Advanced 3G & 4G Wireless Communication
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Lecture - 39
Introduction to Teletraffic Theory

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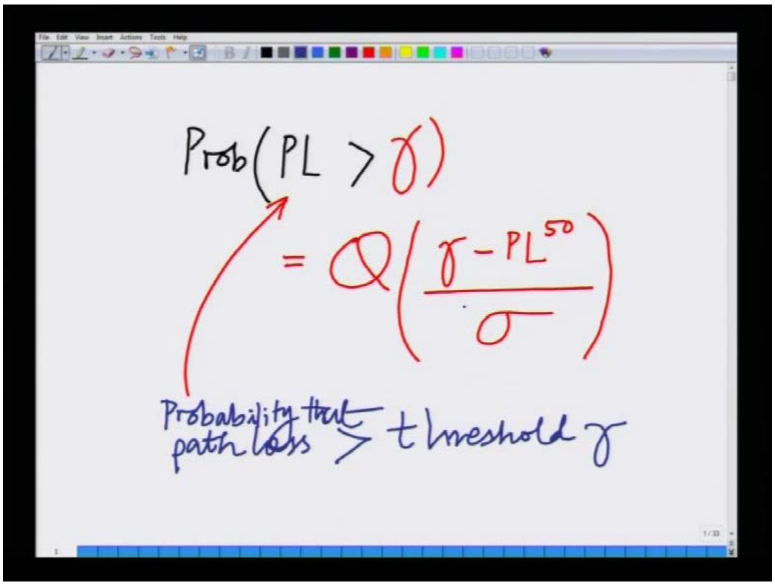

Hello, welcome to another lecture in the course on 3G 4G wireless communication systems. In the last lecture, we completed our discussion on the log normal shadowing, and we said given a median path loss P L 50, that is 50 th percentile path loss. The probability that the path loss is greater than the threshold gamma is given as Q gamma minus the 50 th percentile path loss divided by sigma, where sigma is the deviation of the log normal shadowing.

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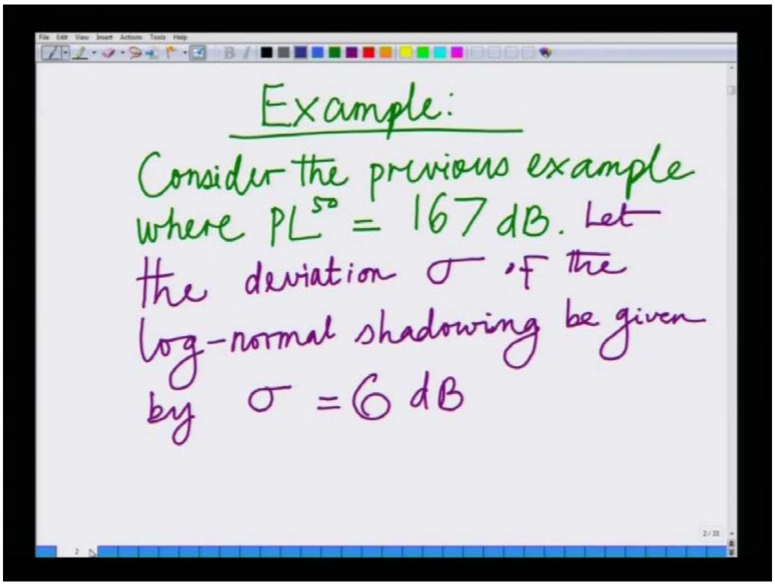

And we would also seen in the examples, in which the median path loss is 167 d B with variants of 6 d B.

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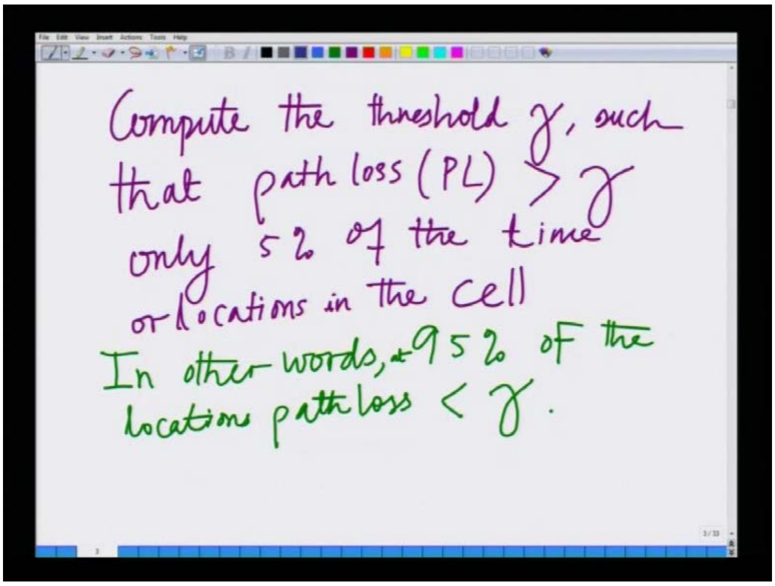

And we wanted to compute the threshold gamma such that, it exceeds threshold only 5 percent of the time, which means the reliability of 95 percent.

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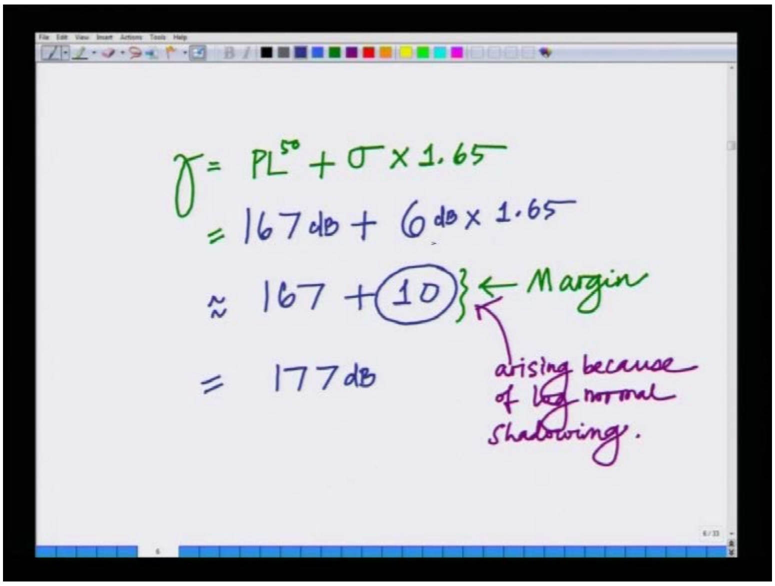

And we said the margin required for that, the margin that is that has to be accounted for this reliability factor or the transmitter is 10 d B.

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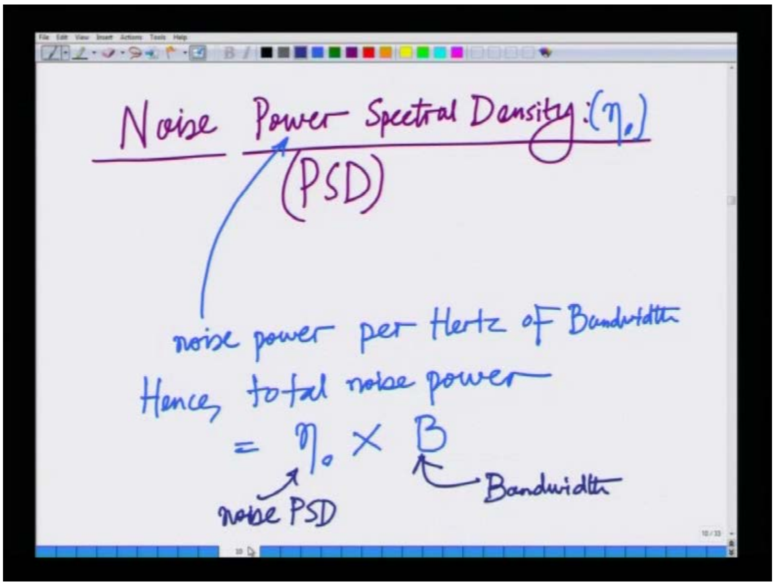

Next, we moved on to the computing noise power, receiver noise power which is essentially given by the product of the noise power spectral density eta naught times the bandwidth B.

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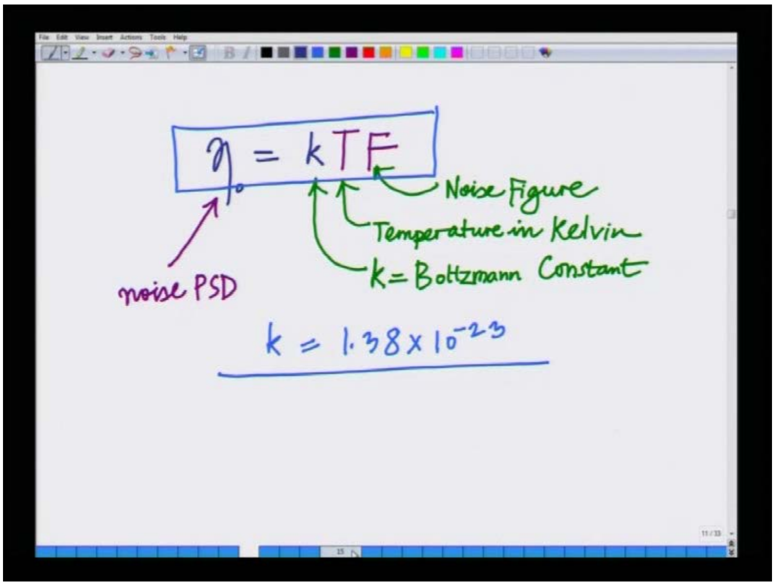

And we said the noise power spectral density eta naught can be computed as K times T times B, where K is the Boltzmann constant, T is the temperature, and F is the noise figure, all right. So, we said that eta naught can be computed as k T F all right.

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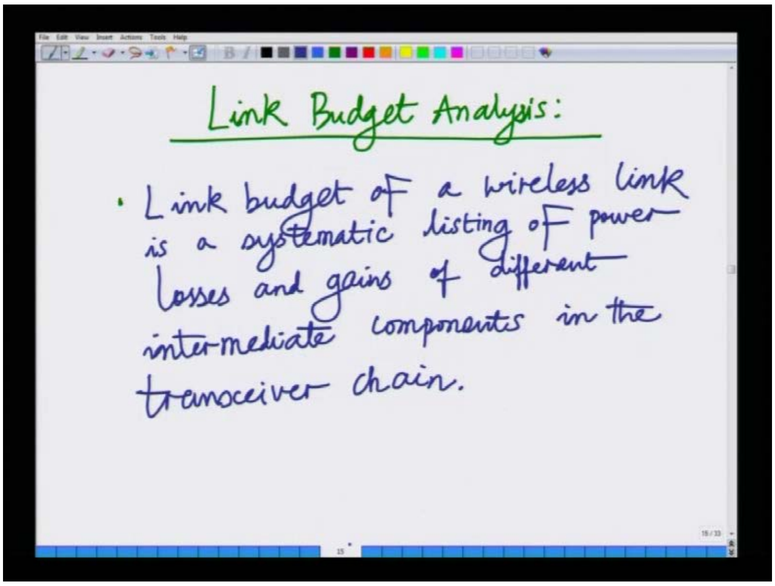

And then, we moved on to a link budget analysis, which is essentially putting all these factors together, the link budget is nothing but, the systematic listing of losses and gains in this wireless communication system which can be listed as follows.

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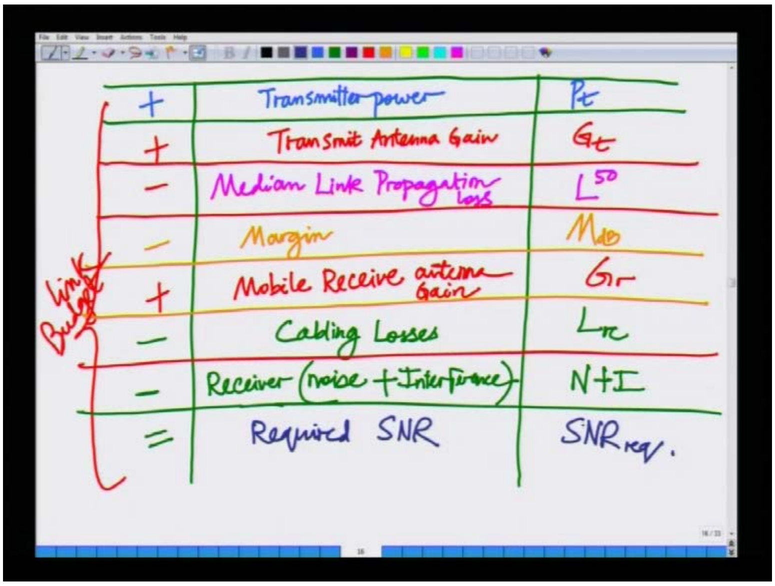

That is the transmitters power P t plus transmit gain G t minus the path loss L 50 minus the margin M d B plus mobile receive antenna gain G r minus cabling losses L rc minus receiver noise plus interference N plus I, which equals to the required SNR. So, what it says? is that transmitters transmitted power plus gains minus the losses equals to the received power of the received SNR. So, it is a very intuitive and simple formulation of the link budget analysis. And then we looked at an elaborate example of the link budget analysis, comprising of several components that is path loss, the margin and so on, and so forth.

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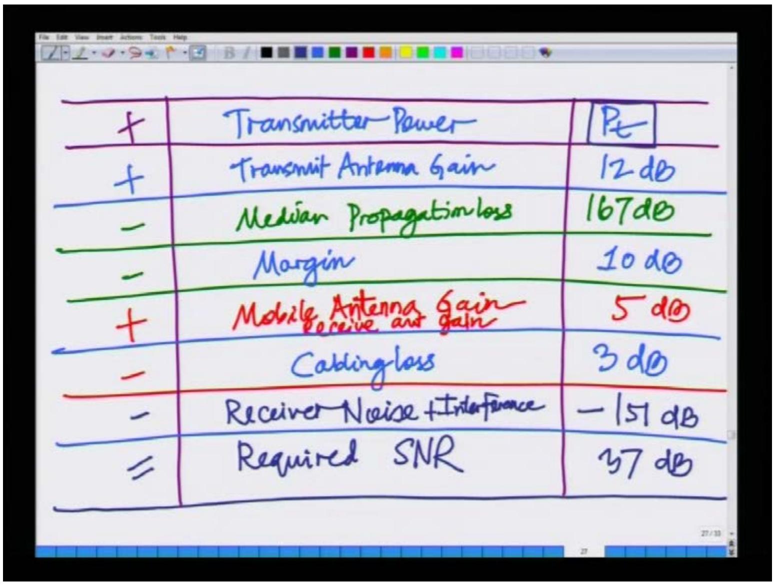

And finally, we had listed these components of link budget, which is the we have to compute the transmit power given that transmit antenna gain is 12 d B. The median propagation loss is 167 d B, margin is 10 d B, and mobile receive antenna gain is 5 d B, and cabling loss is 3 d B, receiver noise plus interference is minus 151 d B and the required SNR is 37 d B which is essentially the SNR, that is required for BPSK decoding with probability 10 power minus 4 in this wireless communication system.

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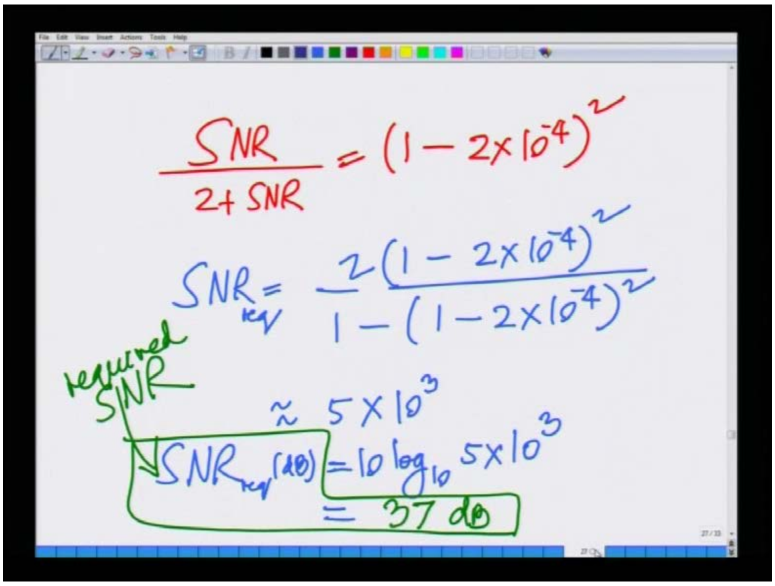

Hence, with this understanding let us complete this, which is essentially as follows.

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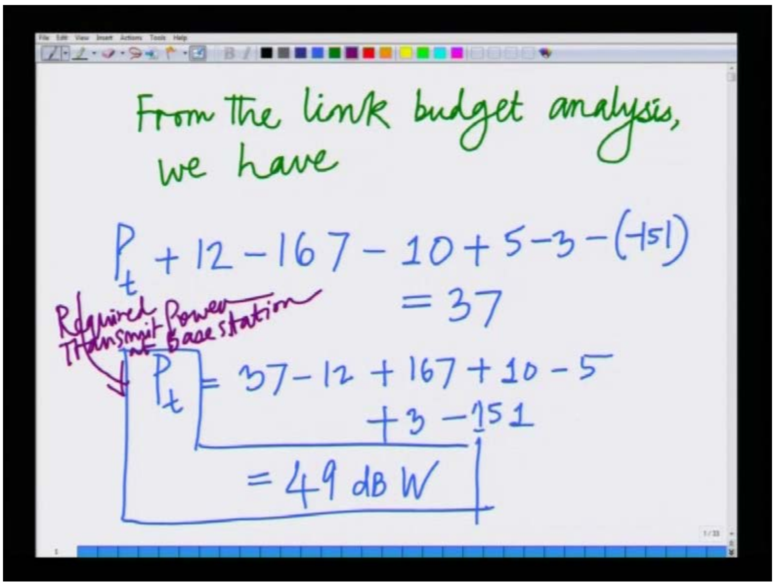

Hence, I can write from the link budget analysis we have, from the link budget analysis we have P t plus 12 minus 167 minus 10 plus 5 minus 3 minus minus 151 equals 37 db, which is the required SNR. Remember 12 is the transmit antenna gain, 167 is the median path loss, 10 is the margin and 5 is the receive antenna gain minus cabling loss, which is 3 d B minus receiver plus noise interference, which is minus 151 d B equals 37 which is the required SNR.

And now, the received required antenna power can be transmitted as 37 minus 12 plus 161 plus 10 minus 5 plus 3 minus 151 which is equal to 49 d B Watts. Hence, this is essentially the computation of required antenna power at base station from the required from the link budget analysis. So, this is the required transmit power, this is the required transmit power at the base station, this is computed is from as from the link budget analysis. Hence, the link budget analysis has the different aspects of propagation modeling, the log normal shadowing, and everything can all be put together to come up with the comprehensive sign of a wireless communication system. That is what is the transmit power required so on, and so forth, for these different factor. Essentially, how do you plan for cellular system? what is the power required and so on, and so forth essentially all right. So, this complete one aspect of modeling of the cellular system.

The other aspect we have to talk in this course, in modeling any cellular system is actually the frequency planning, which essentially talks about how many channels are available in the given cellular system? And how do you plan this channels? such that the users are user demands for the calls, demand for placing call in this system, or in this system to be connected is satisfied; which is essentially you meet the demand for the traffic from the users perspective. That is if you consider this calls, this information, this data, it is been generated as a traffic in your network, how do you model this traffic? And how do you model this traffic? and how do you essentially satisfy this the demand for this traffic? That is essentially what we are going to consider in next part which is essentially critical in the design of any wireless communication system for any cellular communication system which essentially the topic that is known as Teletraffic Theory.

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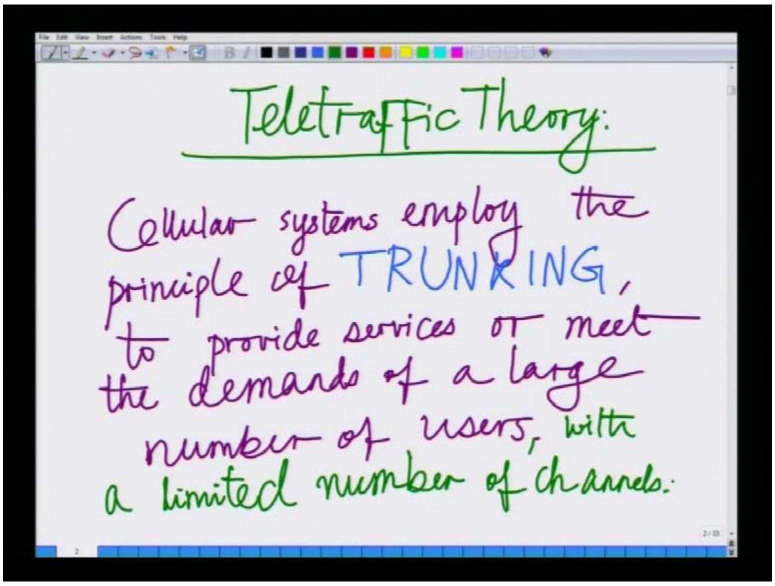

So the next topic which we want to talk about is Teletraffic theory, where essentially we say is cellular systems how do cellular system meets the demand for traffic? That exists in the wireless cellular system, they employ the principle of Trunking. So, in Teletraffic Theory what we are going to talk about is the principle of Trunking and cellular systems, cellular systems employ the principle of Trunking, employ the principle of Trunking to provide services to a large number of users, services or meet the demands essentially communication demands for large number of users all right.

So, cellular systems employs trunking to meet the demands of large number of users, in fact this large number this, this principle of trunking is not unique cellular communication system, in fact this is borrowed from the landline telephone systems. So, what is termed technically as PSTN that is Public Switch Telephone Network, they employ the principle of Trunking to meet the demands of a large number of users, but with the very few channels with number of channels, significantly lower than the number of users, with a limited number of channels.

So, trunking is nothing but, the principle, where the demand for the traffic, where traffic or demands of the user or a large number of user is met with a very few or a very limited number of channels in the communication system; namely it can be used in the PSTN and can also be used in the wireless cellular system, remember in wireless cellular systems the available frequency bands or the available channels for communication are severely limited.

Hence, whatever few channels are there are available have to be used by a large number of users essentially all right.

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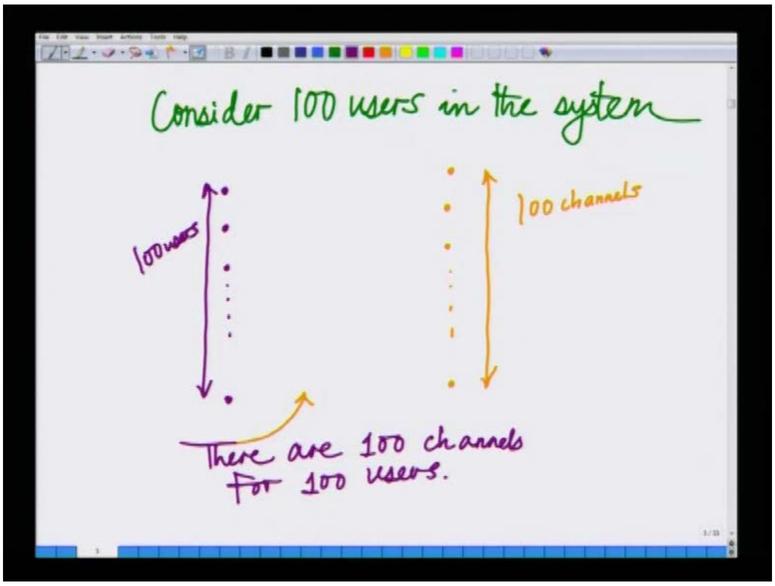

For instance to illustrate this principle, let us consider that there are hundred users, so consider there are hundred users in the system, consider hundred users in the wireless communication system, then these are the hundred users, which we denoted with these points. And now, let us say there are hundred channels available for these hundred users, that is one channel available for each user, these are hundred channels which are essential for the frequency bands or times slots available for hundred users. Hence, what we are saying is hundred channels, there are hundred channels available for hundred users; however, if you remember now, if we have there are hundred channels for hundred users, that is each user has its own channel.

However, this is tremendous wastage of resources, because at any given point of time, only a very few number of users are actually connected to the U system, or at given point of time not all the users wish to be corrected, or there is no there is no traffic demands in all the users, there are many users only a fraction of users all the users, who are subscribed to this system are actually connected to the means of cellular system, large number of subscribers in system only very few users are actually are on the call talking to someone, or any call so on, and so forth. Hence, what this implies is this results in tremendous wastage of resources.

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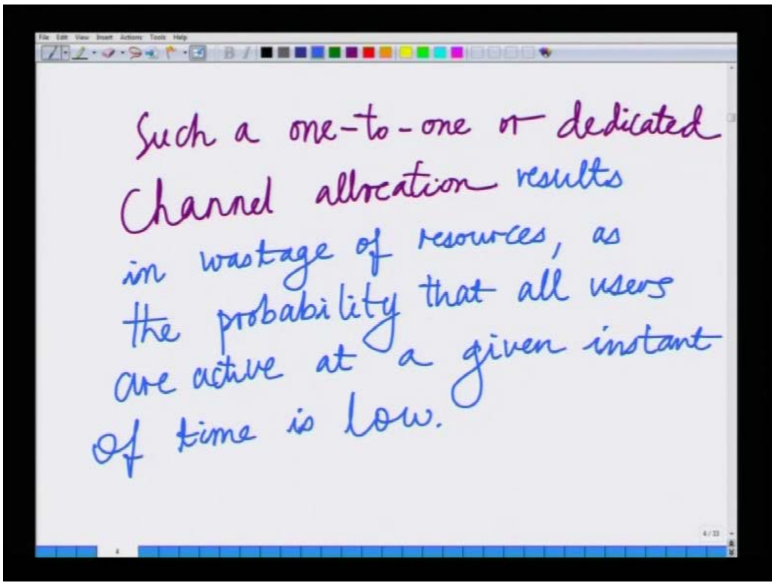

Hence such a fixed a location or such a dedication, or dedicated, such a one to one allocation of channels, or such a one to one or dedicated channel allocation, results in wastage of resources, it results, it results in wastage of resources. As the probability of all users being active, there is traffic from all users given instant of time is very low; as the probability that all users are active at a given point instant of time is very low.

Hence, if you have this one to one allocation, what we have is we have one channels of each user that is any user, who wants to place a call can place a call immediately. However, this results in a tremendous wastage of resources, because we have one channel hold for every user, at any given fraction or point of time, very few users actually would like to place a call; which means all the rest of the channels are lying vacant or empty. Since, this is not the sufficient model for resource allocation or resource profession in this cellular communication system, because the probability if we look at this statistically, the probability that all the users like to use this channels but, in which case it would be useful is very low all right. Hence, what we are saying here, is only a very small fraction of users in the given system are likely to be active at any given point of time which means only a very small fraction of, only a very small fraction of subscribers are likely, are likely to be active at a given point of time all right.

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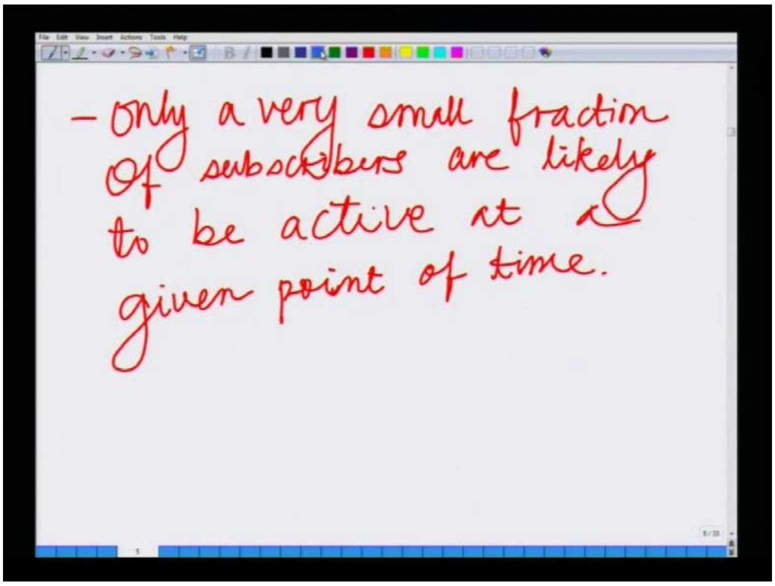

So, only a very small fraction of these users are likely to be active at any given point of time. Hence, what that means is practically, very few channels are necessary. There are n users, you do not need n channels to chater to the demands of the n users, you need only a very few channels to actually meet the demand, because only a fraction of these n users are active at any given point of time.

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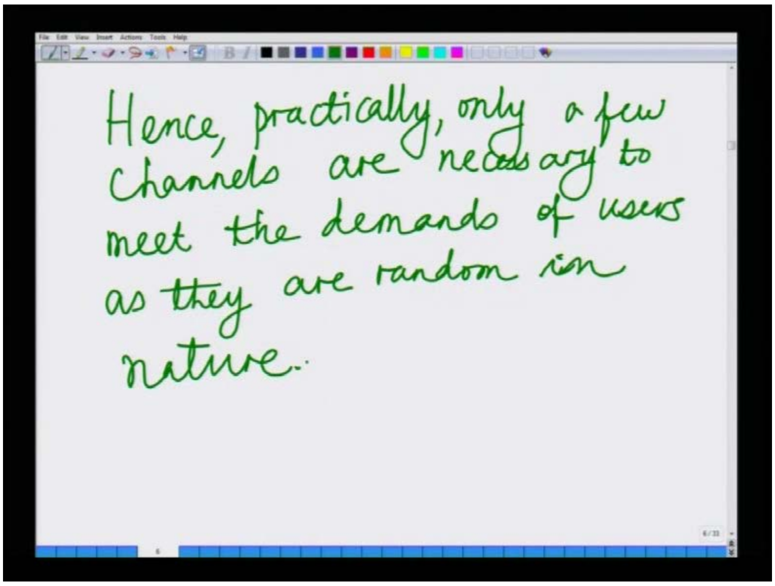

Hence, speaking practically, hence practically only a few channels are necessary to meet the demands of users, as they are random in nature, what we are saying is the desire to place a call or the desire or the pro or the event that is traffic arises in particular user is a random event all right. So, because this is random that we can now, talk about the probabilities and probabilities that all users have to place a call at the same instant of time is very very low. At any given point of time these are random instances, in the sense these happens randomly hence randomly has set would like to place the call, hence the probability that all users would like to place a call is very low.

And these events, that the users connected to the network or would connected to the base station place a call is random in nature, and the probability that all the users would like to do is very low. And this at random nature of placement of calls can be essentially efficiently allocate resources through a principle, which is known as statistical multiplexing.

Hence, multiplexing the different users that is using the same preferences, same resource or frequency bands to multiplex all these users, that is transmit all their information or place all these calls however, you are multiplexing them statistically.

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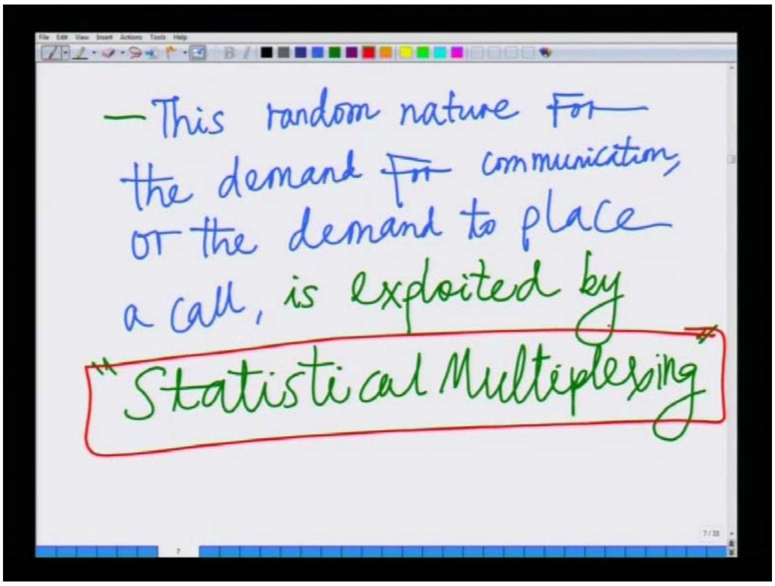

Hence, this random nature for demand for communication, or basically the demand to place a call is exploited by statistical multiplexing. This is exploited by this technique term statistical multiplexing, which essentially says that you can statistically multiplex all these users, because the placement of calls is a random event. And this statistical multiplexing may be used to support a much larger number of users with actually a very few channels, and that is what we are going to see, how that is possible is what we are going to see in the rest of the topic.

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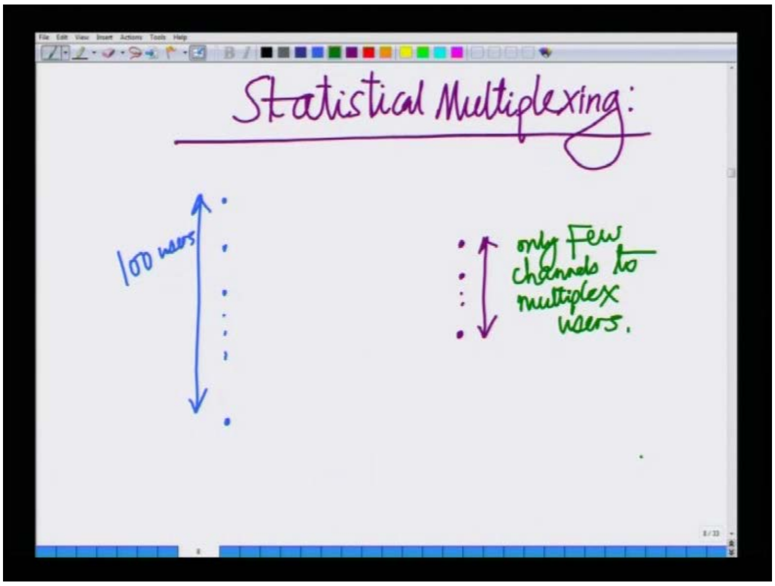

So, what is statistical multiplexing, so if you were asked the question, what is statistical multiplexing? So, let us start defining statistical multiplexing, which is essentially let us say 100 users now in my system, I have the same hundred users, I would like to have only a few channels. Now, to multiplex all these users now, I no longer have a large number of channels but, few channels I have only few channels to multiplex these 100 users. Let us say, I have about into 10 to 15 channels, I have 100 users only have 10 to 15 channels to multiplex all the users.

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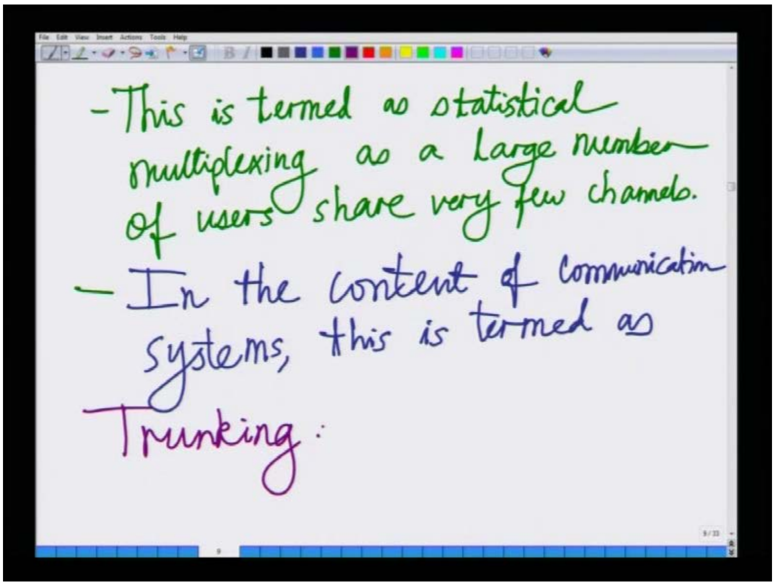

This is termed as statistical multiplexing, we are essentially used using the statistical properties of the traffic to multiplex a large number of users, this is termed as statistical multiplexing, this is termed as statistical multiplexing. As a large number of users share a very few channel, this is termed as statistical multiplexing, as a large number of users share a very few channels. And in the context of cellular system, this is essentially termed as trunking, where the multiple users in the context of cellular system, this is termed as trunking; where a large number of users share of the very few channels, that has frequency bands number of lines, that are available in the in the cell or in the exchange. So, in the context of communication systems, this is termed as trunking, and how does trunking works?

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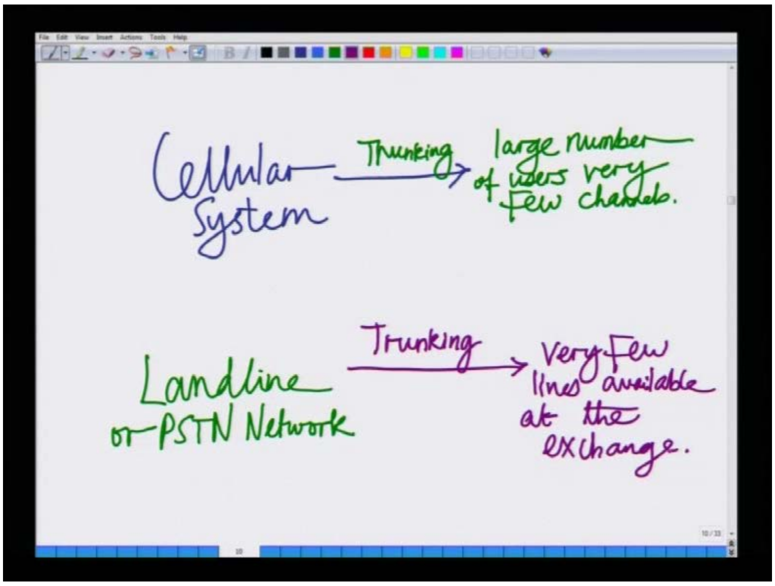

In a cellular system which is our concerns, in the cellular trunking essentially large number of users very few frequency bands have very few channels, a large number of users can use a very few channels. In the context of a traditional telephone exchange or a PSTN network landline or PSTN network, which essentially stands for public switch telephone network, I employ trunking. And this is how trunking originally began, I have the large number of users very few lines available in the exchange, that is what gives rise to the nature, that is what used in the old days, which refers to it as trunk caller.

Trunk caller refers to the nothing but, there is number of trunk of lines which contains a very few lines compared to the number of users, hence you have to wait for your term on that trunk, because you are allocated lines sequentially on that trunk. Trunking is nothing but, there are, saying that there are small number of lines and a very large number of essential users, that you are supporting using this trunk.

In the context of cellular system it becomes all the more important, because over the air frequency resources in 3 G systems 2 G systems all systems are limited, that is the frequency bands so on, and so forth, are limited. Hence, it is not possible to have an unlimited number of channels, or the number of channels that grows from proportionally to the number of subscribers, because the number of subscribers are of the orders of the hundreds of thousands. So, how to deal with that every cell is that, if have a large number of subscribers, you have only a very few channels, and then you have statistically multiplex these users as per the demand for traffic. And this is essentially called as trunking which is essentially important in the cellular system to allocate channels to the users ok.

Hence, however notice that since, the number of channels is much smaller than the number of users, then always the probability is small but, there is always the finite probability with which user can be blocked. Because, let us say there are hundred users and ten channels, there is some probability with which ten users are active, and now the eleventh user tries to place a call, he is going to be blocked, hence no matter. But, the probability will be small but, what is said is that, there is always the finite probability with which this eleventh user is blocked.

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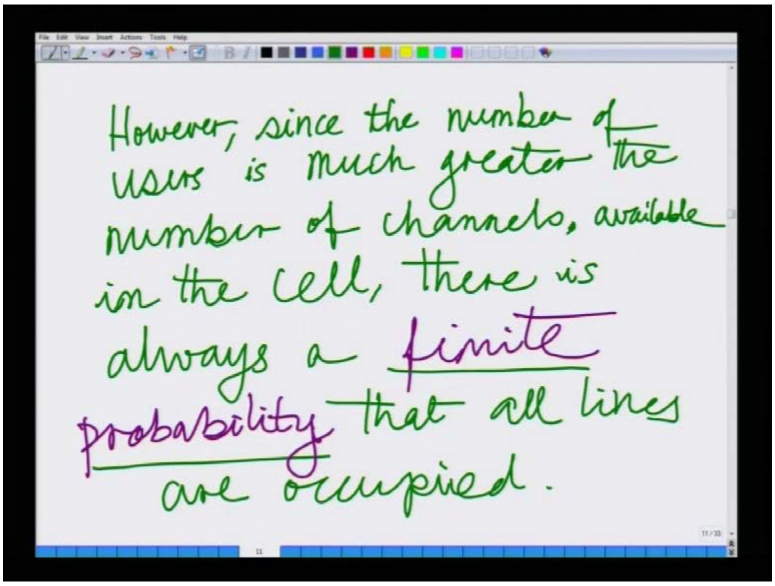

So, however since the number of users, let me write this down however, since the number of user is much greater than the number of channels, since the number of user is much greater than the number of channels available in the cell, available in the cell. There is always the finite probability, finite probability is the key here, there is the finite probability, there is always the finite probability that all lines are occupied.

Hence, what it means is the number of user is much greater than the number of channels that is always the finite probability, that all lines in this cell, all lines in this cellular system are occupied; which essentially means that, hence the new user request, now I new user places the request for the channel in this state, or in this situation his called the block.

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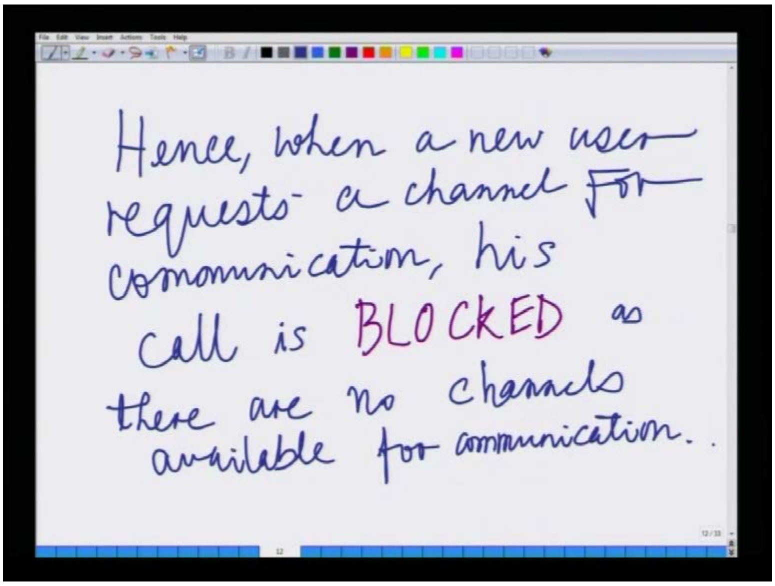

Hence, when a new user request a channel for communication or communi when a new user request channel for communication his call is blocked, that is there is no channels available to place his calls hence, this channel is termed as blocked access 59. Hence, for communication his call is blocked, as they are no channels available for communication, his call is blocked in the event that all the available channels are occupied, and this is termed as blocking probability, which is the characteristic feature of any trunking system.

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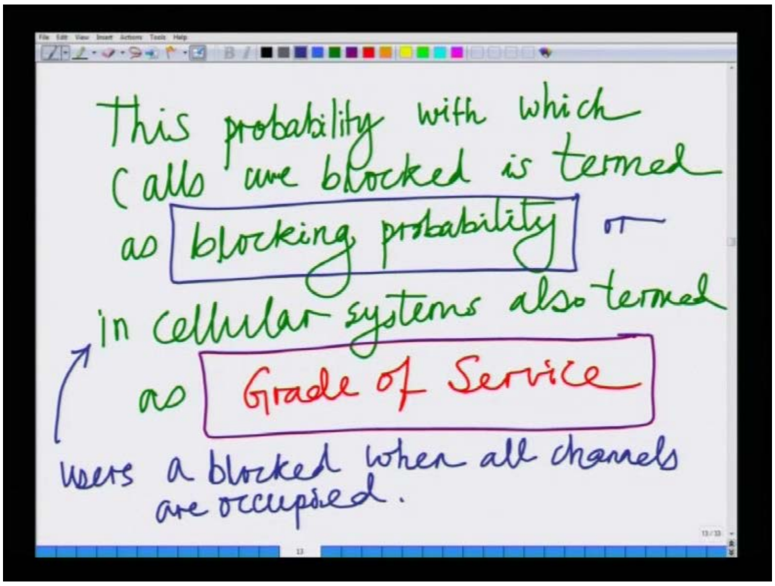

This probability, this probability with which calls are blocked is termed as blocking probability, this is the very important parameter which we would like to compute. This is nothing but, blocking probability that is the probability, that if a new user place a call, what is the probability that all the channels are occupied? and that my call is denied this is termed as blocking probability, or in cellular systems also termed as grade of service. And this is the key parameter blocking probability or the grade of service, which essentially says that the users are blocked, when all channels are occupied, the users are blocked, when all…

For instance, let us consider trivial example let us say, there are hundred users but, let us say there are thousand channels, hence the number of channels is more than the number of users. Hence, the demand of any user for a call will always be met all right, in that case blocking probability is 0 but, consider a situation in which there are 100 users but, there are only 10 channels available; which means that if all the user which means greater than ten decides to place a call, which happens with some probability, then the eleventh user who wishes to place a call will be blocked.

And another you can see, as the number of channels increases in this system blocking progressively decreases, for instance there are 50 channels, then the blocking probability is much lower. And when it is increased to 100 channels in this system, since this is 100 users, the blocking probability is 0. As the number of channels that are there in this system provision for this system increases, the blocking probability decreases, so the performance needs a trade off.

If you want to have the low blocking probability, you need more channels, but more channels are expensive and the resources are not available, so it is a performance versus price trade off. You do not want to get optimum performance at the optimum price, that you pay for the acquiring these channels of these communication channels, which are essentially the frequency bands in a cellular communication system all right. It is a very important, so it is a frequency planning, and management it is a very important part of any cellular setup, cellular communication system setup process all right. And this blocking probability, which is the key parameter of the cellular system is what we want to derive it in the teletraffic.

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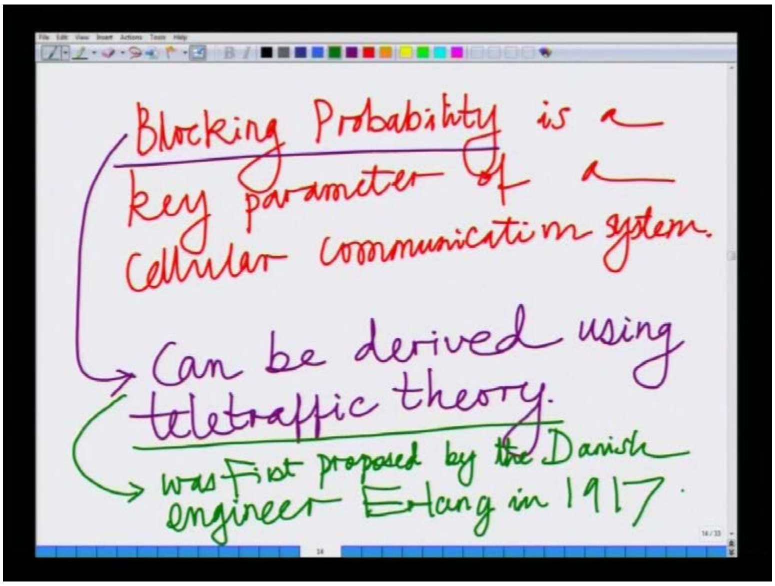

So, the blocking probability is a key parameter of a cellular communication, blocking probability is a key parameter of a cellular communication system, and this is what have to derive and this essentially derived in teletraffic theory. And we would like to do this and blocking probability can be derived, we would like to characterize that can be derived, using this blocking probability can be derived using teletraffic theory. And this teletraffic theory was proposed by the latest Danish engineer Erlang in 1917, and this was first proposed teletraffic theory was first proposed by the Danish engineer Erlang in 1917.

And this is what the blocking probability is what we would to derive, which is the grade of service of this wireless communication system, or the wireless cellular system which actually first derived by Erlang in 1917 in the context of trunking for landline telephone system. That is PSTN which is the same theory that can use in modern wireless communication system now, which essentially means we have to start characterizing the traffic that is, how do we characterize the demand for place the call by this different users?

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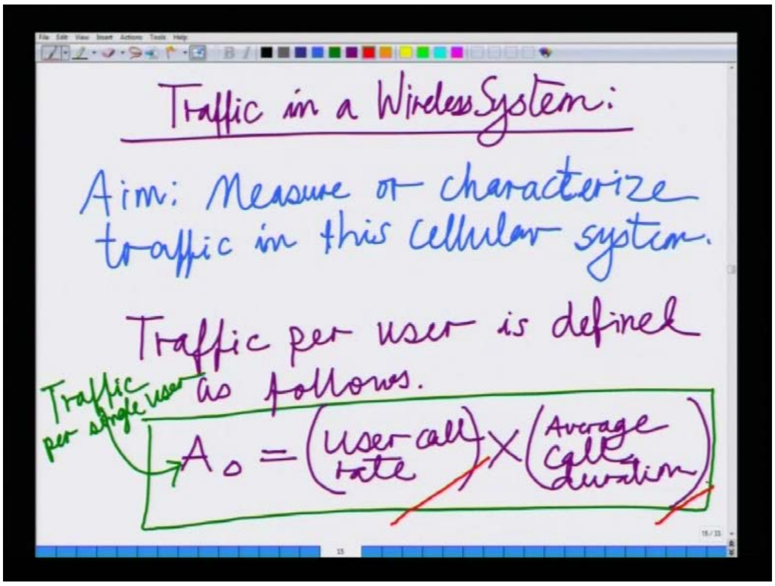

So, hence first we have to start with traffic by characterizing traffic which is traffic essentially characterizes traffic in wireless system characterizes the demand to place a call by this different users. So, how do we measure our aim is as follows, the aim is to measure or characterize the traffic in the cellular system, our the aim is to measure or characterize the traffic in the cellular system. The per user is measured as follows, the traffic per user, the traffic per user is defined as follows, which is essentially defined as A naught equals user call rate into average call duration.

So, the traffic per user which is A naught is measured as A naught equals which is the user call rate into average call duration, this is nothing but, the traffic per single user. So, as you can see this traffic increases, if either the user call rate increases, that is the users are placing more calls. That is users are frequently placing calls or the average call duration, that is they are not placing as the pure calls but, the duration of the each call is longer. And naturally it is proportional to a product of these two things, which is essentially the traffic per single user.

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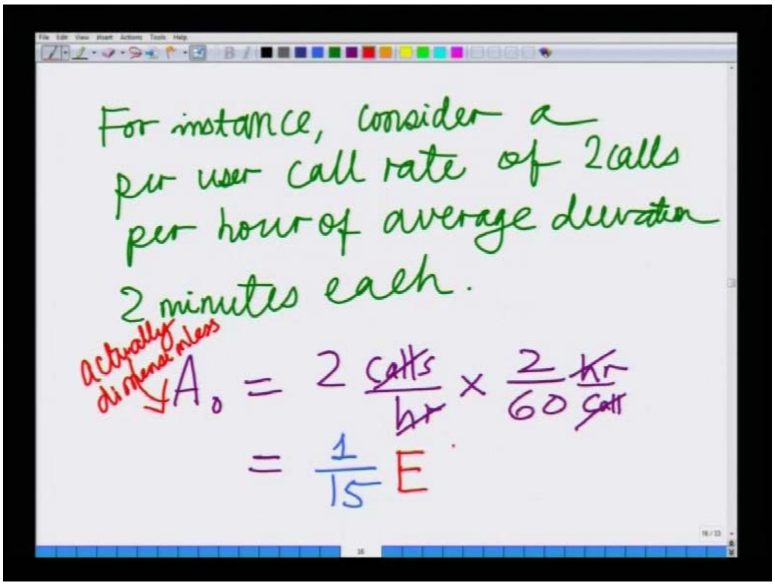

And now for instance, consider the following, consider the following example, consider a call rate, consider the per user call rate, for instance consider a per user call rate of 2 calls per hour all right of average duration to hour of average duration 2 minutes each. The traffic per user A naught is now nothing but, call rate that is 2 calls per hour into the average duration, which is essentially a minutes, I have to convert into hours; which is 2 by 60 hours, which is essentially nothing but, this is 1 over 15. If you compute this, this is 1 over 15 and now, if you look at this and this is average duration hence, this is hour per call.

Hence, if you look at this, these units they cancel out, and the traffic is actually a dimensionless quantity. If you look at this, this is actually a dimensionless quantity however, this traffic similar to d B like quantity. This traffic is measured in the units of erlang, we said one call per hour into one per, one call per hour into one hour per call, we say it is measured dimensionless quantity is measured in units of erlang. Hence, we write this here, hence we say this traffic hence, although strictly speaking A naught that the traffic is dimensionless, it is assigned in the units of erlang.

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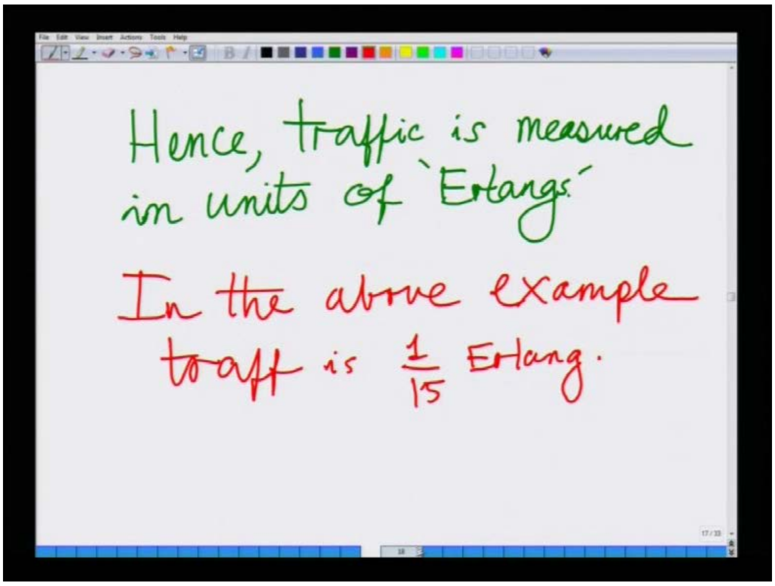

Hence, traffic is measured in units of Erlang which is denoted by the capital E, for instance in the above example the traffic is 1 by 15 erlang. All right in the above example the traffic is 1 by 15 of an Erlang now, we can compute the aggregate traffic which is the traffic given large number of users.

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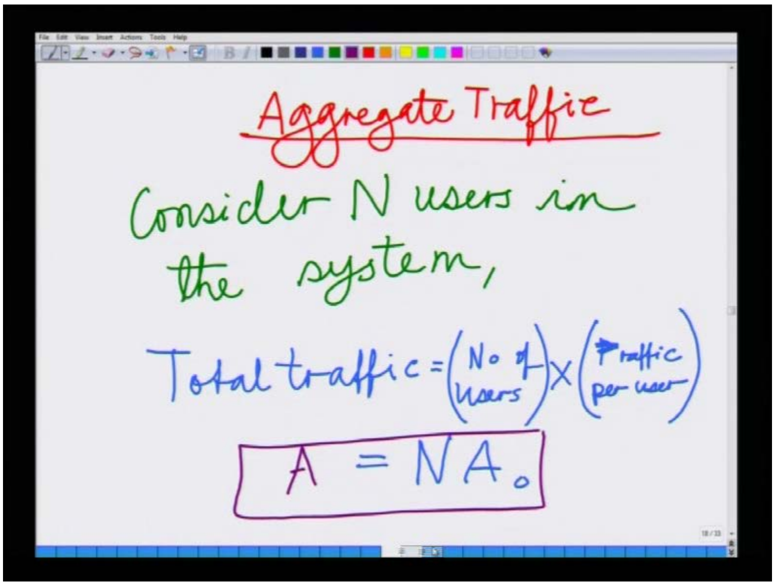

Let us consider N users system, let us consider the aggregate traffic, consider N users in the system, consider the N users in the system then the total traffic, now is given as is nothing but, number of users into traffic per user. That we are saying traffic per user is A naught and the number of user is N, then the total traffic is nothing but, product of number of users into traffic per user, which is N times A naught. Hence, this quantity is nothing but, N times A naught and this is denoted by A.

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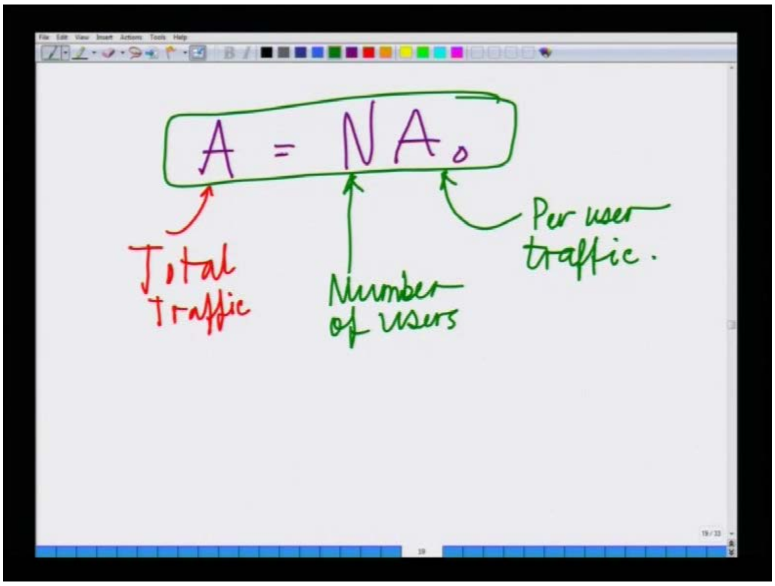

A equals N times A naught, and if I have to write this, this is A equals N times A naught, where this is the total traffic and this is the number, this is the number of users, and this is the per user traffic. And this is the expression we have for the traffic in this cellular communication system ok.

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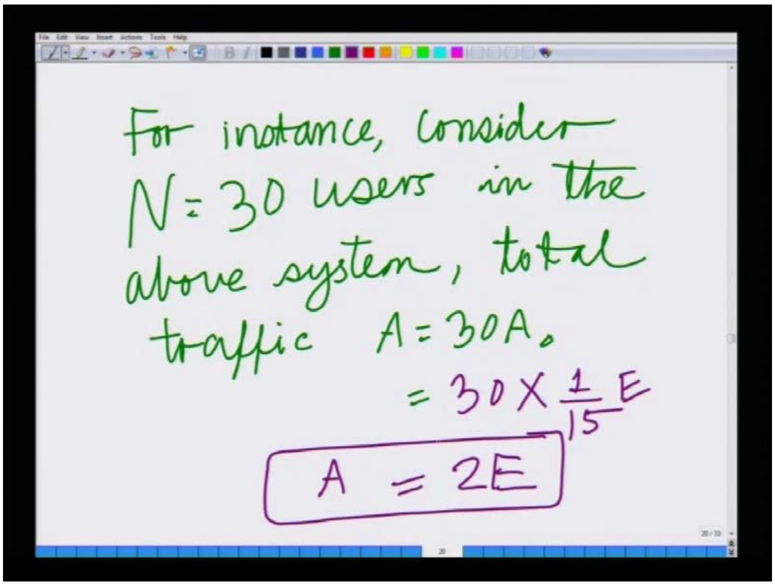

Now, for example, previous example again to look at an example, for instance for instance consider N equals 30 users in the above system, consider N equals 30 users in the above system. The total traffic A equals 30 A naught equals we said that traffic per user is A naught is 1 over 15 erlang, this is 30 times 1 over 15 erlang which is equal to 2 erlang. The total traffic in the previous system corresponding to 30 users, where the per user is 1 over 15 erlang is nothing but, 30 times 1 over 15 which is essentially 2 erlangs of net traffic in this system.

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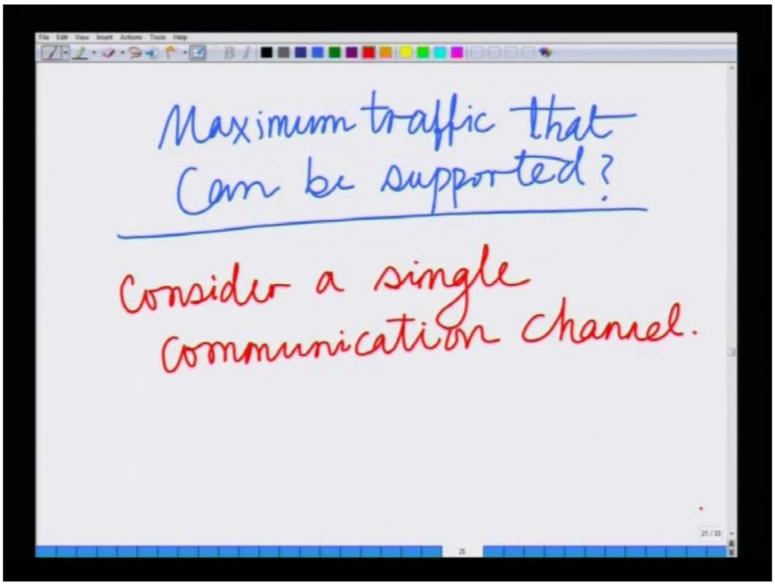

Now, let us look at what is the maximum traffic, that can be supported in this system, what can be maximum traffic that can be supported? What is the maximum traffic that can be supported in this system? and we consider a single communication channels. For instance, consider a single communication channel, consider a single communication channel. Then, you have 1 channel I can support, calls at the rate of 1 call per hour into each call for a duration of 1 hour. That is the single channel look at the traffic I can support, I can support 1 call per hour for a duration for 1 hour, or I can support 2 calls per hour. But, then I cannot support each call for 1 hour, I can support each call for the duration of half hour only.

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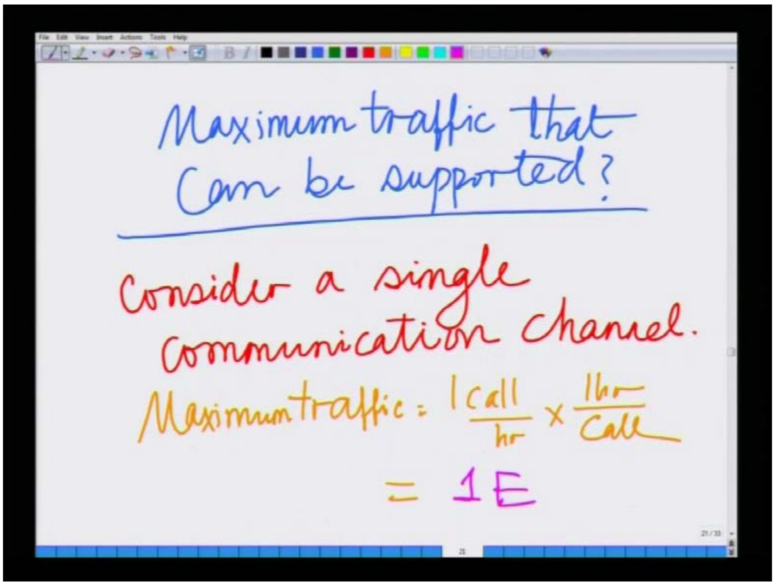

Hence, if I have 1 traffic channel, I can support N calls each for a duration of 1 by Nth of a time, hence I can support 1 erlang of traffic. Speaking of a single communication channel maximum supported traffic equals 1 call per hour into a duration of 1 hour per call which is nothing but, 1 erlang of traffic.

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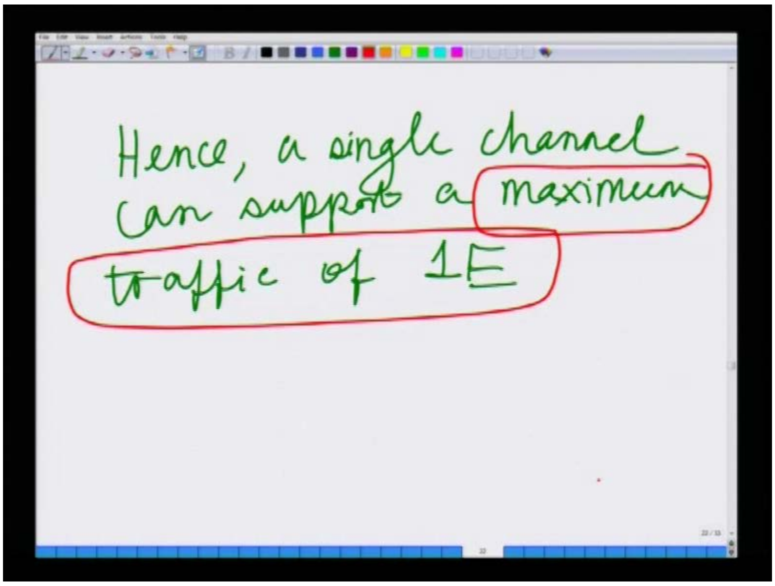

Hence, a single line, hence a single channel can support a maximum traffic of 1 erlang, hence a single channel can support a maximum traffic of 1 erlang, which means N channels. Hence, N channels let us have N channels, the maximum channels supported in the cell, that we have N frequency bands or N times slots, the maximum supported in the N channel is N Erlangs.

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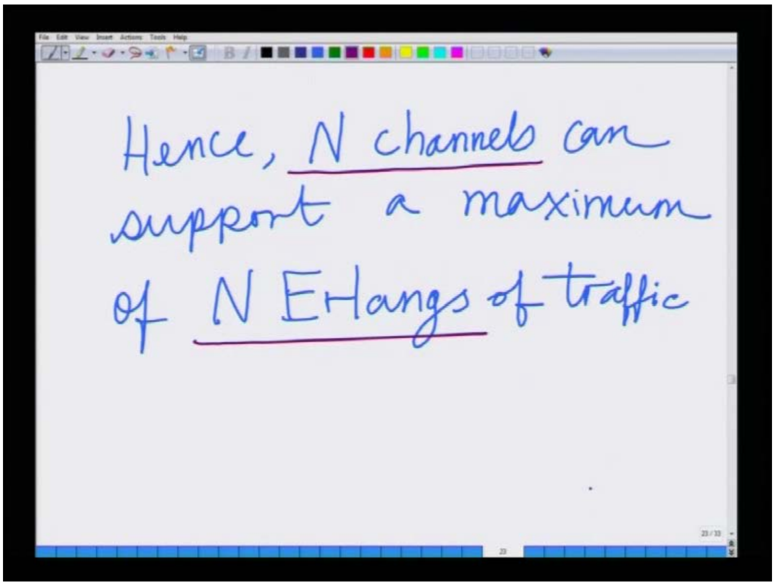
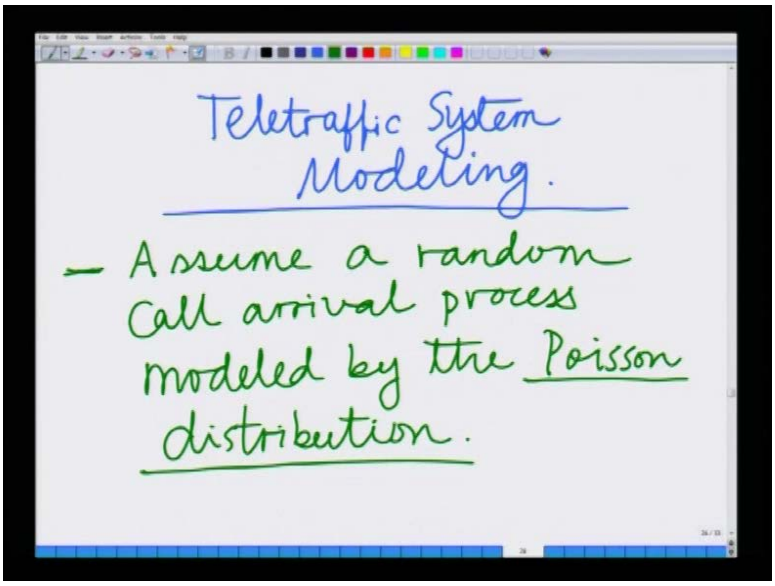


Hence, N channels can support a maximum of N erlangs of traffic, which essentially says if I have N channels, I can support a maximum of N erlangs of traffic. So, that is how we measured traffic? we looked at different ways, how do we the measure traffic? traffic is nothing but, per user the average call duration, call rate into average call duration, and total traffic is number of users into the average per user traffic. And the maximum supported traffic per channel is 1 erlang, which means N channel that is N Erlangs. (Refer Slide Time: 49:55)



Now, we want to go it to the teletraffic modeling aspect, that is how do you actually model this teletraffic system modeling. So, let us go into we want to go into the teletraffic system modeling. Assume a random variable so now, we are going to call the processes the probability that, these call events with the random now, we have to start with the random a frame work, a probability based frame work to model these call processes. Hence, assume a random poisson call arrival process, so we start with the fundamental assumption, assume a random call arrival process modeled by the poisson, poisson distribution. This is modeled by the poisson distribution, so this call arrival process modeled by the poisson distribution, and one critical aspect of the poisson distribution is the poisson parameter lambda, which is nothing but, the call arrival rate.

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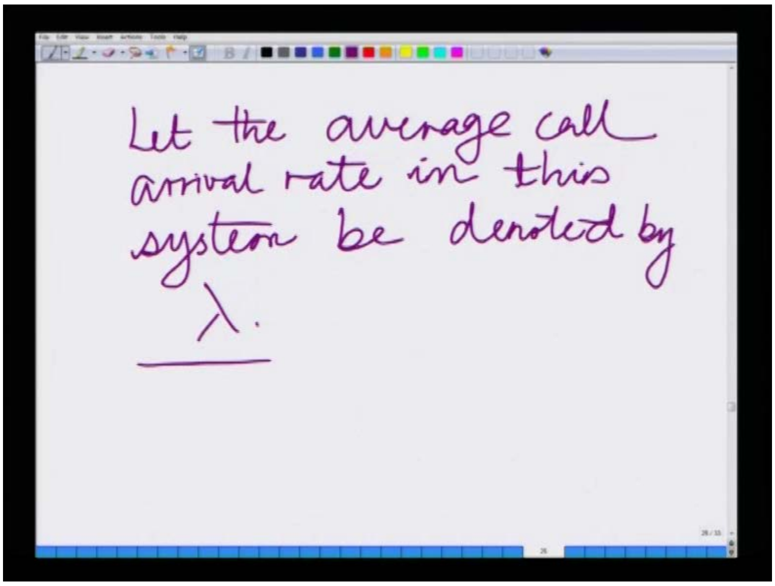

Hence, we denote this call arrival rate, let the average call arrival rate in this system, so we are denoting the average call arrival rate system by the poisson parameter lambda. That is what we are saying is the calls are arriving, in this system at the rate of lambda at the base station, that is essentially the users are placing calls and these calls or if you look at the base station, they say its approximately roughly lambda calls are arriving per unit time. This is known as the poisson parameter, which is specifically the call arrival rate.

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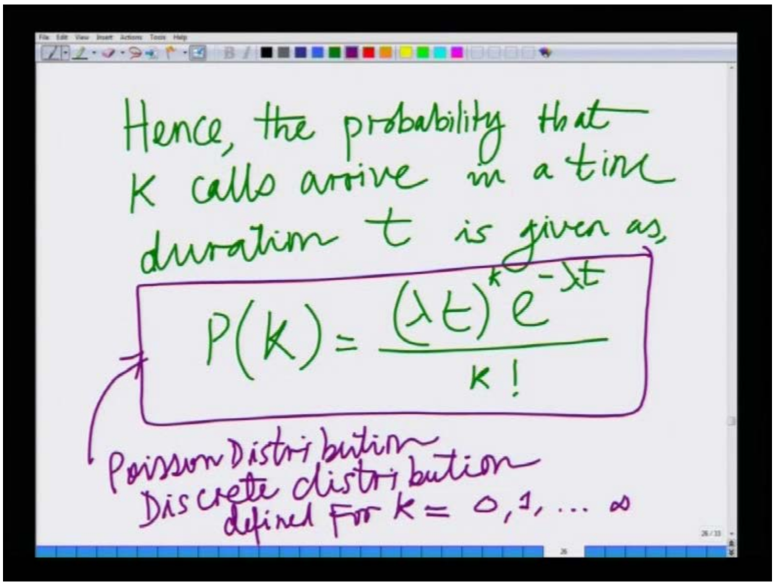

Hence, as per the poisson distribution the probability that K calls arrive at the base station in the time t is given as follows. Hence, as per the poisson distribution the probability that K calls arrive in a time duration t is given as, the probability that K calls arrive in this time duration t that is from 0 to t is given as, probability of K that is K calls arriving which is equals to lambda t to the power of K e to the power of minus lambda t divided by K factorial. This is essentially the expression for poisson distribution with parameter lambda, which is nothing but, the call arrival rate. We are saying that the probability that K calls arrive in this time interval t is nothing but, lamda t to the power of K e to the power of minus lambda t, divided by k factorial that is nothing but, the probability that K calls arrive in this time duration t all right.

Hence, you can see that this is nothing but, the poisson distribution, this is nothing but, the poisson distribution, and it is defined at discrete points. That is defined at that is 1 calls, 2 calls, so on up to so forth N calls, and so on. It is defined only for it is a discrete distribution, it is a discrete distribution defined for all right, it is a discrete distribution which is defined for K equals 0, 1, infinity and so on all right.

So, what we are doing is we are trying to characterize this call arrival process, which is a fundamental part of any wireless communication system or any wireless cellular system, and we are saying this is poisson distribution, which is the discrete distribution, and it is defined for K equals to 0, 1 up to infinity. And the probability the K calls arrive in the time interval t is nothing but, but lamda t to the power of K e to the power of minus lambda t divided by K factorial; with this let us end up this lecture, I continue from here in the next lecture.

Thank you very much.