Broadband Networks

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Lecture - 3

ATM Networks

So, in the previous lecture we have seen that ATM has mainly 4 types of traffic types. One is the constant bit rate which is primarily used for doing circuit emulations for the transport of telephone voice etcetera. Then we have the variable bit rate and variable bit rate also can be of 2 types; real time variable bit rate or non real time variable bit rate and essentially the variable bit rate is the traffic which is coming from a VBR and coded video encoder or voice encoder or for that matter, any real time encoders.

Now, it is for the variable bit rate VBR kind of traffic, the ATM offers statistical multiplexing gain along with the quality of service guarantees. The third type of the bit rate the traffics types is available bit rate or the ABR traffic types which essentially for the transport of the data packets. However, the difference between the ABR and the UBR is that a ABR traffic types have certain guaranteed minimum cell rate; on the other hand, for the UBR traffic types, there is no quality of service guarantees absolutely at all.

Now primarily, we have seen that CBR, VBR and ABR traffic types require certain quality of service guarantees. The CBR and ABR traffics sorry CBR and VBR traffics are subjected to certain admission control and signaling mechanisms. On the other hand, the ABR traffic is subject to certain floor regulations based on feedback about the congestion conditions in the networks.

Now, we will now in the remaining lectures, we will now focus; how we can offer quality of service guarantees to a CBR or a VBR kind of a traffic in a statistical multiplexer like in ATM ne2rks. In the first lecture we had seen that such quality of service guarantees can be given in terms of packet loss rate if each source specifies its probability density functions. Then what we do? We determine the density function of the combined output rate and from that we determine whether the combined output rate exceeds the capacity or the bit or the maximum bit rate of the link. If it exceeds the maximum bit rate with a certain probability which is tolerable, then the calls can be admitted. Otherwise, you know, the calls will be accordingly blocked.

Now since, it is not possible for traffic to characterize its probability density function; the ATM standardizing body like ATM forum or ITUT has specified that the traffic must specify its characteristics in terms of its traffic descriptors. So, what are those traffic descriptors? So, we will just have look at them; what are those traffic descriptors.

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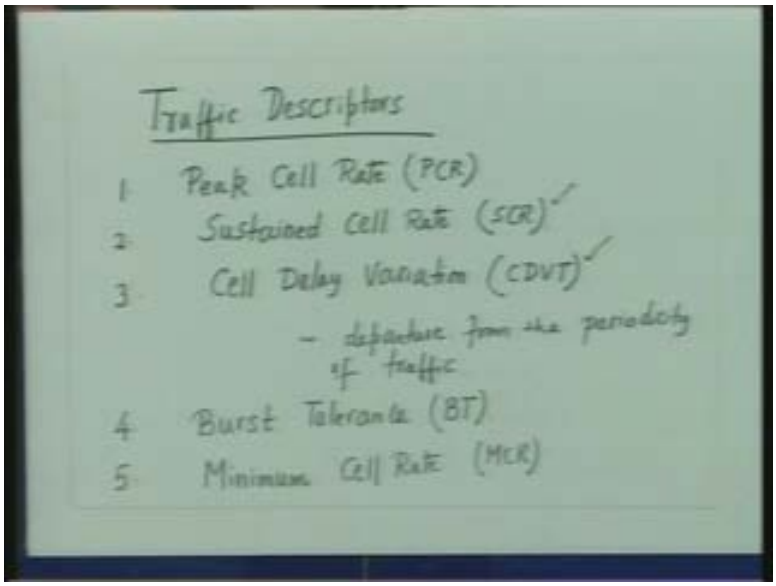

So, the traffic descriptors which have been specified by the ATM standards are a peak cell rate which is called as PCR, 2 is sustained cell rate, 3 is cell delay variation or what is called as CDVT. Now, the cell delay variation is a major of the departure from the periodicity of the traffic. Then, we have the measure of the burst tolerance BT and fifth is the minimum cell rate or what is called as MCR.

Now, the sustained cell rate is actually a measure of the average rate which the traffic will have and on the other hand, the cell delay variation is the departure from the periodicity of the traffic, may be the departure from the constant bit rate traffic or the peak cell rate. The burst tolerance is a measure of the maximum back to back packets that can be sent especially for the bursty kind of VBR traffic and the minimum cell rate is the minimum data rate that is required to be guaranteed to ABR traffic.

So typically, CBR traffic may be characterized by the peak cell rate and its departure from this periodicity which is CDVT cell delay variations and VBR bursty traffics can be characterized by the 4 parameters; that is the peak cell rate PCR, sustained cell rate SCR, cell delay variations and the burst tolerance and on the other hand, the ABR traffic can be characterized by the minimum cell rate.

Now, our problem is that when a source specifies its traffic characteristics in terms of these traffic descriptors and also specifies the quality of service attributes that the source wants; then how will a network determine whether the call can be accepted or not? That means how will a network determine that whether the traffic is admissible or not? For that the network requires 2 components. What are those 2 components?

The 2 components are; the network must first determine whether the traffic source is confirming to its advertise traffic descriptors or not; that is it is confirming to its advertised traffic

characteristics or not and 2 - the network needs an admission control algorithms which can determine whether the call can be accepted or not.

Now, a very … admission control algorithms can be based on the worst case behavior that is a peak cell rate. But that is not we want. What we really want is some kind of a statistical multiplexing gain also should be there in the switch. Otherwise, you know, there is no point in using in ATM network. We will simply degenerate to a circuit switch networks where the calls can be admitted based on peak rates. But of course, at the expense of the inefficiency in the slot utilizations for the bursty VBR traffic.

So, let us see, how a source can ensure that it is confirming to these traffic descriptors and at the same time, the network can monitor whether the source is indeed confirming to those traffic descriptors or not. In other words, we would like to see how indeed a traffic can specify its traffic characteristics in terms of these traffic descriptors.

Now, the ATM standards has specified an algorithm called generalized cell rate algorithm, GCRA which can specify all of these 4 traffic descriptors like the peak cell rate, the sustained cell rate, the cell delay variations and the burst tolerance.

So, let us see you know, how we can specify these traffic descriptors. The ATM forum has standardized an algorithm called generalized cell rate algorithm called GCRA.

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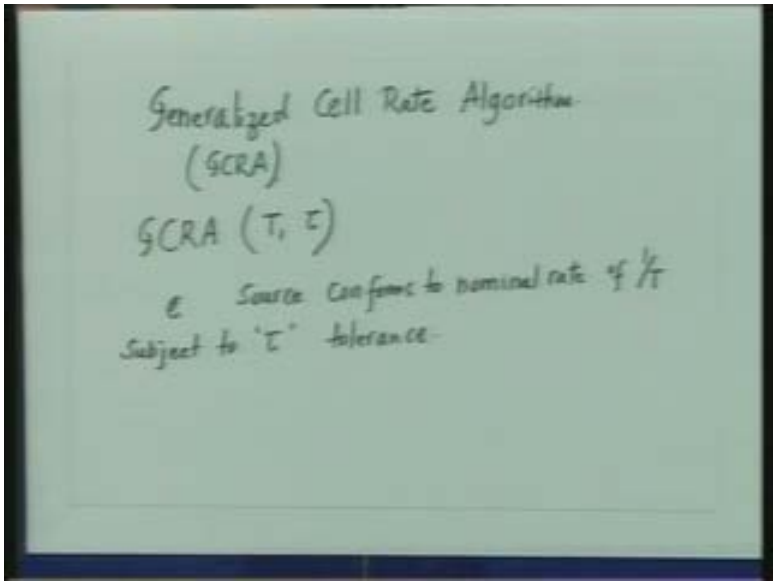

Typically, it is called as specified by GCRA (T, tau). The idea being that if a cell or a traffic source confirms to the nominal rate, confirms to nominal rate of 1 by T; then, tau is a measure of the tolerance. So, the source confirms to a nominal rate of 1 by T subject to tau tolerance limit.
Now, how does it happen? Let me just explain that whether the source is confirming to an GCRA (T, tau) parameters or not. Now, one thing I would like to say is that this is a method of specifying the traffic characteristics through the deterministic bounds. So basically, we are

specifying some kind of a deterministic envelope or in otherwise, statistical bursty VBR or traffic. So, let us see you know, how we can specify that.

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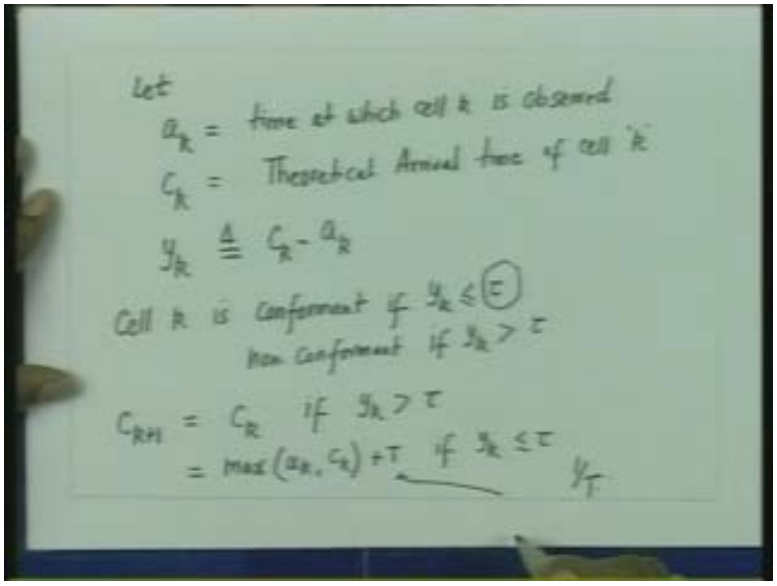

Now, let a_k be the time at which cell k is observed and c_k is what is called as theoretical arrival time of cell k. Now, theoretical arrival time is the time at which cell should arrive theoretically and a_k is the time at which the cell k has been observed or it has you know has come. Then let us say, y_k is c_k minus a_k. Then, we say that the cell k is confirming to this GCRA (T, tau) if y_k is less than tau. That means the difference between the times at which the cell has actually come minus its theoretical arrival time that should be less than tau. Then, the cell is conferment. It is non conferment this y_k is less than or equal to tau and it is non conferment if y_k is greater than tau.

Now, if the cell is conferment, then we said c_k plus 1 that is the theoretical arrival time of the k plus 1th cell will remain c_k if the cell was non conferment that is y_k is greater than 2 or else it will be set as maximum of a_k c_k plus T if y_k is less than or equal to tau. That means if the cell is conferment, then it will be set to maximum of a_k c_k plus tau.

Now essentially, what we are trying to say is the tau is measuring the departure from the nominal rate which is 1 by T. Now, if you see here, then what is really important here for the cell to be conferment; that the difference between its theoretical arrival time and the actual time at which it is arrived must be you know within tau limit. Otherwise, the cell will be non conferment if it is greater than, if it is greater than tau and the late arrivals of the cells the late arrivals of the cell will actually delay the possible allowable theoretical arrival times of the k plus 1th cell. That you know, we can see from this equations.

Now, let us consider an example to explain this point. Now, what we are trying to really see is that remember that the VBR traffic is generating a bursty variable bit rate characteristics. Now,

what we are trying to say whether the arrival times of these traffics which are getting generated whether; the arrival times of traffics which are getting generated, whether they are confirming to these GCRA (T, tau) parameters or not. That is what we are trying to say. Now, let us let for an example consider that we have GCRA (10, 3) as a parameter.

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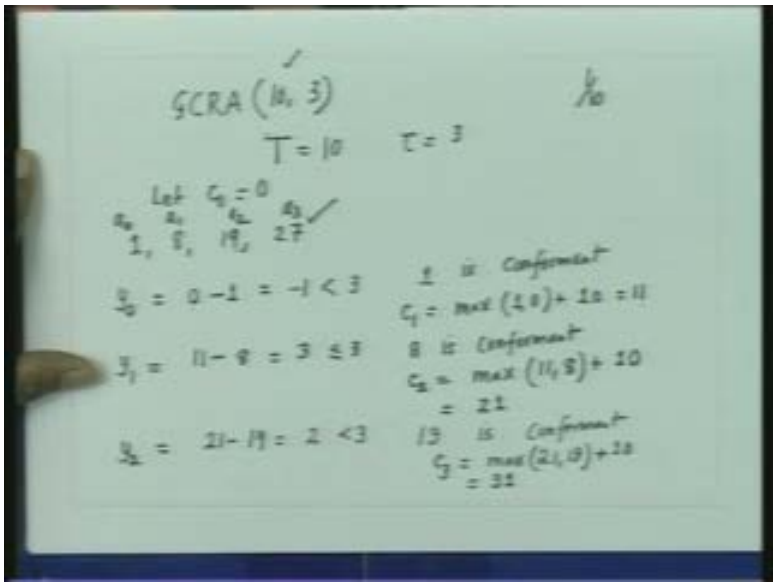

Let us see that how an example works like GCRA (10, 3). Now, what is the matter of GCRA (10,3)? Here, T is 10 and tau is 3. Now, let us say that c_0 is 0 and consider an example where the arrival times are 1, 8, 19, 27 and so on.

Now, let us try to see whether these arrival times as per the arrival times, they are conferment to these 10, 3 or not. Now, the interpretation of this is that the nominal arrival rate is you know 1 by 10. That is what the interpretation of this is with a periodicity or with a departure or with a tolerance of 3. That means the cells are expected to arrive at 0, 10 and so on. But there could be a departure subject to the tolerance of 3.

Now, let us see whether these cell 1, 8, 19, 27; whether it is conferment or not. So, what is y_0? Now, y_0 happens to be 0 minus 1 that is c_0 minus a_0. Now, remember that these are a_0, a_1, a_2, a_3. So, this is minus 1. What is minus 1? Minus 1 is less than 3, so definitely cell 1 you know is conferment.

Now since it is conferment, what will be the expected theoretical arrival time of the next cell? The expected theoretical arrival time of the next cell c_1 will be set as max of 1, 0 plus 10 you know as per our earlier formula. That is with we are saying is max of a_k c_k plus T. So, that is what you know we are doing here that is c_1 is max of 1, 0 plus 10 and which gives us 11. So since, the cell has arrived at 1, the expected theoretical arrival time of the next cell is required to be 11. But the next cell actually arrives at 8, it arrives earlier. So, let us try to see whether it is confirming to the to the GCRA (10, 3) or not.

So, what is y_1? y_1 becomes 11 minus 8 which is equal to 3 and since 3 is less than or equal to 3, 8 is conferment. Since 8 is conferment, we need to set you know the next arrival time which is c_2 and my c_2 will be set as max of 11 and 8 plus 10 which will be set as 21.

Now, what about y_2? Now, y_2 has come with 19, so ck c_2 was 21. 21minus 19 is 2 and 2 happens to be less than 3. So indeed, this cell you know is conferment. So, the cell 19 is conferment and since the cell 19 is conferment, my c_3 is set as max of 21into19 plus 10 which is you know 31. Now, this is 31. Now, the next cell that is a_3 comes at 27. It is expected to come at 31 but it comes at 27. So, let us see whether the cell which is coming at 27 is conferment or not.

Now if you see here, the expected theoretical arrival time is you know 31 and we will try to see whether the next cell is confirming to that or not. Now, next cell is coming at 27. So, our y_3 is 27 sorry this should be 31 minus 27 which is 4. Now, this 4 is definitely greater than 3 and therefore 27 is non conferment. What will happen? The specification says the GCRA (10, 3) specifications that since the previous cell had come at 19, the next cell can actually you know come at 31 only. Now since the next cell is coming earlier 27, come at 28 let us say if it comes at 28; then the difference would have been 3 and the cell would have been conferment. But since it came a little earlier, it is a violation of the departure from the periodicity and therefore this cell will not be allowed. So, it is indeed a non conferment cell.

Now, a way of another way of representing this GCRA (10, 3) is by what is called as a leaky bucket algorithm. Popularly this GCRA (10, 3) has been implemented as a leaky bucket algorithm. I will just explain through the same example, how the things can be interpreted in terms of the leaky bucket algorithms. But before that I just want to tell you that in practice actually what will happen is that a traffic source is generating a variable bit rate bursty data.

Now suppose, it has negotiated with the network that it will specify its traffic descriptors in terms of you know a certain t and tau parameters. Now, the network knows that the source will be transmitting its data in such a manner that it confirms to these T and tau parameters. But the source of course, if generating a variable bit rate or bursty data which is essentially statistical in nature, then what do you do at the source?

At the source, we will put this GCRA (10, 3) traffic shaper at the source whose output will confirm to these GCRA (T, tau) parameters. At the network, it will put a similar GCRA (T, tau) traffic regulate or traffic monitor which will see whether the cells which are coming from the traffic source is confirming to those T tau parameters or not. So, the device which we will put at source will actually be regulating or shaping the output in such a manner that the traffic confirms to these T tau parameters and at the network, the device will be put to make sure that the traffic source is indeed confirming to those advertised traffic descriptors of T and tau or not. So, now let us now see the its interpretation in terms of a leaky bucket.

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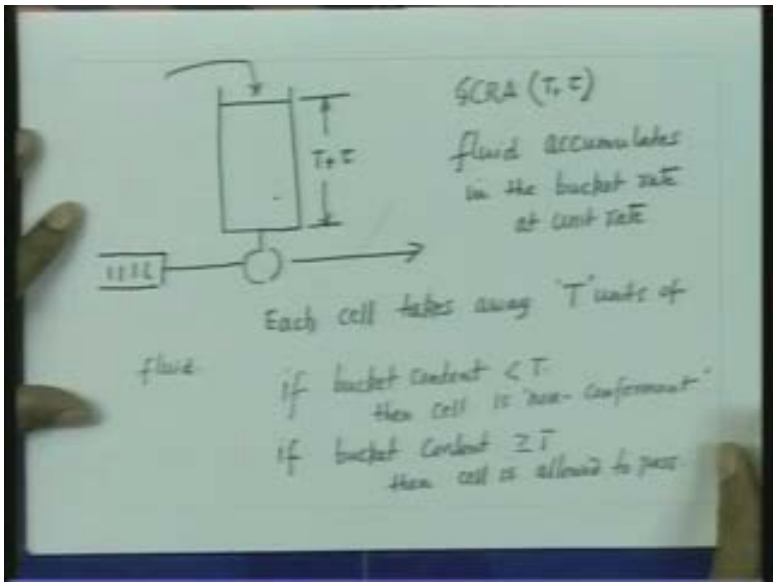

Now, leaky bucket interpretation is something like this. Now, this is a this is a leaky bucket for GCRA (T, tau). Now, this bucket has a maximum depth of T plus tau fluid, as I say accumulates; fluid accumulates in the bucket at unit rate.

Now, the cells are coming. Whenever a cell comes, it takes away T units of fluids. So, each cell takes away T units of fluid. Now, if a cell comes and it finds that the fluid contains in the bucket is less than T. So, if bucket content is less than is less than T, then the cell becomes non conferment.

Now, if we are putting this device at the source, then what we will do is that if a cell comes and if it finds that in the bucket there is less than T units of fluid and the cell will be simply waiting in the buffer and it will be transmitted only if the content becomes capital you know content becomes at least equal to T here in the bucket. But if this device is put at the network side and if a cell comes and if it finds that the bucket is not having enough fluids, then obviously that cell is not confirming to GCRA (T, tau) and then the network may drop this cell because this cell is not confirming to the advertised traffic contract.

Now, if bucket content is greater than equal to cell, it is greater than or equal to T. Then of course, the cell is allowed to pass through and the content of the bucket decrements by T. Now, let us take the same example that we had considered. Now for this, examples which we took was GCRA (10, 3) you know, this was the examples that we have considered and the some example will try to explain by the leaky bucket.

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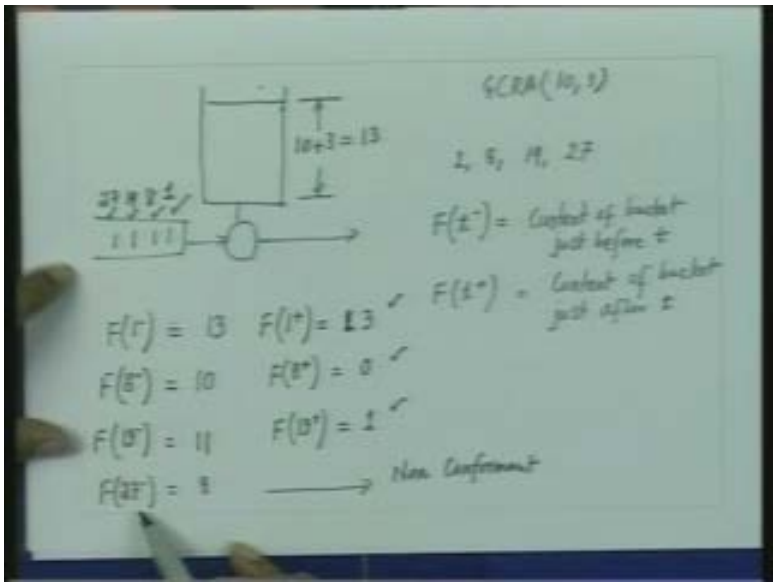

Now, by this example, what does it mean that initially the bucket content where T plus tau which in this case was 10 plus 3 which is equal to 13. So, we are trying to explain this for GCRA (10, 3). So, here is a leaky bucket structure. Now, these cells are coming at different times and we assume that the cells are coming at a time of 1, 8, 19, 27. Now, let us say F(t) minus denote the content of the bucket or amount of the bucket just before time t and F(t) plus denote the content of bucket just after t.

Now, let us see what happens. The first cell comes, the timed contents are 10 plus 3, 13. So, that means F(1) minus this content is you know 13. Now, this cell comes one, it takes away t units of fluids as we had said; so when this cell goes F(1) plus, the content becomes, how much? 1. Because, it takes away 10 units of fluids. Now let us say, F(8) minus. At F(8) minus sorry the contents here becomes 3. So, they are 13, you take away 10 units of fluids and the contents here becomes actually you know 3 not 1.

Now F (8) minus, already 3 units of fluids were there and in these 8 from 1 to 8, total 7 units of fluids will accumulate. We are assuming that the fluid is accumulating at a unit rate. 3 was already here, so F(8) minus is 10 and F(8) plus that is let us say, this is the cell which has come one and this is the cell which has come at 8. So, at F(8) plus, the content will become 0 because it will get decremented by 10. So, there will not be any fluid remaining now at F plus.

Now, F the third cell which is coming at 19; so F(8) 19 minus, the content in the bucket would be, how much? Here they were 0 and 8 plus to 19, we would have accumulated the content to be 11 and therefore on F(19) minus 19 plus, the content would become 1.

So therefore, this cell will be conferment, this cell will be conferment and this cell be conferment. Now, the fourth cell comes which is at 27. So, now let us see what will be this content at F (27) be minus. Now, the contents at F(27) minus would be actually 8 and this is not

sufficient for this cell to pass through, because minimum 10 units fluids are required in the bucket.

So as a result, this cell is declared non conferment. Now, it has to if this device if you are using it at the source, then this cell 27 has to really wait in the buffer and how much time it has to wait? It has to wait for 2 more units of fluids to get accumulated. That means you know it has to wait till the time becomes 29 till the time becomes 29. And, when the time becomes 29 minus, then the content in the buckets would become 10 and then the cell can be passed through.

So, now we have seen therefore, how you know this can be implemented in terms of a leaky bucket algorithms although for the explanation purposes we are saying here that the fluid accumulates in the buckets at a unit rate and a cell takes away capital T units of fluids whenever it comes. But as you know, in practice, it will be implemented simply as a counter. So, what we are saying that the counter has certain maximum certain maximum unit up to which it can count and in this case it is T plus tau.

So, the counter is incrementing at a unit rate. It keeps on counting, it is incremented at a unit rate and wherever a cell comes, the counter needs to be decremented by capital T and if you find that by capital T, the counter is not becoming negative. That means you can decrement it by the full capital T amount without becoming less than 0, then that cell is conferment and it is allowed to pass through and the counter is decremented by the capital T amount.

So, it can be you know this can be simply implemented as a counter. Now remember, again at the traffic source, this works like as a traffic regulator or a traffic shaper and at the network side, it works like as some kind of a traffic monitor. Now, as we have seen that the traffic descriptors which a network is actually asking the source to specify or something like peak cell rate and the cell delay variation tolerance. So, now let us see you know how these confirms to those kind of a traffic descriptors. So, let me just explain that.

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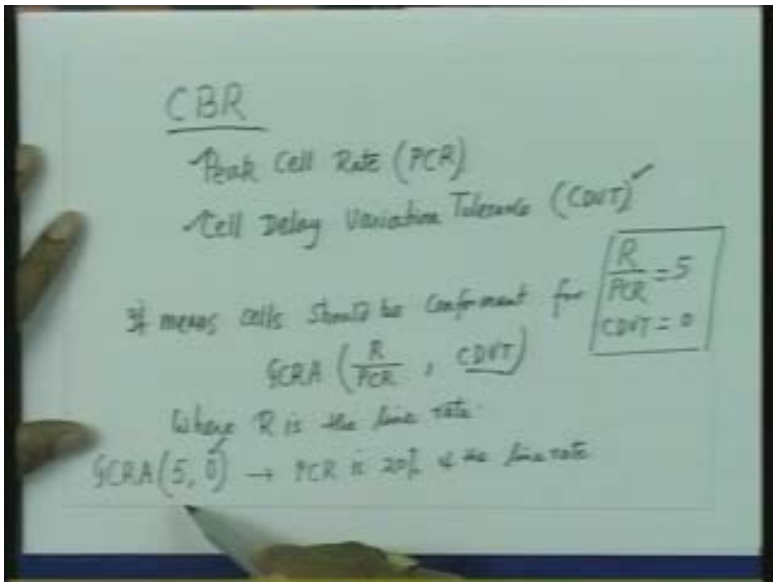

Now, let us say that it is a CBR traffic source. By a CBR traffic source, by a CBR traffic source we mean that it is a constant bit rate traffic source. Now, this constant bit rate traffic source will be specified by what we call as the peak cell rate and the cell delay variation tolerance.

Now typically, in a constant bit rate traffic, it is assumed that the bits are coming at a constant rate. But still for the cell rate, the cell rate may not be constant because there may be a deviation from the constant cell rate in terms of the packetization times and so on.

So even though the bits are coming at a constant bit rate, but the cells may not be coming at a constant cell rate. There may be a departure from the exact periodicity of this constant cell rate and that is given by this cell delay variation tolerance. So, we say that a CBR traffic when it specifies its peak cell rate and cell delay variation tolerance, it means that all the cells should be conferment for GCRA (R by PCR, CDVT) where R is the line rate where R is the line rate.

Now, what does it mean? It actually means that the cell can come at the peak cell rate but the CDVT that is the cell delay variation tolerance, actually measures the departure from the from its exact periodicity.

So now, let us say for an example that if I say that GCRA (5, 0). What is 5, 0? 5, 0 means that R by PCR this is 5 and CDVT is 0. Now by saying R by PCR is 5, it actually means that the peak cell rate is 20% of the line rate peak cell rate is 20% of the line rate. What we are saying that for the CBR traffic, it is expected that the cell should come at this constant rate PCR. But the cell delay variation will measure the departure from the periodicity.

Now in this case, the cell delay variation, the tolerance we are saying that it is 0. Now, when we say that the tolerance is 0; then the obviously the question is that in that case what is the fastest cell sequence you know that is expected? And, the fastest cell sequence that is expected will be minus 1.

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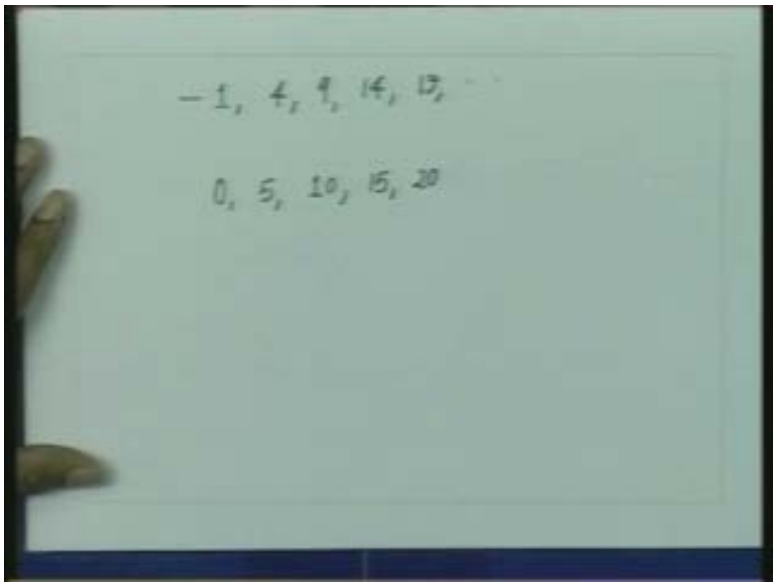

Now, remember that you could come at 0. But since you have a cell delay variation tolerance of 0, you are allowed to come at minus 1 time as well. So, fastest cell sequences minus 1, 4, 9,14, 19 and so on. Another cell sequence which will possible is 0, 5, 10, 15, 20 and so on. Now, this confirms to the constant bit rate of 5,0. If we had a tolerance, a cell delay variation tolerance, some tolerance; then it would have determined the departure from the exact periodicity as we had considered in the previous example of GCRA (10, 3).

Now, GCRA (10, 3) means 10 is actually equal to the ratio of R by PCR. In that case, we are saying that the peak cell rate is 10% of the line rate, the peak cell rate is at 10 % of the line rate. But that capital T is 10, but the 3, the delay, the tolerance 3 is measuring the departure from the periodicity of this constant bit rate source.

Now, let us see how we can represent the burst tolerance? This is okay for the constant bit rate traffic, but what about the bursty variable bit rate traffic? Because, the bursty variable bit rate traffic will actually be also sending back to back cells in the form of a burst and again for a long interval of time, it may not send any burst or any packets and suddenly it may send the burst.

So, how do you represent such a variable bit rate bursty traffic through some kind of a similar mechanism like leaky bucket or so? Now, let me just give you, explain that through an example. Let us say GCRA, let us say that GCRA, this time instead of 10, 3 let us take an example of GCRA 20 and 57; so, GCRA (20, 57).

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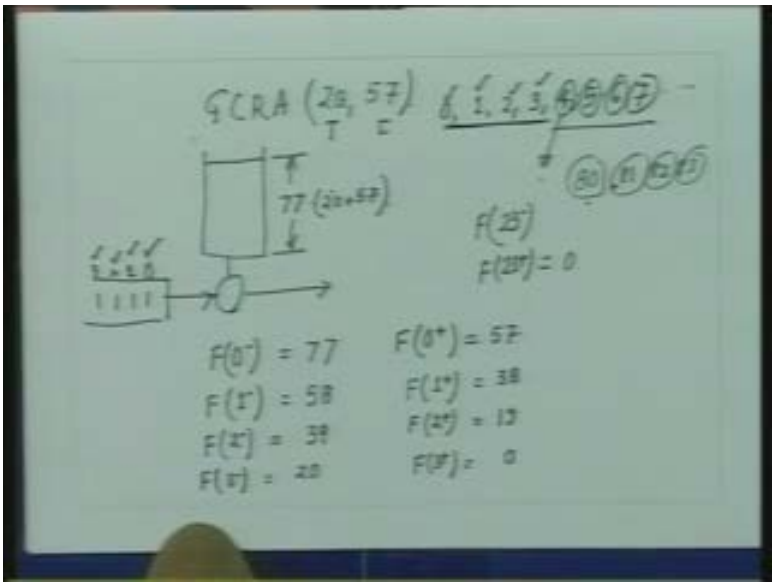

Now, let us say we have traffic source. So, let me just explain with this 20, 57 and then… Let us say that the cells are coming like at 0, 1, 2, 3, 4 so on. These are the cells which are sort of coming. Now, let us see what happens?

Now, the leaky bucket will have 77 units of fluids initially which is 20 plus 57. So, these are the cells which are coming. So, F(0) minus, when the cell is coming at 0; the fluid amount was 77. Now, when this cell came, the first cell at 0; it takes away 20 units of fluids, capital T. So, this is capital T and this is tau. It takes away 20 units of fluids. When it takes away 20 units of fluid, F(0) plus, that becomes 57.

Now, the second cell comes at time 1. Let us see what is there F(1) minus? What is there in F(1) minus? F(0) plus, already 57 units of fluids are there and 1 unit of fluid would have entered in the time you know from 0 to 1 and therefore, the total units of fluids that will be there will be 58. Now, this cell will take away 20 units of fluids and therefore the fluid content F(1) plus will become 38. F(2) minus, F(2) minus is again 39 and F(2) plus, F(2) minus remember here it is a 38 units of fluids and one more unit of fluid will accumulate and when the cell 2 comes here, it will decrement by 20 and therefore F(2) plus will become 19.

Now, the third cell comes at F(3). So, what will be at F(3) minus? Just before the time 3, 19 units of fluids are already there at 2, one more unit of fluid accumulates and it becomes you know 20. So therefore, when a third cells comes, it decrements by 20 and F(3) plus becomes 0. Now, these 4 cells zero 1, 2, 3 are allowed to transmit. Now, the fourth cell if it comes, it cannot transmit here because it wants enough amount of fluids to get accumulated.

So, for how much time it has to wait? It has to wait till 20 units of fluids to get accumulated and 20 units of fluids will get accumulated only at the time of… Since the fluid is accumulating at a unit rate, since the fluid is accumulating at a unit rate, it will have to wait till F(23) minus. That

is the cell will have to wait for 19 more units because it has to come at time unit 4. It has to wait for 19 more unit in the buffer before it can be allowed to transmit.

Now, what is the interpretation of this? The interpretation of this is that on an average, the source can transmit 4 cells back to back. That is what we have allowed. Now, if the source again wants to transmit back to back cells, then it has to wait for how long? It has to wait till time 80. At time 80, see remember, if these 4, 5 these cells are not transmitted, you want to transmit again these back to back cell, let us say 4, 5, 6, 7 these 4 cells also have come. Now, if you want to transmit 4? Well, there will be enough fluid content at F(23) minus and you can transmit 4. But then immediately if you transmit, F(23) plus will become you know 0 and therefore the fifth cell, you actually cannot transmit.

So, if you want to transmit these 4 back to back cells, then you need to wait till the time 80. At 80 time unit, at 80, 81, 82, 83; you can transmit 4 back to back cells again. So, what is happening essentially is that the source is able to transmit approximately 4 cells in a time unit of 80. If it has to transmit always in the bursty form, then it can transmit 4 cells in a time units of 80. This gives an average rate of 4 by 80. That is 1 cell in approximately every 20 time units.

On the other hand, the burst it can transmit, a maximum burst is of 4 cells back to back. So, this actually represents a variable bit rate bursty source, a source whose average rate is 1 cell in every 20 time units that is what its average rate is. On an average, it can transmit 1 cell in 20 time unit and it can transmit a maximum burst of 4 cells back to back.

So, this is like saying that the sustained cell rate you know the sustained cell rate or the average cell rate is 1 cell in every 20 time units and its maximum burst size is 4 cells back to back.

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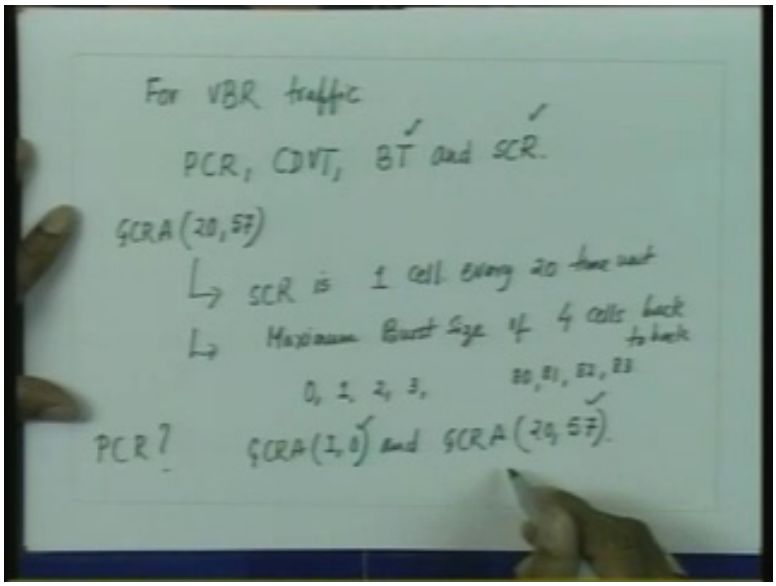

So, for the VBR traffic therefore, the ATM forum you know specifies that for VBR traffic; the ATM forum specifies that source should be confirming to the peak cell rate, the cell delay variation tolerance and burst tolerance and sustained cell rate. Now, we just saw an example where we are saying GCRA (20, 57) which we were saying is a representative of sustained cell rate is 1 cell in every 20 time units and maximum burst size maximum burst size of 4 cells back to back.

We saw that those 4 cells back to back, when they were sent? They were sent as 0, 1, 2 and 3. Later on, then we sent as 80, 81, 82 and 83. So, what is the minimum time interval between the cells if you say, if you want to know? What is the peak cell rate? What is the peak cell rate? Honestly, the peak cell rate, the minimum time interval comes out to be as 1 and the cell delay variation tolerance comes out to be you know 0.

So, we say that this source is confirming to GCRA (1, 0) and GCRA (20, 57). That is what this source is confirming.

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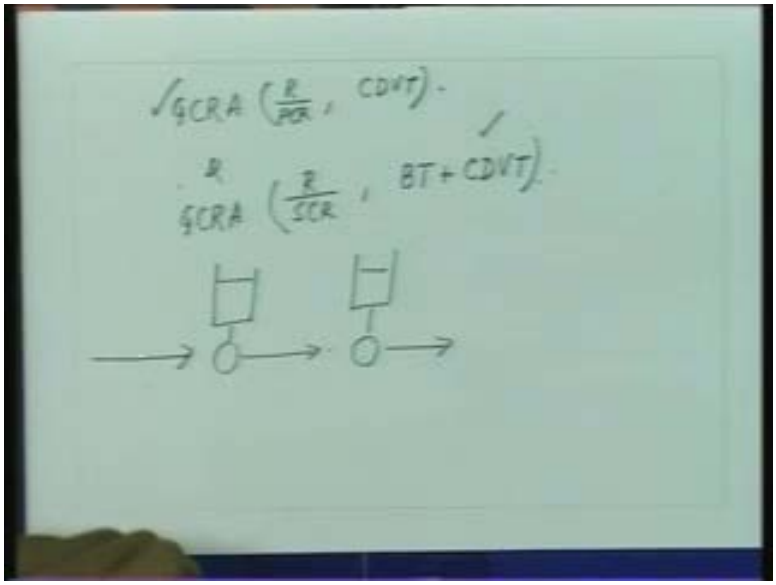

The meaning of these parameters says that a VBR source, a VBR source should be confirming to some GCRA (R by PCR, CDVT) cell delay variation tolerance and GCRA (R by SCR) burst tolerance plus CDVT. What does it mean? If a traffic stream is coming, it should first pass through a leaky bucket which will make it confirming to this GCRA R by PCR in cell delay variation tolerance and then it should also confirm to R by CR, burst tolerance plus cell delay variation tolerance. This it should be conferment for both.

This will give you that it is conferment to the minimum transmission time or the minimum interval between the cells and the other leaky bucket. That is R by SCR and CDVT will give you that it confirms to the burst tolerance and the sustained cell rate.