and today we are again at the forefront of 5G.

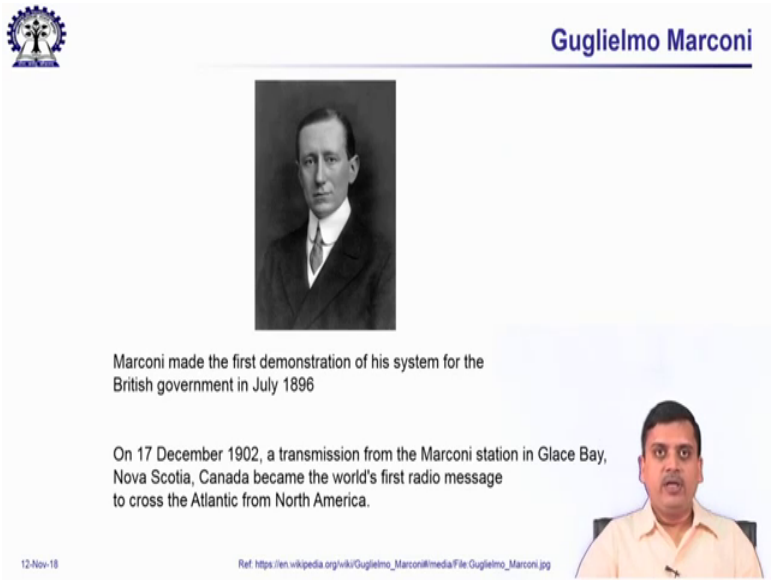
(Refer Slide Time: 18:03)



At this point it is essential that we look at one of the important contributors to the development of wireless communications and this was Sir Jagadish Chandra Bose, and he demonstrated the first experiment of wireless communications around 1894-95 in Calcutta. And a very interesting fact which I would like to point out and some of you may have already known is that he used the millimeter range of wavelength of microwaves in order to demonstrate the particular experiment.

Now, what is important is that this particular frequency is again becoming one of the fundamental spectrum bands; where 5G is expected to work. So, this is more than 100 years ago this particular technology was used for wireless communication. And we are back again going to use this particular spectrum for communication into 5G. So, this particular image and the scientist plays a very vital role even though it 100 and year more than 100 years back it is very much relevant for 5G.

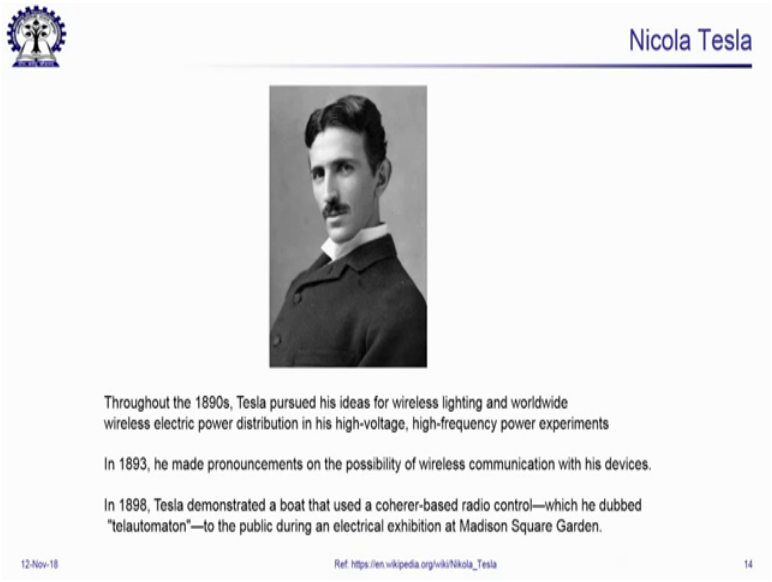
(Refer Slide Time: 19:17)



Marconi is does not require any mention and one of the biggest contributions in that he did was long distance wireless telephony. So, when we look at 5G today that is going to come; it is expected to encompass not only terrestrial and small distance communication. In fact, it is expected to encompass even satellite communications.

So whereas, in 4G it was more restricted to terrestrial communications; in 5G we are not only going to have very short distance communications ultra reliable communications, but also will be having very very large distance communications if not interested probably the next generations would be able to have some methodologies through which these could also be done. Again, we what we are seeing is that although these inventions were made more than 100 years ago; they are still somehow relevant for the modern generation.

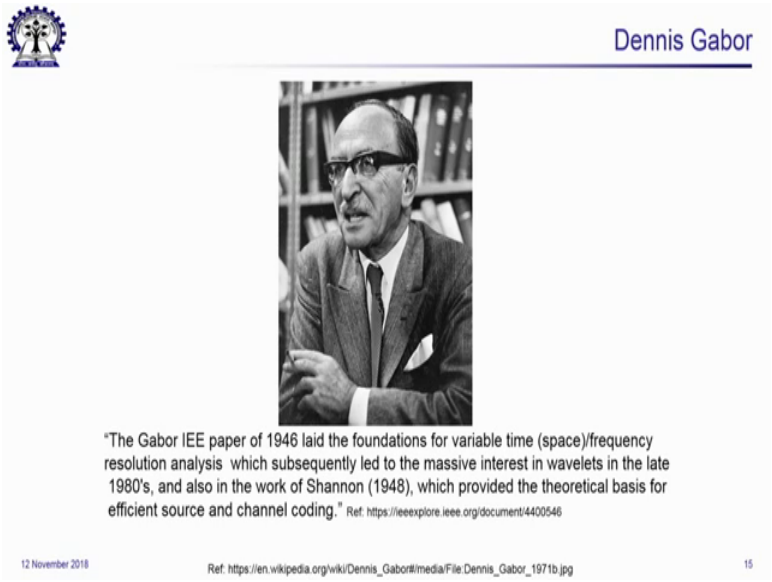
(Refer Slide Time: 20:09)



It is important that we recognize the contributions by Tesla and amongst the various contributions that he mentioned would like to focus on the wireless side wireless communication or aspect. So, one of the last statements that is written in the particular slide again it is taken from internet resources; it clearly states that around 1898. I mean nearly 1900, he had developed a coherer waste radio control which he dubbed the telly automation and it was used to demonstrate a boat could be maneuvered using remote control.

So, again whatever we are seeing today that remote controlled application especially UAVs and others are already demonstrated more than 100 years ago. Of course, what we have today is much more advanced technology super level of control which has been contributed by the by the development over the last 100 years. The method of wireless distribution of electricity today we are having wireless charging. So, again the philosophical concepts were there, but it took a long time before it could be made of use to the general public which will again form one of the basis for future generation communication systems.

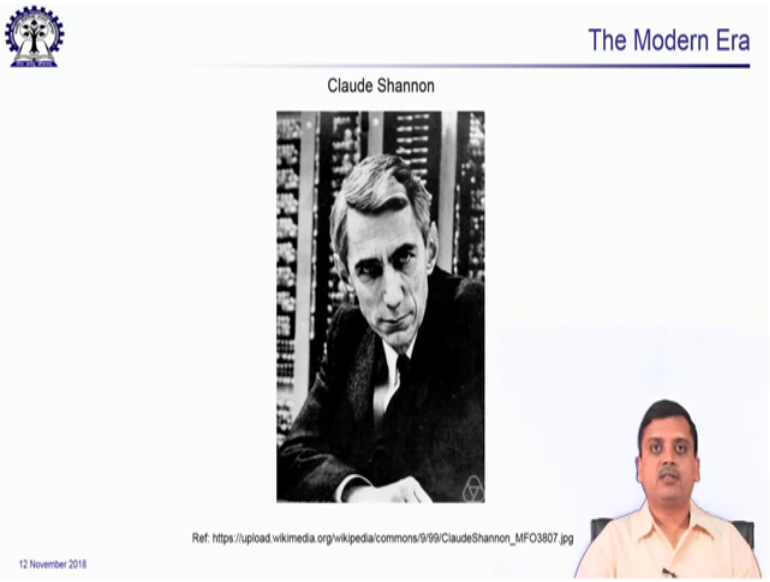
(Refer Slide Time: 21:25)



This is an interesting personality whom I would like to bring forward probably it is usually missed out when we discuss about communications is Dennis Gabor. Although, he is famous for hologram his work as has been given there particularly lays the foundation for the time frequency resolution analysis which again found its importance during the contention of waveforms on 5G.

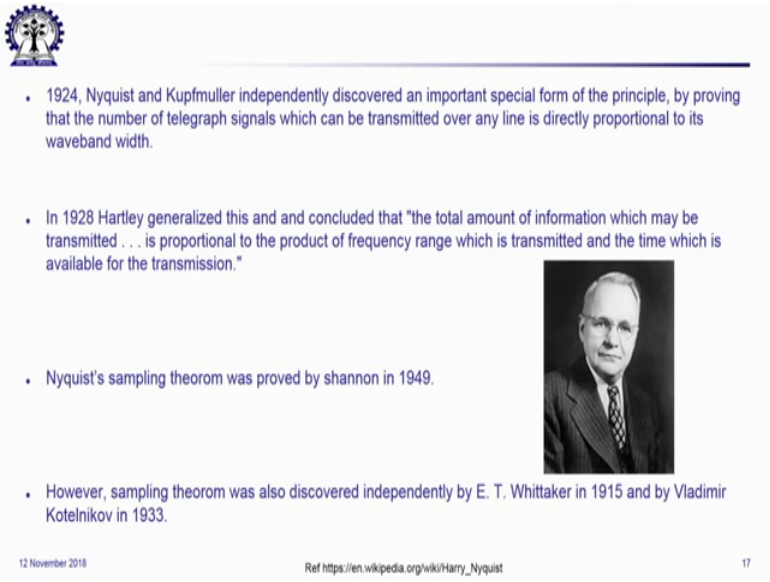
So, he was one of the founders of the waveform analysis space where the Gabor waveform was developed and the generalized frequency division multiplexing which was one of the contenders for 5G is based on the structure and time frequency analysis as presented by Gabor. And we hope probably in future generation of wireless communication system this advanced methodology finds its place and its mature enough to be used as a technology solution.

(Refer Slide Time: 22:23)



Shannon requires no further explanation; he is the founder of information theory. Again a lot of things that we see in 5G our because of the foundations that have been laid in information theory; whatever we see in MIMO and massive MIMO are again having foundations back in information theory. Whatever we talk about non orthogonal multiple axis has again been proved in information theory to provide the high spectral efficiency for multi user communication as is possible.

(Refer Slide Time: 22:51)



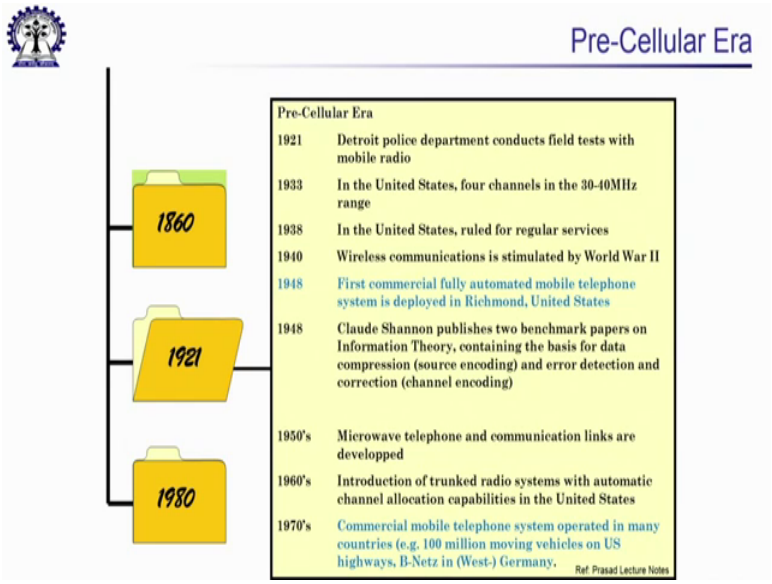
Some side note on the Nyquist contribution because the entire domain of communications depends upon sampling which was due to Nyquist. So, we just need to remember some of the major contributions because as we move beyond and look into the advanced technologies. We sometimes miss out the minute nitty-gritties which run into the system so often that we tend to neglect them.

So, I take this opportunity to remind ourselves of the great contributions. And probably there could be greater contributions by the future generation researchers motivated by some of the fundamental works done at an early stage.

(Refer Slide Time: 23:31)

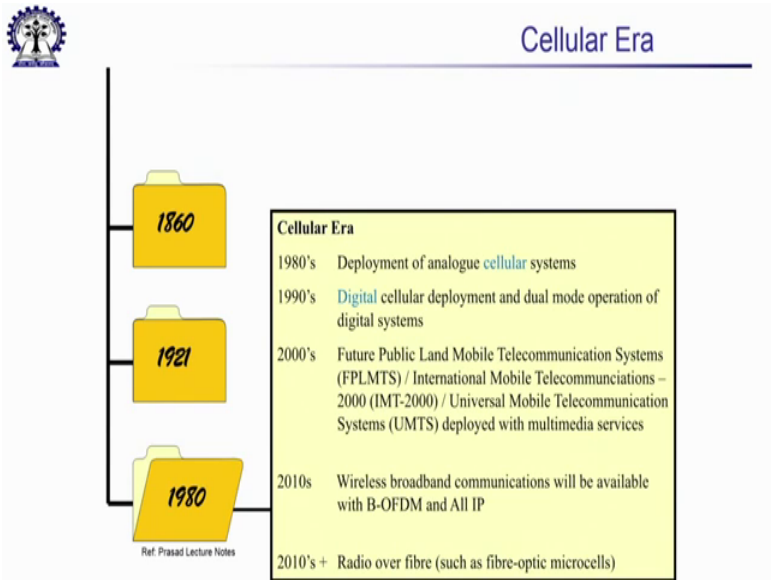
So, thereafter was the age where instead of individual contributions they were more of a holistic or system level of group level contributions. Because, it was more of system development when we look at 5G the development is because of hundreds and thousands of engineers and scientists all over the world who has gone together to produce the technologies which will be of use. So, it is no longer one single persons; it is more of a team effort and we briefly take a look at some of the developments which have happened over the past so, that we are in sync with some of the aspects.

(Refer Slide Time: 24:11)



In the 1860s it was mostly the developments that we had seen before thereafter it was the period where the cellular telephony, became important around 1948, 1950s it was the region where fully automated mobile telephony came into play. And then around 1970s to 1980s the mobile telephony became very commercial; lots of people were using it.

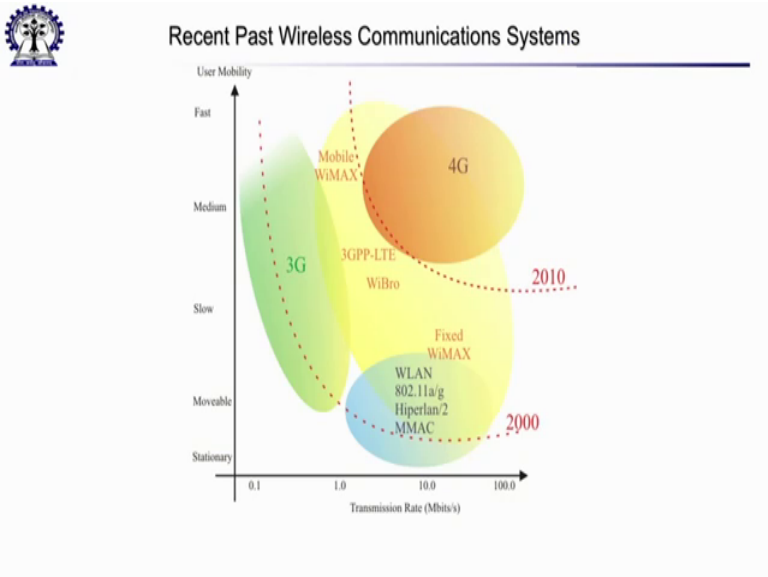
(Refer Slide Time: 24:37)



From 80s onwards it was the cellular concepts which came into being and today we are still using concepts of cellular, we have cells, we have frequency reuse. And this is one of the most important methods by which the area spectral efficiency has been increased

over the different generations from 1G to 2G to 3G to 4G and 5G. And over the years the cells have become smaller and smaller and smaller, because the spectrum is limited and this is one way by which you could simply keep on increasing spectral efficiency.

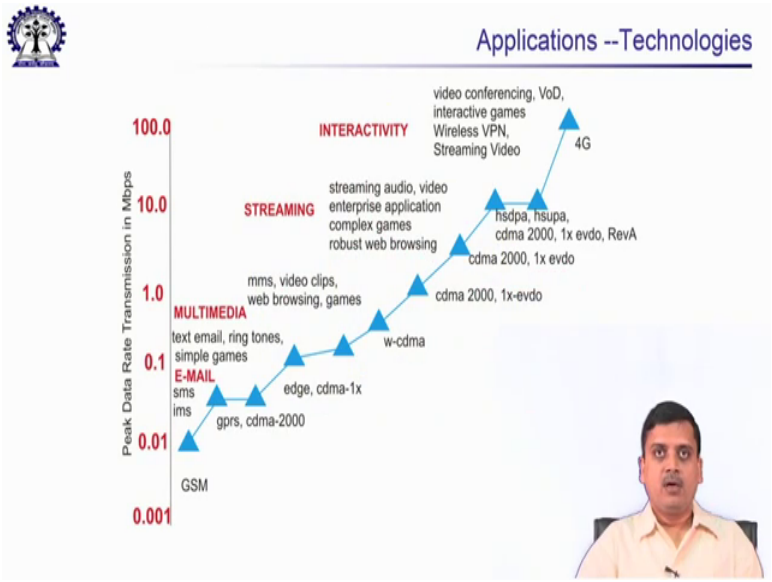
(Refer Slide Time: 25:15)



This particular picture is capturing some of the technologies of the yester years that is up to 4G we deliberately did not bring 5G into account because that is yet to come which will see in some future slides. However, in this particular slide we try to bring about the locations of the different technologies with respect to user mobility and transmission rates.

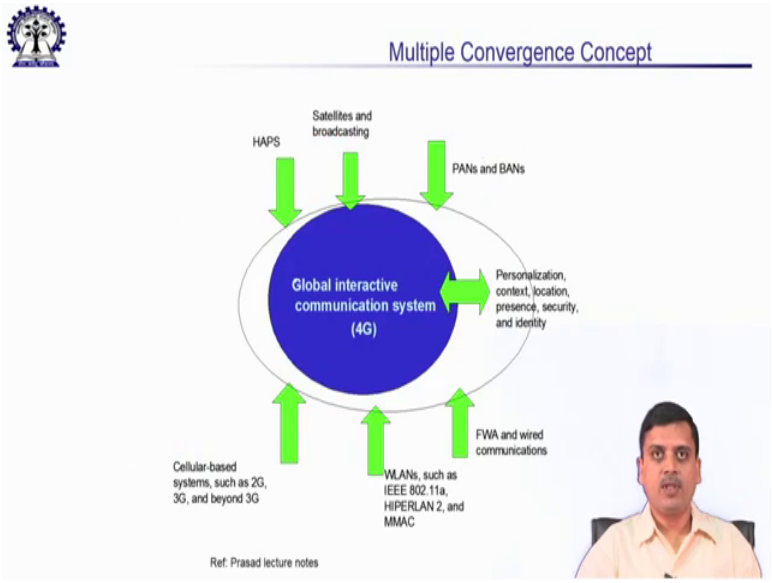
So, what we see is that some of the technologies were very good at providing high mobility support, while other technologies were very good in providing the high data rate, but at low mobility and 4G had a target of providing very high data rate while providing very high mobility. Now, when we look at 5G; 5G also aims to provide very high data rate also supports very high mobility, but that is not the only aspect as will be clear in the future lectures.

(Refer Slide Time: 26:13)



In this particular figure, we try to see some of the different applications that have been pushing the development of the earlier generation mobile communication systems. And we will slowly look at some of the applications which are the drivers for the 5th generation mobile communication systems.

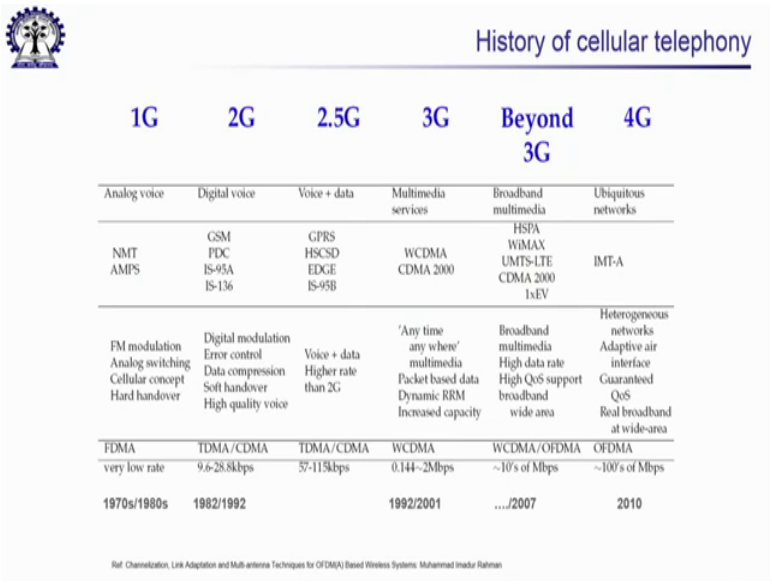
(Refer Slide Time: 26:33)



Till recent past there have been lots of effort where different types of communications have been brought into convergence. Although, this particular picture shows that there has been lot of effort in trying to bring them into one board, but unfortunately that has

not happened much, but that is one of the agenda that 5G wants to achieve that they want to bring around different communication methods and applications under one platform.

(Refer Slide Time: 27:03)



So, this particular slide summarizes the different technologies along with some of the timelines. So, as we go from 1G to 4G we see that analog modulation slowly moved towards digital modulations. The access technique moved from time division multiple access to code division multiple access; then there was wideband code division multiple access and when things move towards 5G there was orthogonal frequency division multiple access.

One of the major changes that happened over the periods was the frequency reuse factor which was initially a large number. Then finally, it came down to frequency reuse of 1. And although OFDMA systems are of frequency division multiple access nature, but still they use they are capable of using frequency reuse factor of 1, in order to provide very high spectral efficiency, because additional higher level higher layer methodologies bring into account interference management techniques which help it survive.

We stop this particular lecture here. And, in the next lecture onwards we will look at the different aspects of 5G, and how it stands with respect to the previous generation mobile communication standards.

Thank you.