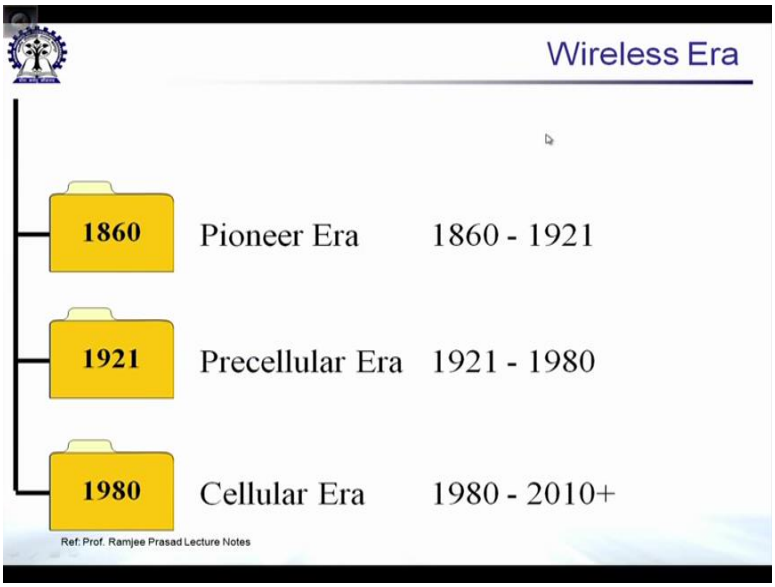
Fundamentals of MIMO Wireless Communication
Prof. Suvra Sekhar Das
Department of Electronics and Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 01
Evolution of Wireless Communication Systems 1G to 5 G

Welcome to the course on Fundamentals of MIMO Wireless Communication. This is the first lecture; today we are talk about brief history of wireless communication and give you a brief overview of the things that remain for us to do in this whole course. Today we are going to talk about Evolution of Wireless Communication Systems has it has gone from 1G to 5G.

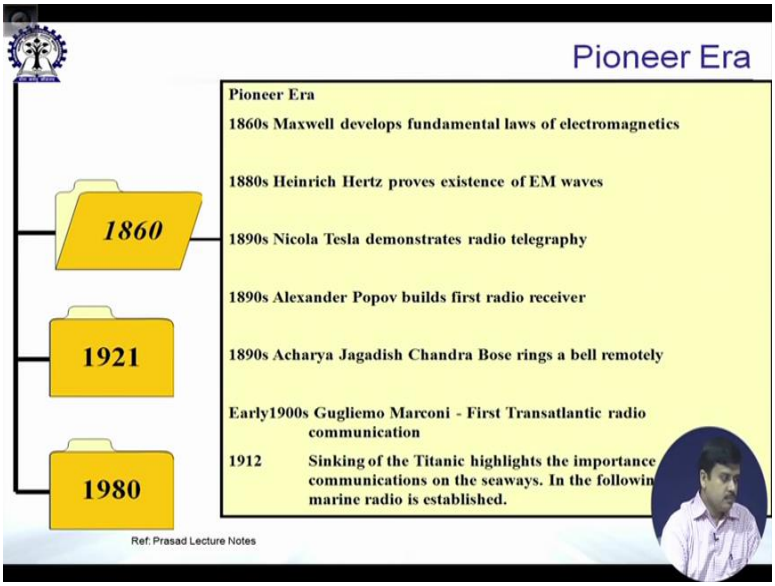
(Refer Slide Time: 00:47)



The whole era till today can be briefly divided into three parts; the Pioneer Era, the Pre-cellular Era, and the Cellular Era. The pioneer era is from the period 1860 in Maxwell derived equations to 1921 when they were first experiments of electromagnetic wave propagation. Then we take the take a look at pre-cellular era in the 1921 to 1980, in this period there was commercial deployment of e m way propagation in what is known as today mobile communications. After that period where mobile communication was proven to be successful we move in to the third era where we call the cellular era.

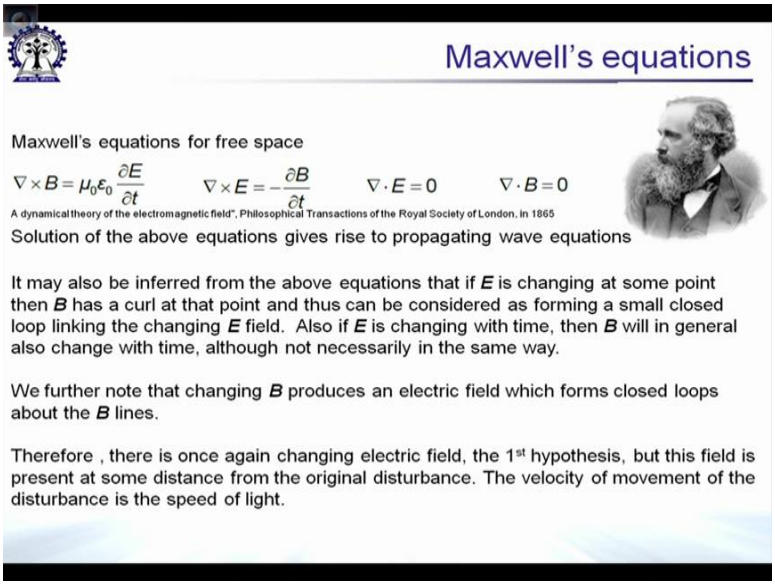
It is started with the concept of cellular systems which is initially developed in bell labs. What is not given over here is the last era as of now which is going beyond cellular on which is cell less architectures. We will remain contended within these three errors because the cell less architectures is still evolving and it is not yet known what kind of architecture it is going to come up. So, probably in future courses you might come to know about a modern cellular systems or the modern radio access network.

(Refer Slide Time: 02:14)



The pioneering era begins with Maxwell developing the fundamental laws of electromagnetic waves. So, we have a whole list of a people including Heinrich Hertz, Nicola Tesla, Alexander Popov, Acharya Jagadish Chandra Bose and Gugliemo Marconi who are demonstrating these experiments.

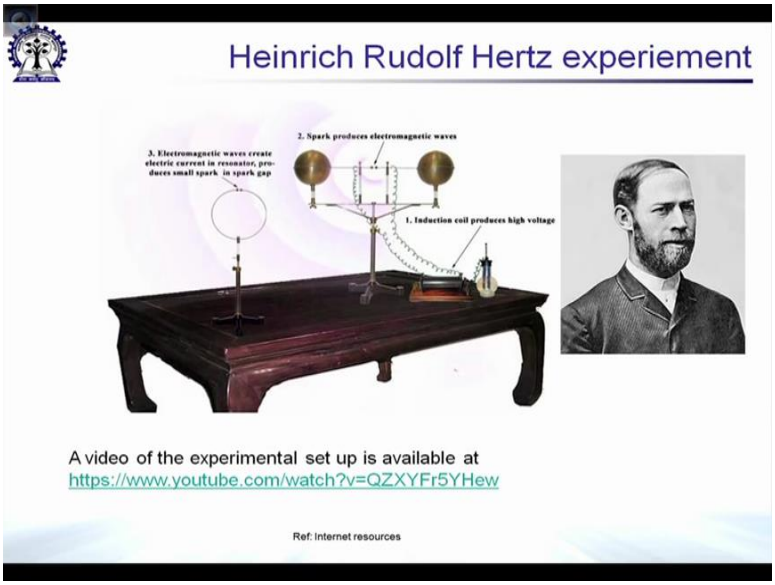
(Refer Slide Time: 02:38)



See if you take a look at how things work, the Maxwell developed these set of equations it was first published around 1865. If you look at these equations what we can see that if E field that is electric field is changing at some point in the magnetic field as a circulation. Also it can be considered as to forming close to loop linking the electric field. It is also true that with the E field changes with time then the magnetic field will also change with time, although it is not necessary in the same way.

If we note the next expression what we find that the second expression tells us the change in the magnetic field produces electric field which forms close loop around the magnetic field lines. So therefore, we are back to our first hypothesis which stops about the change in electric field, but this field is at some distance from the original disturbance. The velocity of the disturbance is the speed of light. This has been well investigated and available in initial course on electromagnetic theory. So, clearly what we seen is there was (Refer Time: 03:54) that a change in electric field could propagate through a medium through a distance and what was discovered is the speed at which things propagate is the speed of light in free space.

(Refer Slide Time: 04:06)

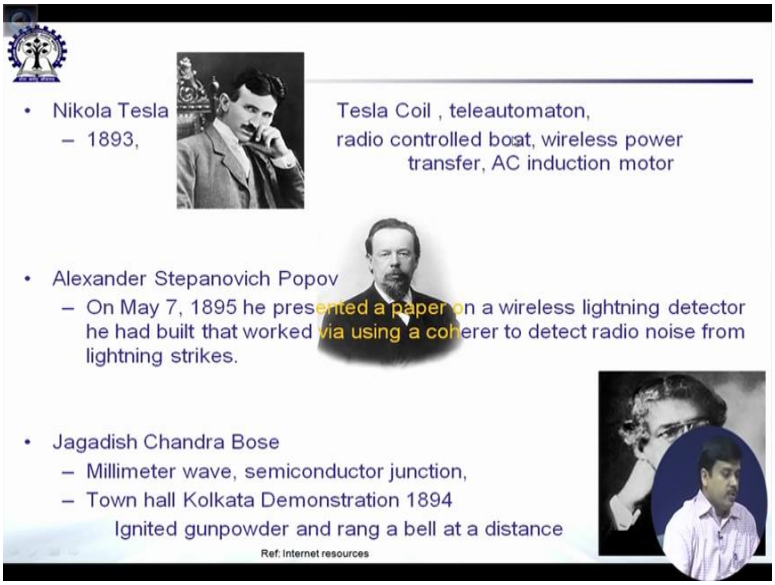


Moving on to further what we have is the experimental setup which Heinrich Hertz used. What I have given below is the YouTube video link which real demonstrates in a nice way how this experiment was performed. What you have done was used an oscillator as indicated by the mouse pointer here, and he has used a spark gap in between where they used to be occurrence of sparks due to be oscillation.

He used a resonator at as a receiver where he further had a gap and he believed that if the spark over here which will cause change in electric field and thus change in magnetic field followed by change in electric field which will propagate to the receiver. And would induce a small current into this loop there by causing sparks loop appear in this tiny place as can be in this region.

What he had experimented was when this distance in the first experiment was around two meters he could see sparks coming. And was a proof that electromagnetic waves do propagate in medium. I would recommend seeing this video just very nice then you could get a feeling how the experiments were performed.

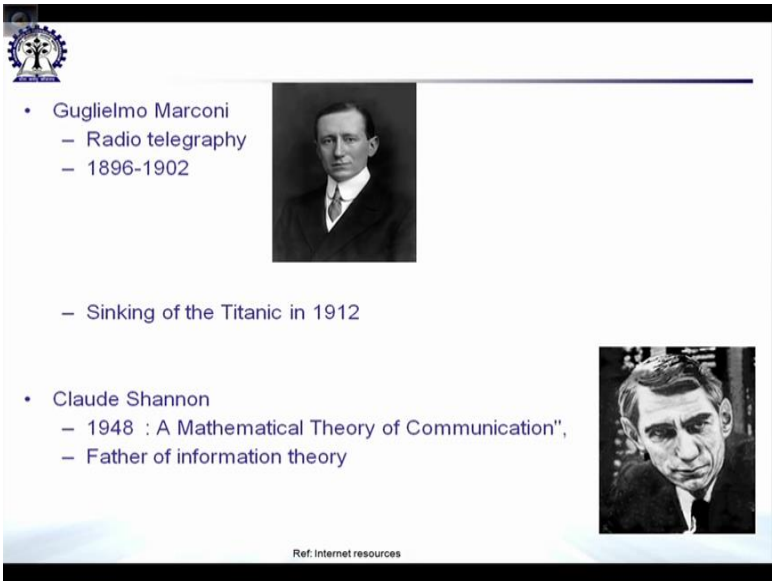
(Refer Slide Time: 05:31)



Moving down further we have the next list of three people the first Nikola Tesla. He was one of the scientific genius who invented many things among which well known are tesla coil and at that time around 1893 he proposed teleautomation where he was demonstrating radio control boats. He was mainly interested at the point of wireless power transfer which is almost a reality today. He was one of the pioneers of introducing the AC induction motors. So, Nikola Tesla around 1893 did one of the first experiments where energy could be transmitted from one point to another by electromagnetic waves.

Following him there was Alexander Popov, he did his experiments around 1895 and he presented a paper on wireless lightning detectors that he had built using the coherer. The coherer was a famous part of the receiver which is used by several people including Marconi. Around that time in 1894 in Calcutta scientist Jagadish Chandra Bose he demonstrated radio waves in the Town Hall Kolkata. One of his biggest contributions in that era was millimeter waves and the concept of semiconductor junctions. In his demonstration ignited gunpowder and rang a bell at a distance. It is often thought that it was a Bose was 60 years ahead of his time.

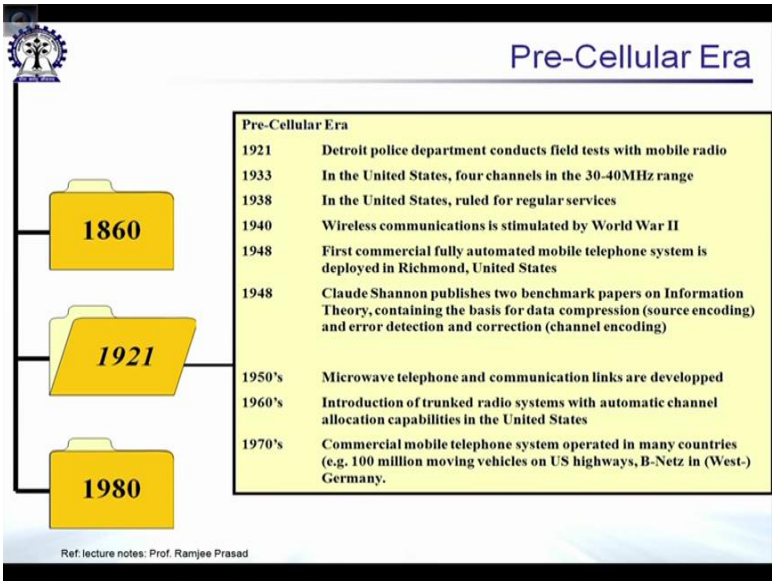
(Refer Slide Time: 07:02)



Moving further we have Guglielmo Marconi who demonstrated radio telegraphy and showed that radio communication could be used to send messages across the Atlantic across 2200 miles. This thing became even more important with the sinking of titanic where radio signals helped save a few life during the tragic incident. Thereafter it became even more or the importance of radio wave or radio communication became very very significant after that tragic incident.

As we move down further the next very important milestone was in 1948 where Claude Shannon produced the Mathematical Theory of Communication. It is often known or he is often called as the father of information theory which changed the way we look at communication systems. In our course on MIMO communication we will use quite a bit of information theoretic which results to derive the capacity limits of MIMO.

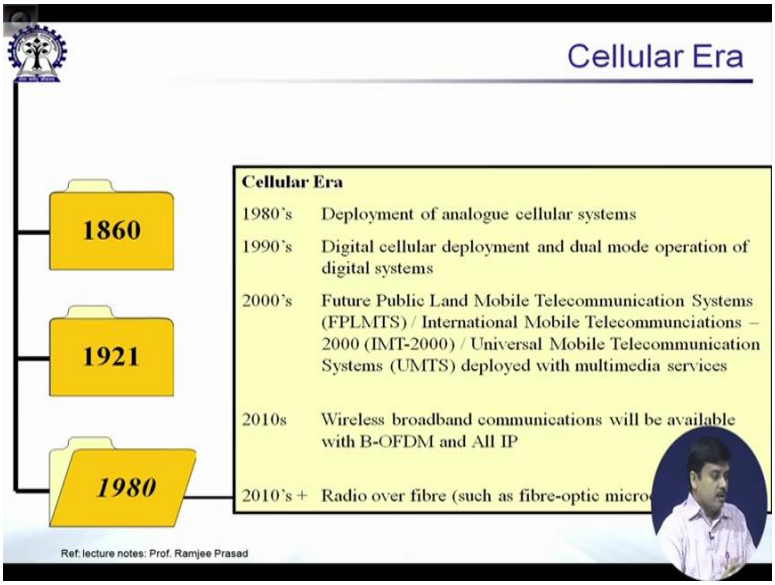
(Refer Slide Time: 08:06)



With this we move on the 1921 era or the second era which is pre-cellular and what we see is they were initial deployments of homeland security that is it was used by the police department. As it is necessity in that period there was wide spread use of card mobiles. However, these one not connected to the public speech telephone network. These networks more or less operated independently.

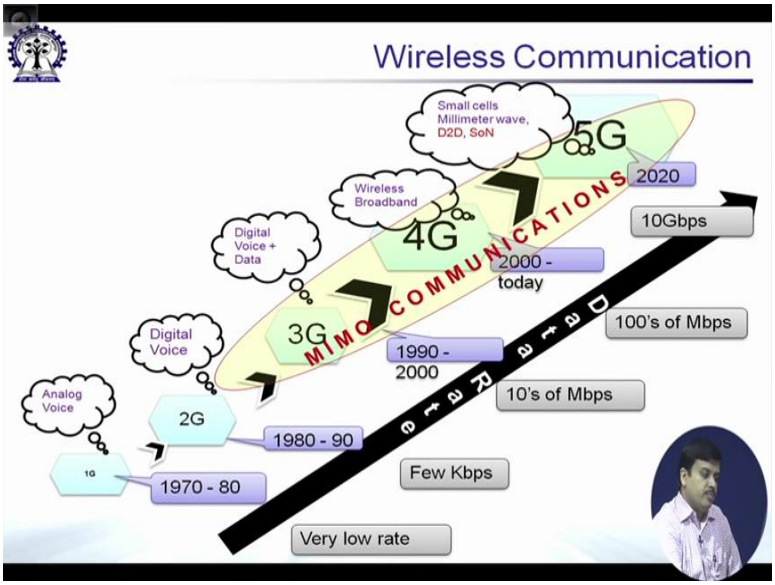
There were problems regarding hand off and there was limited zone of coverage in this region. Around 1940 during World War II he was huge stimulus to the radio communications, he was huge growth in development of handled devices using semiconductor transistors and so on.

(Refer Slide Time: 09:04)



Thereafter we move on to the next phase in which is beyond the 1980 which started with the deployment of analog cellular communication systems. The analog communication system were followed by digital cellular communication systems and then there was a future public land mobile telecommunication systems, and finally IMT-2000 which led further in 2010 the adoption of IMT advanced which uses OFDM as it is mentioned. Beyond 2010 as of now we are seeing deployments of 4G systems as well as active work is going on for 5G system.

(Refer Slide Time: 09:46)



If you look at the timeline how things are evolved initially we see that there was the 1G system which is around 1970s 1980s period fundamentally it was for analog communication and there was a voice was the main deciding factor of the design factor. There was no data communication supported using the system. Then as things moved on things wanted that improved we go on to the 2G system or the second generation system.

The second generation system is characterized by digital voice, so the biggest difference that we see is digital communications. However voice still remained as the most important traffic that is to be carried. While things were going from 2G to 3G there was a period which is sometimes referred to as 2.5G where data was introduced to be carried over mobile networks, systems which you were aware of such as GPRS, EDGE etcetera were introduced which would carry data within the same channel as the signals to be which were carried used to carry the voice signals.

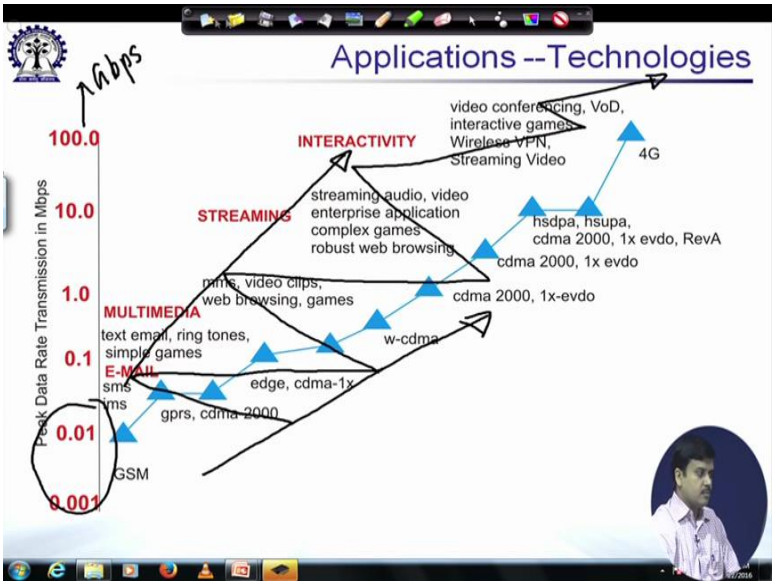
Around in the period of 1990 to 2000 3G was developed and the deployment of 3G was happening in the early period of 2001 onwards, there it is of course fully digital system. However, it introduced separate paths for voice and data. If we compared with what happened in the previous system in 2.5G there data was carried within the voice channel whereas in 3G systems there are separate path for voice separate path for data.

As things improved and people became used to data service or the need for data service became more and more important especially with the use of wide spread use of inkrnet. For all purposes right from entertainment to scientific and administration purposes there was more and more demand for data centric services, because of this when things moved on to fourth generation mobile communication system it became fundamentally data traffic oriented. To such extent that 4G was all IP as will be seen later this all IP's Because, primarily designed for data and voice would be carried as voice over IP also known as VOIP

Moving further today we are in the era that 5G is getting developed. Amongst many things which are moving towards the direction of 4G there have been development of small cells, there have been development to device to device communication, self organizing network. Some of the important things which 5G is expected to see are millimeter wave communication and massive MIMO amongst others.

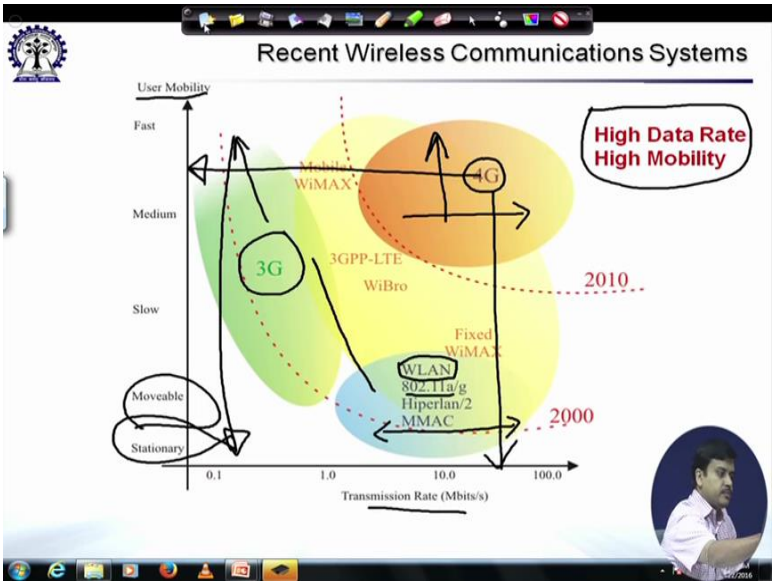
What we see is when things move to 4G it was one of the first experience of wireless broadband systems where data rates in the order of 100 Mbps were achievable. Iin this period between 3G 5G MIMO communications were introducing in to the systems and what we shall see in 5G is huge use of MIMO communication systems. 4G systems also use a lot of MIMO techniques, however there is limitation on the size of MIMO. In 5G we are expecting a variety of use of MIMO or that being one of the fundamental technology changes beyond earlier systems.

(Refer Slide Time: 14:34)



If you look at how these things have grown right from the GSM era to 4G era, what we see is that, the data rate requirement was very low in earlier systems. As data rate was supported with newer and newer systems new and new applications came up. So these went hand in hand, there was data rate supported there was a data service that required higher data rate more and more user started growing and this went on, on and on and today we have moved beyond 4G into the era of 5G. In this wave where this data rate requirements have gone beyond 100 Mbps to Gbps range.

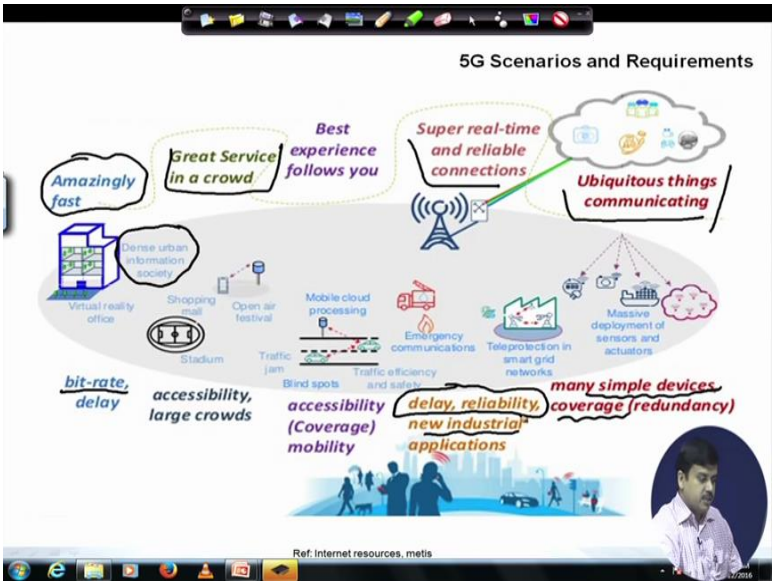
(Refer Slide Time: 15:38)



This picture shows how the 4G systems were started with. If we look at the chart the x axis talks about transmission rate, the y axis talks about user mobility. Some of the components shown over here are pretty well known to us if we take over look at wireless LAN system which can be described by the 820 dot 11 a or g standard or hiperlan or MMAC it supported n's of Mpbs. However, it is mainly for stationary or moveable notes. As we move towards the mobility axis we have 3G systems which clearly provides a huge support for high mobility, but at the same time there is no data rate support.

So, at that time the target for 4G was set that it should be high in mobility and high in data rate. If you look at this diagram it shows it is presence over here. And therefore the target to be achieved in 4G systems was high data rate under high mobility systems and that was quite achieved in such systems.

(Refer Slide Time: 17:07)



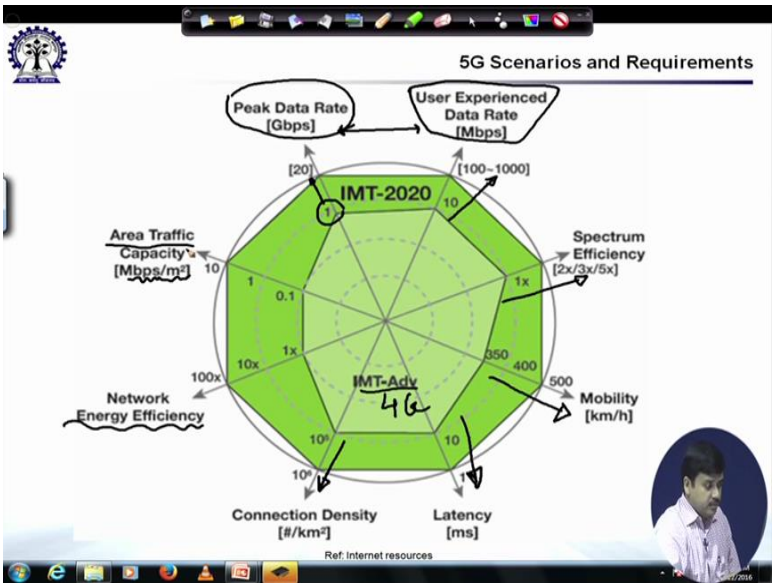
If we move on this particular slide of course I would should put a disclaimer that this is internet resource it is available at several places namely (Refer Time: 17:18) as well as Ericson and other places. So, I have used this internet picture to show with 5G scenarios and requirement.

What we see over here 5G is distinctly different from 4G. In the sense that there is a wide variety of requirements coming up and they could be summarized as amazingly fast that is how the description is, great service in crowd, best experience follows you super real time and reliable connection ubiquitous communications. Ubiquitous communication would mean internet of things machine to machine communications where millions and millions of devices would be connected.

There is another very important scenario which is the dense urban information society. Under this it is expected as a huge density of users would be present in the small location. There would be also requirement of services were delay and reliability would be very very critical. For example, industrial applications there would be always the requirement of bit rate, but along with this there would also be requirement of support on many simple devices there would be requirement of coverage.

Whereas, if you seen 4G one of the most common things that was running through all the system was requirement of high data rate communications.

(Refer Slide Time: 18:57)

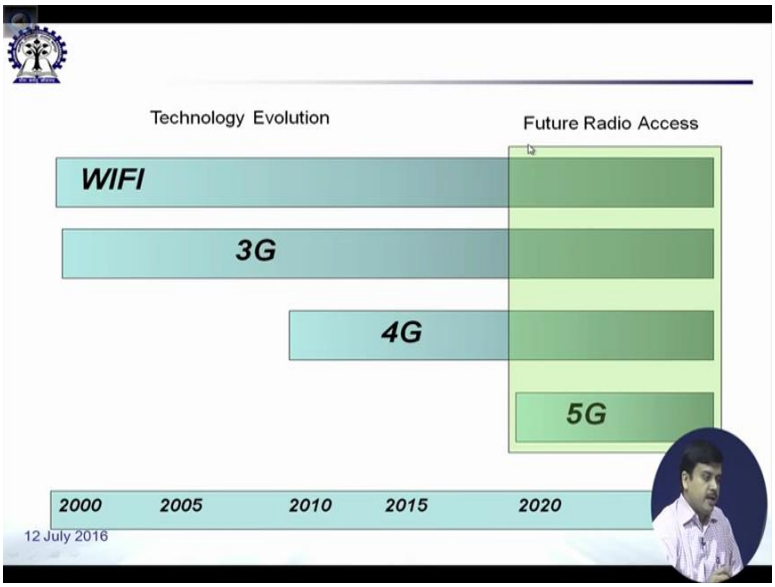


If you move further the requirements of 5G's would be specified in this way where we have the peak data rate requirement of in terms of GIGI bits per second. Moving beyond IMT 2020 or moving beyond IMT advance inner circle is IMT advance is IMT 2020 it is several times more on than Gbps or the peak (Refer Time: 19:22) supported by IMT advance. Why IMT advance we mean basically 4G systems. User data rate moving from 10 of Mbps to 100 of Mbps the difference between peak and user data can be summarized as peak data rate is a sum of user through put within a cell or supported by an axis point. Whereas, user data rate is what one particular user would experience.

Spectrum efficiency is expected to be several times more than that achieved in IMT advance system, it is expected to provide higher mobility support, it is expected to provide reduced latency to support real time systems or cyber physical systems, huge increase in connection density from in order of from 10 to the power of 5 and 10 to the power of 6 energy efficiency is one of the other important aspects of 5G systems area traffic capacity which is defined in terms of bits per second per metered square.

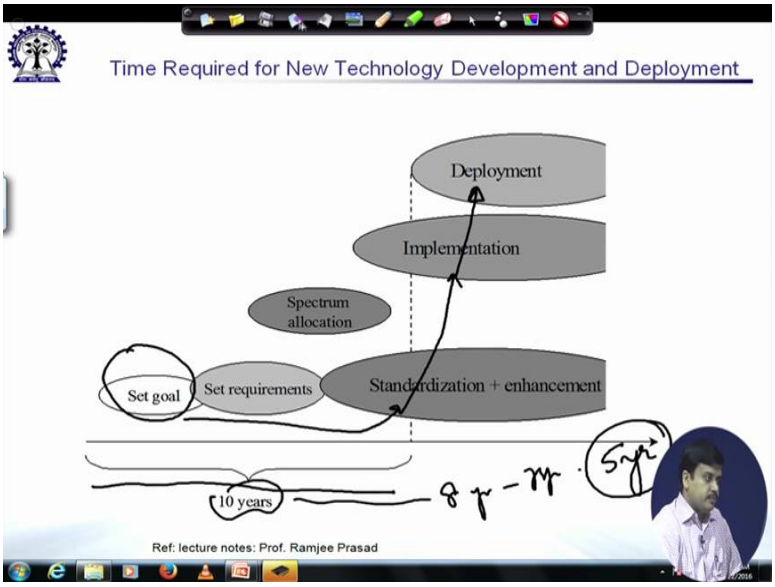
So, these are some of the important performance matrix by which 5G systems would be measured.

(Refer Slide Time: 20:40)



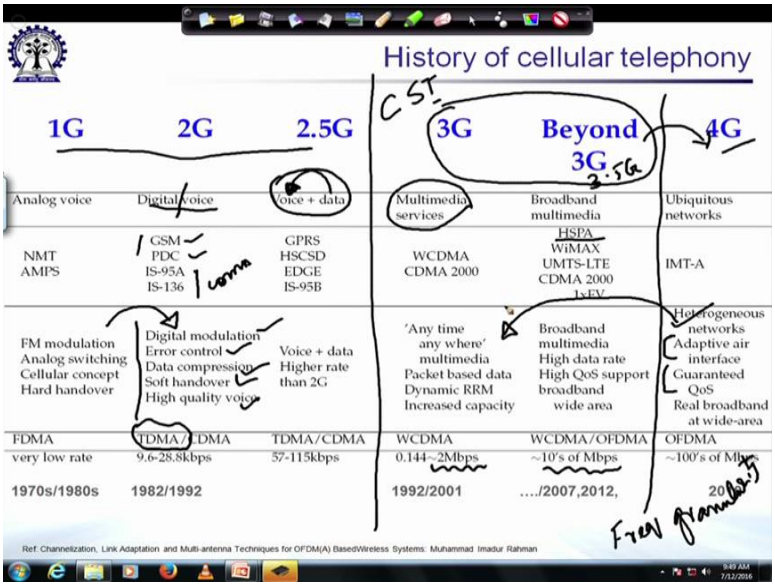
If you look at the timeline of broadband technologies things have been developed from 2000 to the period of 2015 where activities of 5G system have started to grow.

(Refer Slide Time: 20:54)



If you take a typical look at how things are developed or how this particular standards are developed what we see typically there used to be 10 years cycle from the time the goal was set to work on a particular technology and by the time the standardization would happen there would be implementation trials and finally deployment. However, what we see today this 10 year period is getting reduced with periods of 8 years, 7 years, and sometimes even people say it is in the period of 5 years which is really-really short. And if you look at the number of changes that are happening is really-really great compared to earlier systems.

(Refer Slide Time: 21:51)



Moving on further this particular slide we summarized the technology changes that have happened from 1G to 4G. We do not summarize what is there in 5G because 5G is not clearly defined it is under development so we hope that around 2020 we would get the final specifications and technology solutions of 5G. If we look at 1G we seen it is mainly analog and voice as it was said there were some of the systems one of them was AMPS which is widely known. There was introduced the technology of FM modulation which is high (Refer Time: 22:37) to noise. Cellular concepts were also introduced and handover hard handover concepts were also introduced.

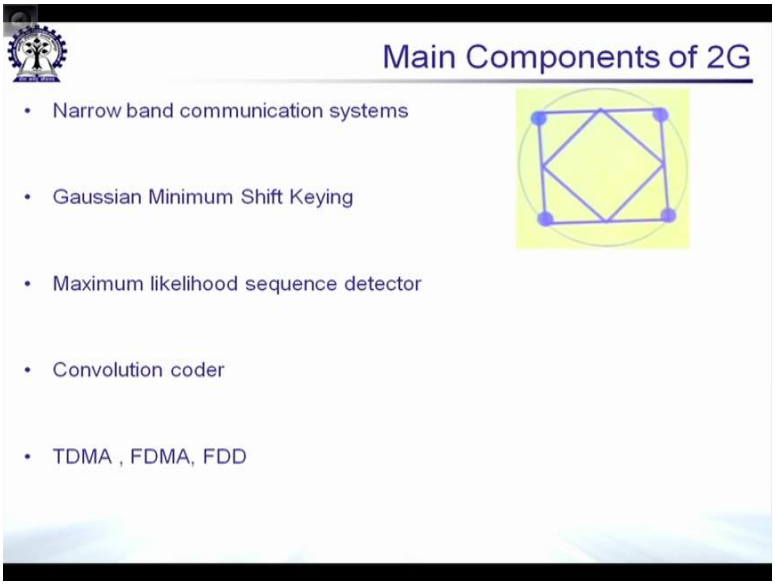
Now, some of these concepts were very very critical in the success of cellular communication in today. We see this knowledge have been extended right through to 4G systems. Next we take a look at the 2G system which is again digital as well as voice GSM, PDC, IS-95 which are CDMA based systems were used. GSM and PDC we see they were time division multiple axis systems that was. Of course, digital modulation there was error correction coding there was data compression soft handover and voice quality.

If we compare the changes between first generation and second generation it was significant technological developments that are happened in that period. As we move further as said earlier there was voice and data which were introduced. However, the data was carried within the voice channel no separate channel was available for carrying data. As we moved further with 3G data became one of the important things and multimedia services gained prominence. And there data rate requirement were being written down for on the first times were initial targets were 2 Mbps.

Moving beyond 3G or sometimes also known as 3.5G systems there we see high speed packet access and other systems where tens of Mbps of data rates were achieved. They used white band CDMA, band width of 5 mega hertz. Sometimes OFDM a is also called 3.5G systems where (Refer Time: 24:33) for instance is also known as 3.5G and IMT advance is called as 4G systems. In 3G systems or beyond 3G systems we will see some of the very important changes that have happened beyond 2G. In the sense channel state information were been used to transmit data to multiple users whereas in 1G to 2G it was mostly static link adjustments.

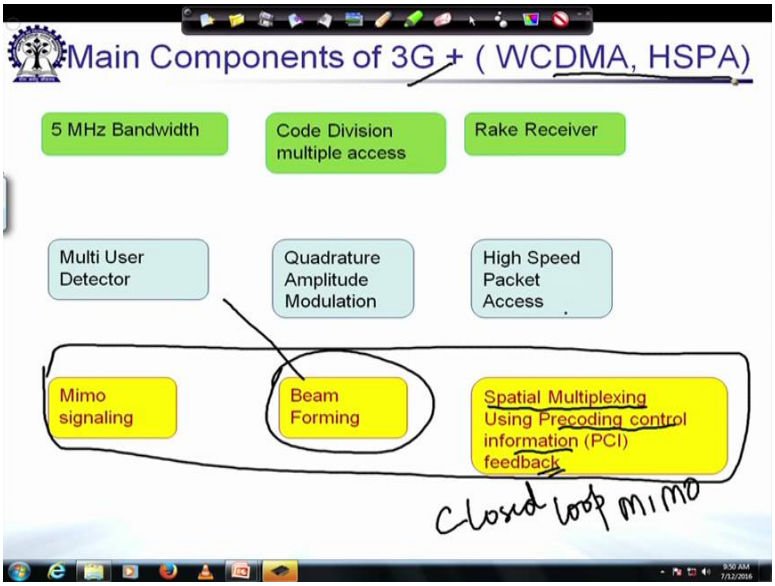
In 4G the major difference between these systems and 4G is what we saw as there was access to frequency granularity. There was guaranteed QoS support, there was adaptive air interface, along which there was heterogeneous networks. The heterogeneous networks were supported in 4G, however later it was also supported in 3G systems for instance in the form of (Refer Time: 25:40). If we look at the data rate that was supported by the systems what we see is the data rates ranged from a few kilo bits per seconds upto hundreds of Mbps. And 4G systems are a reality today.

(Refer Slide Time: 26:01)



If you now take a look at the 2G the important components of 2G were narrow band communication systems, Gaussian minimum shift keying was used, maximum likelihood sequence detector was used, time division and frequency division multiple access and FDD systems were used.

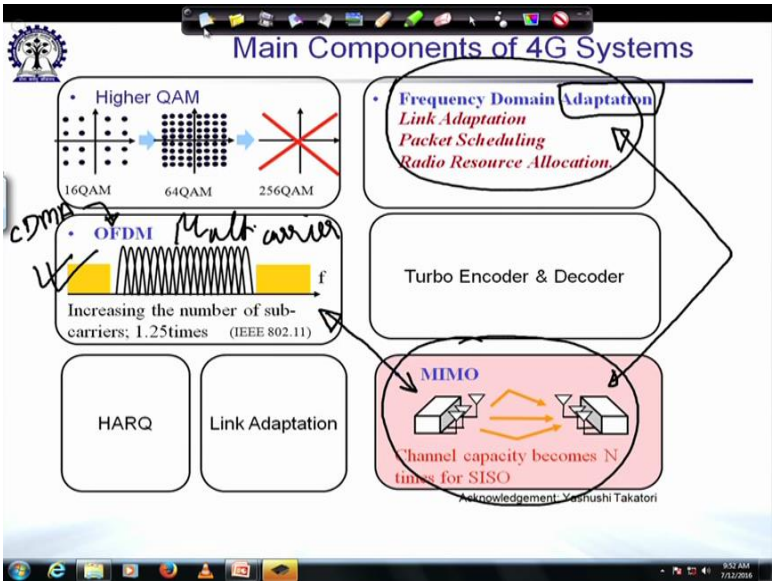
(Refer Slide Time: 26:21)



In 3G the major difference is what 5 mega hertz bandwidth beyond moving beyond narrow band systems. This code division multiple access is rake receiver was multi user detection, QAM; quadrature amplitude modulation and high speed packet access systems. Also, interestingly we see that MIMO signaling started to appear in 3G system, It appear as beam forming which could also be used in multi user detector, it also supports special multiplexing as well as pre-coding control information by feedback. Or what we have in modern days notation closed loop MIMO.

So, when I mean in 3G plus I actually mean WCDMA plus HSPA, not limited just WCDMA systems.

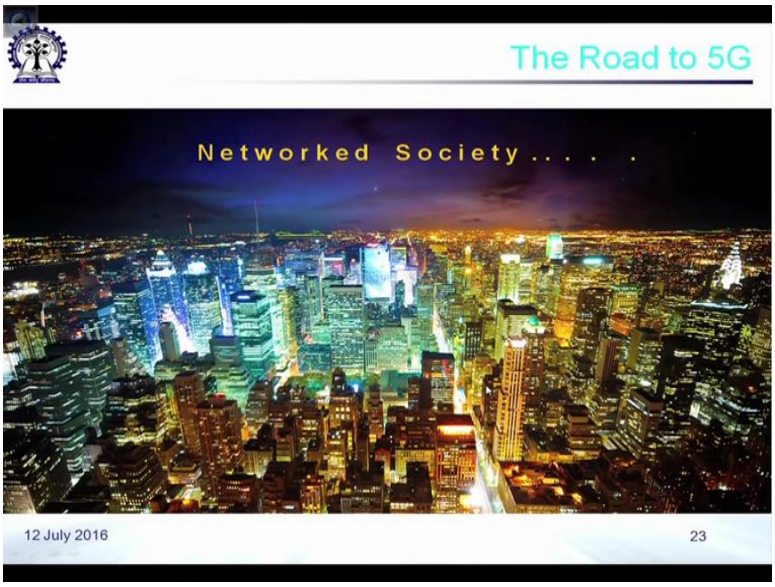
(Refer Slide Time: 27:26)



If we look at the main components of 4G again we see the prominence of MIMO techniques coming into picture along with frequency domain link adaptation or frequency domain radio resource allocation. So, these two together forms the major gain provider of 4G systems compared to earlier communication systems. What we see over here is adaptation is one of the major things that were supported to 4G systems. Of course, we have OFDM this is not mentioned because this is so well known today.

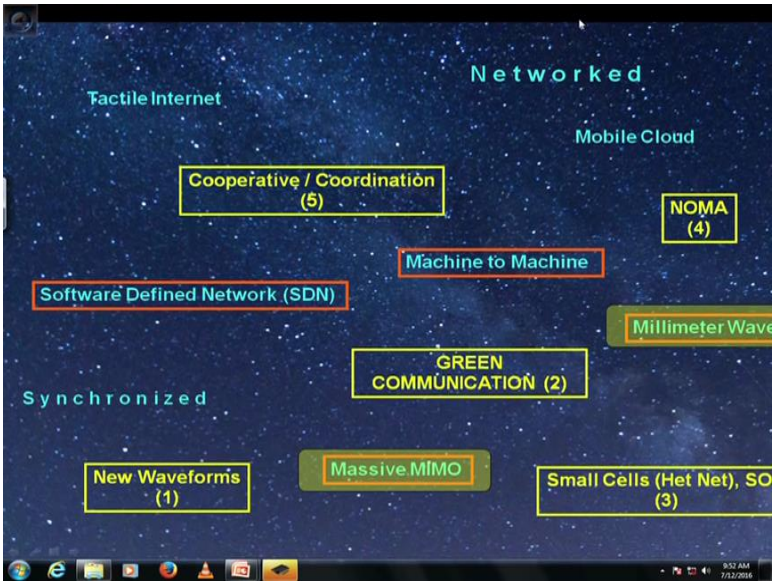
So, beyond CDMA the transmission technology was changed OFDM based or multi carrier based. And somehow this OFDM had the natural affinity to support MIMO communications. So, everything was as if in place on 4G systems.

(Refer Slide Time: 28:42)



If we move further, we move on towards going appear in 5G. 5G there is a consensus it will be a network society where everything is going to be connected.

(Refer Slide Time: 28:51)



Some of the important technical solutions that are going to appear in 5G are as listed here. And what we see as identified some of the technology enablers for 5G are massive MIMO, and millimeter wave amongst others.

So, if we summarize at this point what we see is that MIMO communications have been one of the most important techniques which have been providing us with higher data rate as well as giving quality of service. MIMO communications have been introduced in 3G systems it is there predominantly in 4G systems, and what we find in 5G systems one of the most important or early versions of 5G systems that we are expect into see would be supporting the massive MIMO communication. And hopefully the millimeter wave to go along with massive MIMO which appears to be one of the enablers.

So, what we can say is that MIMO communication techniques what we are going to learn in this particular course is very pertinent and very important which will provide significant development in the technologies that are present are going to come and hopefully many more new things that will happen in future.

Thank you.