Evolution of Air Interface Towards 5G
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Lecture – 10
Requirements and Scenarious of 5G (Contd.)

Welcome, to the lectures on Evolution of Air Interface Towards 5G. So, currently we are reviewing the minimum requirements for IMT 2020 or 5G.

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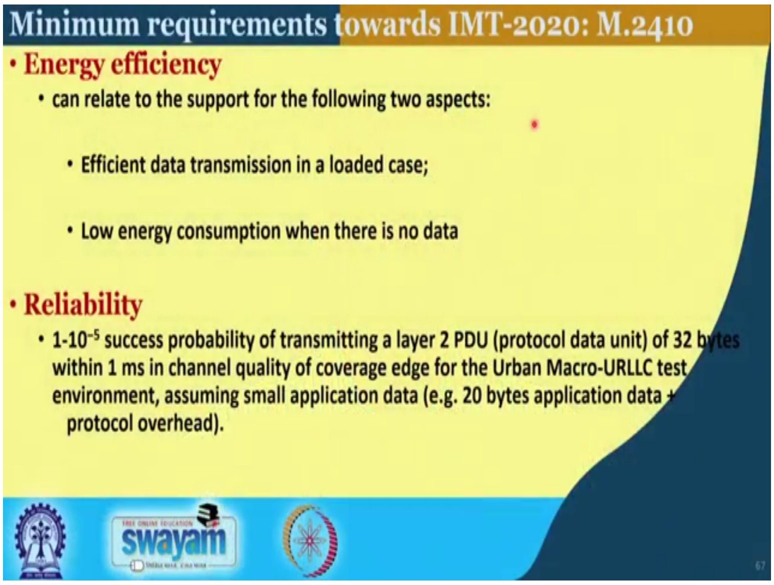

And in the previous lecture we were seeing some of the requirements. So, here we continue on that. So, as was briefly mentioned that energy efficiency is an important metric which we should be taking care of. And in that efficient data transmission in loaded case is something which we, we should look at. As well as low energy consumption when there is no data.

So, these are the two different aspects which are to be looked at and we will try to look at some of these; in the later part of the course. Reliability is in the range of 1 minus 10 to the power of minus 5 success probability, that is very huge success probability for layer 2 PDU of 32 bytes within 1 millisecond in channel quality of coverage edge for the urban macro URLLC test environment, assuming small application data.

So, basically it talks about huge success probability when you talk of reliability, a packet delivery probability; that means, with a very large number of packets most of it is successfully delivered within the channel conditions of the test environment as would be specified. So, this alter reliable low latency communication test scenario which is of interest under this condition a very high success probabilities is required during low latency, a very low latency has to be satisfied.

And there is certain packet size which is to be a specified and probably larger packet size would be also ok, but one has to check with the latency requirements. So, such requirements are usually with respect to control and command applications. So, then large packet size is generally not the situation in that case which has to be delivered within short delay.

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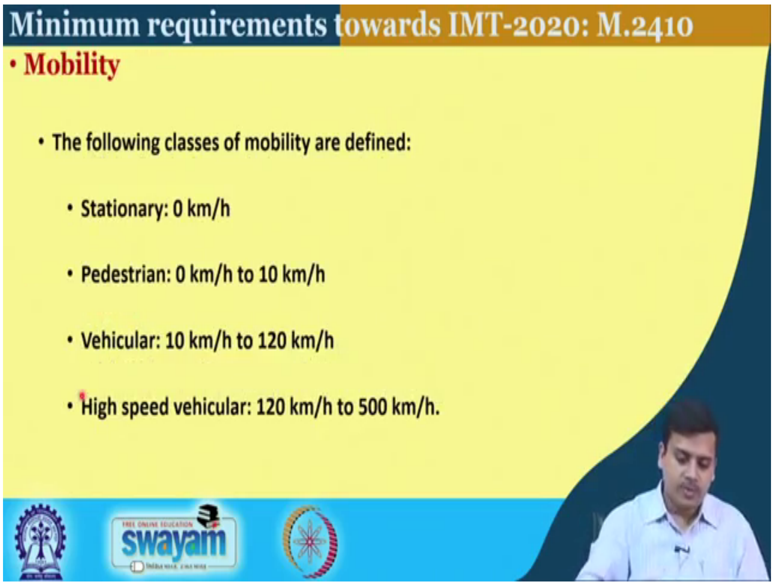

So, moving beyond this was one of the last things that we were seeing in the previous lecture. So, here mobility has been specified in multiple classes like; stationery, pedestrian, vehicular, and high speed vehicular. So, there are different range of velocity stationeries of course, 0 km per hour, a pedestrian is like walking. Vehicular is with the traffic with cards and others other things moving around in city and urban areas, semi urban area.

Whereas high speed vehicular is kind of moving on highways and high speed trains so speed up to 500 km per hour have to be supported. So, what this essentially means is that this influences Doppler and further when we have higher and higher frequency bands the cumulative effects become terrific. So, that has to be addressed in some of these solutions.

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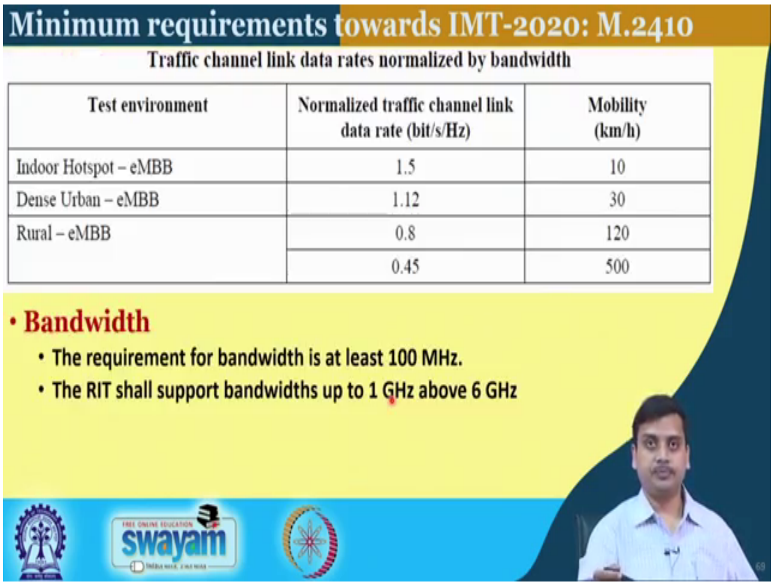

So, the traffic channel link data rates normalized by bandwidth have been specified with different mobility conditions. So, what is it saying like under indoor condition; one has to take the pedestrian and the normalize traffic channel link data it is bits per second by hertz is 1.5; whereas in rural the mobility is 120 and 500 kilometers per hour two different cases are have been have been given. And the spectral efficiency of bits per second per hertz is given by this numbers. So, what we essentially sees that as your mobility increases the spectral efficiency decreases for all reasons of communication and channel properties that keep on getting worse and worse when higher and higher mobility comes into play.

So, what it also says that it should support bandwidth of 1 gigahertz above 6 gigahertz. So, when you talk 1 millimeter wave band this becomes 1 gigahertz bandwidth is required to be supported when we give the specification of bandwidth. And at least 100 megahertz have to be supported in the other bands that, was the substance gigahertz. So, if you go to higher spectrum and we add mobility to that it becomes a terrible situation to address.

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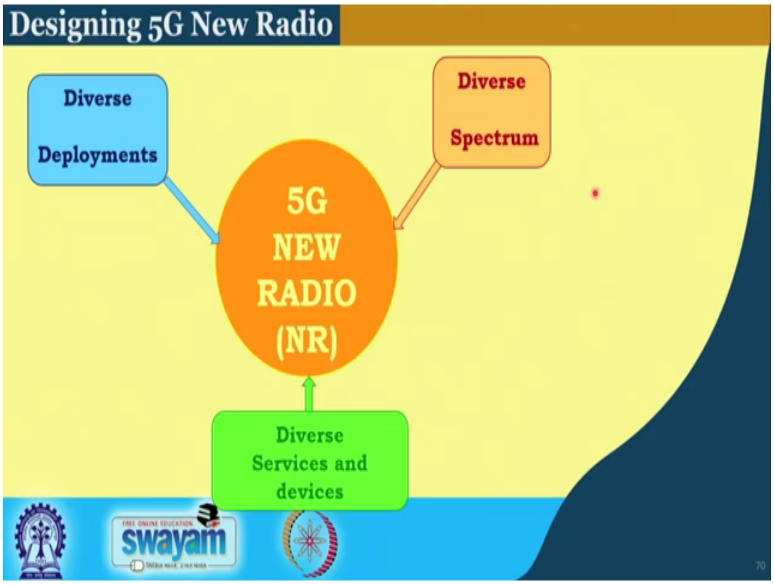

So, what we summarize now all our discussion till date as what we could see is that there are diverse deployment scenarios. We have seen at least three different deployment conditions there is diverse spectrum. We have clearly seen here that one is below the sub 6 gigahertz and the other is above 6 gigahertz which is usually in the millimeter band. And when you go to the 30 gigahertz or 50 gigahertz or 60 gigahertz band of spectrum the propagation characteristics of different the device characteristics are different.

So, this spectrum actually makes provides make lot of impact on the system design as well as not only is your device get influenced, but the available bandwidth is different. And since the bandwidth is different therefore, again you have lot of opportunity to play around with the design of the system.

So, the spectrum is not a single spectrum nor is it uniform it is kind of quite different which is to be present. And they would be variety of services and variety of devices like; machine type communication, smart phones and all things would be present. So, what we are seeing is that by one single technology, one is required to serve difference deployment scenarios, different spectrum and different devices and services and this gives birth to the new radio also referred to as the NR.

So, there on we will start looking at some of the new aspects which have been introduced. But we will lay our foundation strong by revisiting the things which have happened earlier because, what things are going to come in future have their foundation on what is happened in the past. So, we will kind of go back and forth in building the foundation as well as looking into the future technologies.

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So, in this particular screen or in this particular slide we have more or less summarized some of the important aspects or some of the notable contents which come as part of air interface for the next generation. So, the self organizing networks have been there and they will still remain very critical for the fifth generation system. One very important thing that is come up is scalable OFDM wave numerology which is part of the new radio which we will discuss. Multiuser Massive MIMO some sometimes this is an extrovert put along with massive MIMO.

But this class this clarifies the entire details this is also an important part of the fifth generation system. LDPC coding has already been there are more error correction codes which are potentially capable of providing the necessary benefits that are required. Low latency slot structured design. So, basically the to support the low latency one has to redesign the frame structure which is otherwise not supporting low latency; that means, if we look back at the LT advanced or the fourth generation system it is not capable of supporting a very low latency of 1 millisecond as desired in this.

Adaptive beam forming and beam tracking especially in case of millimeter wave is also a very very important. So, we will get some time to look into these aspects. Non orthogonal multiple access, data offloading into heterogeneous networks so these are some of the important modifications or enhancement or improvement in the radio access network or overall radio access technology which drive the future generation or the fifth generation mobile communication systems.

So, with this we more or less close our discussion on the understanding of how the requirements come up. And how things have changed from previous generation right from second generation to fifth generation with one of the important motives is, to understand or to kind of train ourselves and kind of predict the future. That what is expected or how things are going to grow because, we have seen this industry for quite many decades now. And the other aspect is also to highlight how the numbers have changed and what new requirements of come in as well as the deployment scenarios are becoming different.

So, I mean in overall this entire growth in all possible dimensions, if you look back in what we have discussed some of the early generation systems had only few parameters and only countable objectives to meet. Whereas in the newest generation of a technologies the number of parameters to be observed or measured has increased phenomenally as well as the requirements of also grown many folds. And if you check back with the amount of data that expected to be flowing around in these networks it is I mean and is beyond the normal imagination it is a huge amount of data. And, what has what is the outcome of such things is that we have been able to get new technologies new solution ah.

So, there was a challenge and the challenge has been met quite successfully and a lot of development has happened in the technology front which we hope is only going to help us help us the society evolve into a better human society and more safer and probably much superior being in the future. So, with this we continue on this particular lecture and we will look at some other aspects that are necessary as part of the curriculum yes. So, we continue with the next lecture.

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So, in the next part of what we have to cover somehow we were not well synchronized with the timelines for each of the letters lot, but that does not matter we will continue. So, far we have seen the requirements and specifications we also see in the requirements for the fifth generation. And now we are supposed to look into the solutions for the fifth generation, but; however, I thought it pertinent that will look back office at some of the older solutions and some of the foundation.

Now the reason is that if we are supposed to begin with the study of waveforms. Now when we look at the waveforms when we look at the waveforms for the fifth generation we can get a jump start and get into things. But we also have said that we also want to look at some of the front runners in the waveform technology that were in the contention towards being air interface. Here it is important to note that how things have evolved over time when the second generation came in there was the TDMA, FDMA approach or the GMSK which was the fundamental waveform.

At that time the spread spectrum communication was also well known and it was also being discussed. But however, the with consensus people choose to remain with a TDMA FDMA and they came up with GMSK. They rejected the spread spectrum method of communication which could provide us the CDMA technology. When the third generation solutions were been discussed then the multi carrier or OFDM based technology was already available. Now at that time spread spectrum or CDMA technology was a little bit more mature.

And then if you look back into the waveforms for the third generation it was spread spectrum communication it is rather CDMA communication and it is also known as WCDMA white back CDMA. Whereas, OFDM although was pretty much available was rejected as the candidate wave form. When we move forward and go into the fifth generation what we find is that in of 2010 to 2015-16 there have been several candidate technologies which were in the (Refer Time: 12:50). And they were like generalized frequency division multiplexing, filter bank multicarrier, UFMC and many other windows OFDM and many other proposals which have been there.

However, what has been accepted is large largely of variant of OFDM which is the smallest scalable numerology structure of OFDM. So, what we see is that at every stage some technologies which are new which can contend with an existing technology or more mature technology, are proposed, their well compared and usually where this more consensus it is taken. So, it is very vital that we also look at the wave forms which were there and containing for five fifth generation can you get technology.

Because there is a high potential that one of them will become air interface for next generation not simply by virtue of the progression of history. But these were being developed by a large number of people over a long period of time because they had felt that OFDM has certain shortcomings which need to be addressed. So, over the next few years it is further expected that these waveforms and these technologies are even improved beyond what they are available today more things that added to them.

So, that they are more matured and they can probably replace the existing OFDM and overcome someday shortcomings which OFDM has. Now incidentally some of the important waveforms in this category have their roots in the second generation system and some of them like filter band multi carrier and others I have a special property by which the out of band radiation. That means, when the signal goes out into the air interface then the amount of signal that leaks outside it is bandwidth is much lesser in the schemes than in OFDM.

And if we look back at what happened in the second generation that is the GMSK; it is one of the most bandwidth efficient signaling techniques. And when we will look at some of the base line structures and if you study them it will be easier and for us to study the filter bank multicarrier and other setups because, it is built on the same platform. So, in order to create a setup the platform we decided that a let us look into the basics and through which we will cover the earlier generation. As well as give us it will give us the premise and foundation for looking into the future generation systems which are yet to come in.

So, with this we set up the basic signal model. The other intention for us to look into this basic signal model is that they would you many participants who have been working with lot of advanced protocols and mechanisms. But when we talk about signals we need to get back to the basic framework the basic way of writing the expressions so that it so, that we benefit end of the day by revisiting some of the original things so that we get trained. And finally, we are able to write the newer solutions by our-self.

So, for that we need to relook at the foundation we will not really going to lot of great details, but only the important foundation that is necessary to help us carry through the important parts of this particular course. So, with this let us get into the basic signal model.

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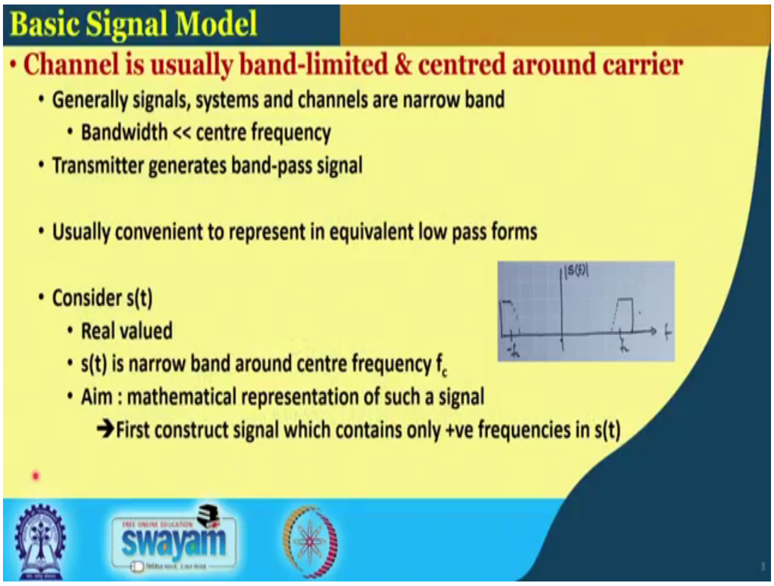

So, typically when we communicate the channel is usually band limited I mean that is kind of understood by all of us. We do not have been fine and bandwidth to transfer the given signal because the channel is split into smaller-smaller chunks and each particular service is given one particular set of bandwidth that is pretty well known to many people. And those were new in this particular domain just taken example of GSM where each of the career occupies 200 kilohertz overall on 1.25 megahertz that is kind of given for communication. If you look at the fourth or the fifth generation is kind of overall 5 megahertz is given for anyone communication band. So, it is always decide the signal occupies a certain finite bandwidth.

And hence we usually say that the channel is the band limited and of course, it is centred around the carrier frequency is a carrier frequency which is associated with the brand. And when we talk about the subsets gigahertz we also mention the centre frequency, when we talk about the millimeter wave we also mention the centre frequency. So, the carrier frequency is kind of the centre of frequency. So, signals and systems and channels are usually narrowband.

And so we are talking about narrowband systems in narrowband systems the bandwidth of the system should be much much less than the centre frequency. So, rule of thumb could be 10 percent, but usually it is even smaller than that. So, we are generally going into the realm of narrowband systems that is something we should remember. The transmitter generate a band pass signal that is again something many problem students would also participating in this particular course and our intention is to set things proper.

So, just to get things in place be the band pass signal is essentially the signal which has a certain band centred around a carrier and carrier is not 0 alright. So, that is what is meant by band pass and when the carrier is 0 and you have your signal which is spanning around the 0. So, it is usually the bass band of the low pass signal that is what is referred to we will see them in the in the model. So, usually it is convenient to represent in equivalent low pass forms of this is what you usually study in digital communications; that is when we are studying systems we can create a signal which we can I convert to any frequency of our choice. At the receiver we have to down convert the frequency and then do the baseband processing.

So, what is very important is that we will look at the baseband signal processing part or the baseband signal model part. Because, if it is only the carrier and we can choose any value of the carrier then we should brother focus on the basement part and when necessary we can uplift carrier to a particular centre frequency and down converted at the receiver. However, we will not put in this particular model, but we will see later on is that since the signal is band pass it passes through a band pass channel to analyze the overall effect we should also have the equivalent low pass of the channel. And so that we can study the entire transmitter channel receiver in the equivalent low pass form.

So, one of our object is here is to start with this setup so that all of us who are on board are able to handle this setup. And understand that many of you already know this, but I also believe that the some of us who would who would be benefited with this basic analysis. So, we consider s t as the signal which is real valued and s t is narrowband and centred around the carrier frequency f c. So, the aim is to get the mathematical expression of such a signal that is that is what we are interested to do. So, we first construct a signal which contains only the positive frequencies is in s t.

So, that is the first step towards getting that so; that means, your S f which is the spectrum of s t is having plus f c and minus f c and signal is around f c ok. So, the f c is the carrier frequency the signal is somewhere around f c and it can have particular structure of the spectrum of occupancy. So, when we say that we want only the positive set of frequency is; that means, we are interested in only this frequencies and the other reason is that from this you can regenerate them. So, it is probably good enough to do with the positive set of frequencies.

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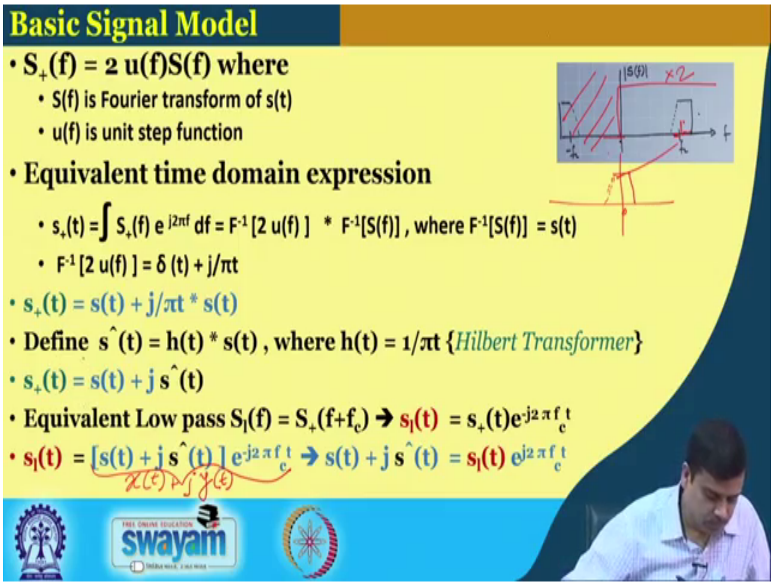

So, S plus of f which the plus indicate the positive frequencies and S f indicates the spectrum of s of t or is the Fourier transform of s t; is two u f times S f. So, where S f is the Fourier transform and u f is the unit step function in the frequency domain. So, that means, you take only the right hand portion and you do not consider the left hand portion. So, that means, as if we do not consider this, but since you considered only half of them because if taken the unit step function, you multiply by 2 so that the total power of the total energy is conserved right.

So, that is why we have to u f S f in order to describe the signal which is not a to describe the signal which contains the positive frequencies. The equivalent time domain expression would be s plus of t which is the inverse Fourier transform of S f or S plus of f. So, which is the inverse Fourier transform of S plus of f, if you look at it; it is basically these two things these two things. So, is convolution of the inverse Fourier transform of to u f and that of S f. Now we already know that the inverse Fourier transform of S f it s t or S f is the Fourier transform s t by definition that is what we have over here that is what is have been given over here.

So therefore, it is a convolution of two time domain signals the inverse Fourier transform of 2 u of f can be written as delta t which is the delta function plus j upon pi t. So, what we have is this entire function convolved with S t this is S t. So, delta function convolved with s t is s t and this particular is expression is something which we should look at. So, here we will define s hat of t as ht convolved with s t where h t is defined as 1 upon pi t. So, see that you have one upon pi t here if I define this as h t then h t convolved with s t is defined as h hat of t. So, this h t which is 1 by pi t is usually known as the Hilbert transformer right which is a 90 degree phase shift.

So, s plus of t can be written as s of t plus j s hat of t going by this expression. If you use this particular line in the previous you get s plus of t plus j s cap or s hat of t. So, this we have obtained as the inverse Fourier transform of s plus of f. So, essential in this is the time domain signal which contains the positive frequencies only; the equivalent low pass that is S l of f ok.

So; that means, we want equivalent low pass from this is very easy that S plus f plus f c; that means, whatever is if I put S l of 0 we get s plus of f c correct so; that means, this is down converting your s plus of to S l right. So, that it is removing the effect of f c right.

So, this is the low pass equivalent form. So, if I put f as the value which is just a little bit positive that mean delta positive this is S l of f is basically s plus of f c plus the little bit. That means, in other words it is nothing, but this particular point. So, like that we can keep increasing values of f and we can collect all the values of f over here and all the values of f over here. So, essentially speaking S l of f would appear like this central ground 0.

So, that S l of f and then we can get the S l t that is time domain representation by simply getting from this which is S plus of t by Fourier transform properties e to the power of minus j 2 pi f c t which is also representing a down conversion operation. And which is equivalent I mean this also is equivalent to the expression of down conversion which is done at the receiver. So, that frequency domain translation of frequency in time domain it is simply the down conversion on multiplication by e to the power of j.

So, this is by virtue of Fourier relationship. So, s l of t that is what we have is the low pass equivalent of the positive set of frequencies of the signal or the signal containing only the positive frequencies; can now be written as s plus of t. We have obtained is plus of t which is over here that is s t plus j s cup of t. And we have the remaining term e to the power of minus j 2 pi of s t. So, what we have over here in other words we could also right that s t plus j s cap of t is s l t e to the power of j 2 pi of s t. So that means s l t is modulated and here what is see this demodulated.

So, this is like up conversion of the low pass equivalent form of the message and this is the structure as it should be. And it is kind of a single sideband transmission that what you have studied earlier in analogue communication systems and other courses. So, this is the baseline structure with some of you have already done and those who still remember it is a revision of those concepts. And those who have problem forgot I mean it is a good way to recapitulate some of the things.

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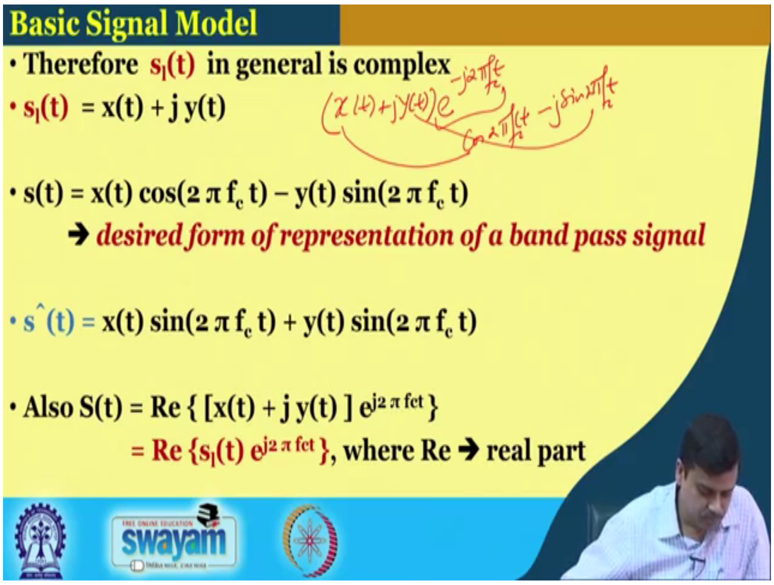

So, therefore, what we see is that s l is in general a complex nature. So, what we see over here s l is having here j and there is e to the power of minus j. So, in general this is a complex in nature is this is complex in nature I could write s l of t as generically x t plus j y t because this is of complex form. But we have seen. So, I could say that let me write it in this form then I have to connect what would be the relationship of x t with s t and y t with s t. So, we are saying that let this whole thing quickly, let me take this whole thing let us write it as x t plus j y t right.

This is what we have mentioned yeah and this is exactly what is written over here. So, if we replace this into the previous equation what we are going to get is s t equals to x t cos 2 pi f c t minus y sin 2 pi f c t. So, this is also straight forward because you can clearly see that you would be writing that x t plus j y t e to the power of minus j 2 pi f c t and this would expand as cos 2 pi f c t minus j sin 2 pi f c t.

So, simply x t cost 2 pi f c t would come over there and y t sin 2 pi f c t would come over there. So, then you have to go back to the previous page and equate the different terms that is there. So, we have s l t with this and we have said that s t is real valued. So, if you take the real valued part of this then. So, basically we are going to have the other terms which is the j y t cos t and j x t sin t. So, the real value terms are x t cos 2 pi of f c t and y t sin 2 pi of f c t.

So, this is the real value terms that you encounter with s t and. So, this is what is the expression of s l t right and s cap of t is basically the other component which is the j component. So, what we have over here is essentially the s of t in the desired form as we required. So, what we get is there is that the transmitted signal there is a cosine carrier is a sign carrier which are quadrature in nature. And we have signal bearing form that is x t and y t which is going to carrier signal.

So, this is a basic structure on which we have to build up on for all possible future expressions. And I think it is very vital that we abide by this framework. So, that all representations that we will do will fall into place. So, when we have s cap of t we have already discussed this. So, you could also write s t what you have done as the real part of this particular thing right; which we have actually done it over here. So, that we could say that it is s l t e to the power of j 2 pi of f c t right. So, when you say it is s l t e to the power of j 2 pi f c t ah.

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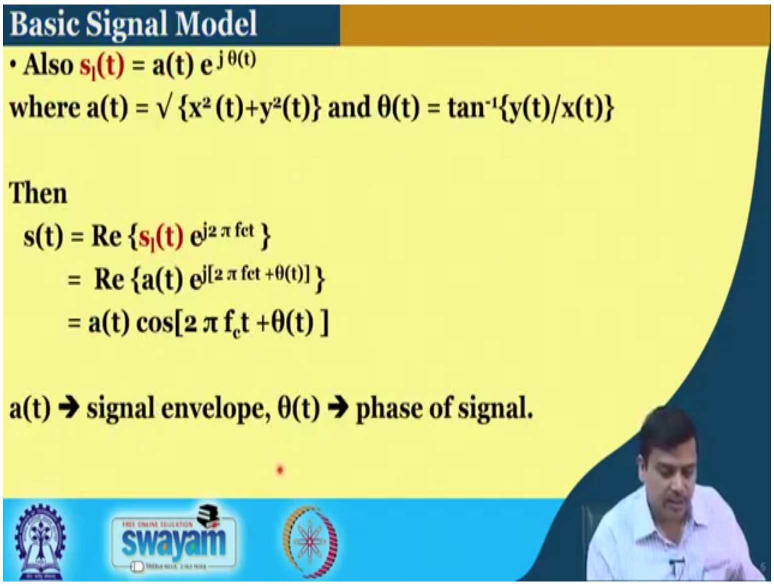

We could also say that we let us right s l t which is in general complex as a t e to the power of j theta t in general we can write that. So, where a t is square root of x square t plus y square t and theta is tan inverse y t. In that case s t can be written as real part of this already you have seen in the previous page and a t e to the power of j 2 p i theta f c plus theta t. So, if shifting the real part; a is real because it is the amplitude over here cos 2 pi f c t plus theta t.

So, this is the familiar form which we are generally used to when we are discussing signals. And this clearly brings out all possible ways of handling the particular signal because here we have a t which you can modulate and you get amplitude modulation you modulate theta you will get phase modulation. You also access to carrier that is and you get frequency modulation.

So, we would like to stop the discussion of the signal model over here now. And in the upcoming next lecture; we will carry on with this basic framework to develop the structures that were there earlier. As well as it will provide us the premise to look into the structures or the signal model that have been there in the IMT advanced, as well as that are going to appear in IMT 2020.

Thank you.