

# The Expedited Forwarding PHB

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- The Expedited Forwarding (EF) PHB is a basic building block in the Differentiated Services architecture
- EF is intended to provide a building block for low delay, low jitter and low loss services by ensuring that the EF aggregate is served at a certain configured rate
- Or example, circuit emulation services could be transported over the EF PHB

# The Expedited Forwarding PHB

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- The dominant causes of delay in packet networks are fixed propagation delays (e.g. those arising from speed-of-light delays) on wide area links and queuing delays in switches and routers
- Since propagation delays are a fixed property of the topology, delay and jitter are minimized when queuing delays are minimized
- For our purposes, we define jitter as the variation between maximum and minimum delay
- The intent of the EF PHB is to provide a PHB in which suitably marked packets usually encounter short or empty queues
- Furthermore, if queues remain short relative to the buffer space available, packet loss is also kept to a minimum

# The Expedited Forwarding PHB

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- To ensure that queues encountered by EF packets are usually short or empty, it is necessary to ensure that the service rate of EF packets on a given output interface exceeds their arrival rate at that interface over long and short time intervals, independent of the load of other (non-EF) traffic
- Thus, EF packets must be guaranteed to receive service above a configured rate
- Moreover, a means to quantify the accuracy with which this service rate is delivered over any time interval must be provided

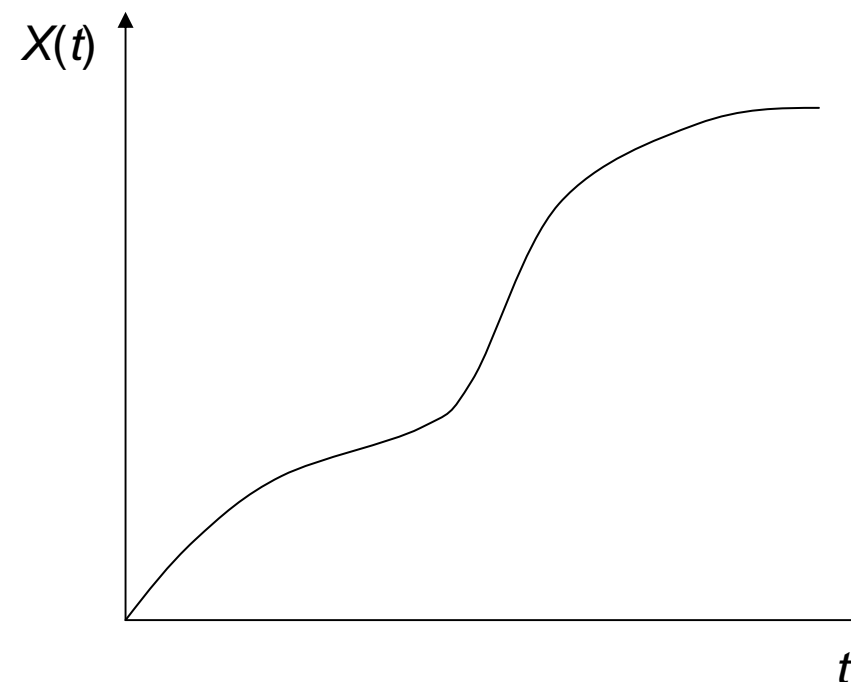
# Traffic and service curves

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- In order to perform basic performance evaluation, two basic notions must be introduced:
  - ◆ Traffic curve
  - ◆ Service curve

# Traffic curve

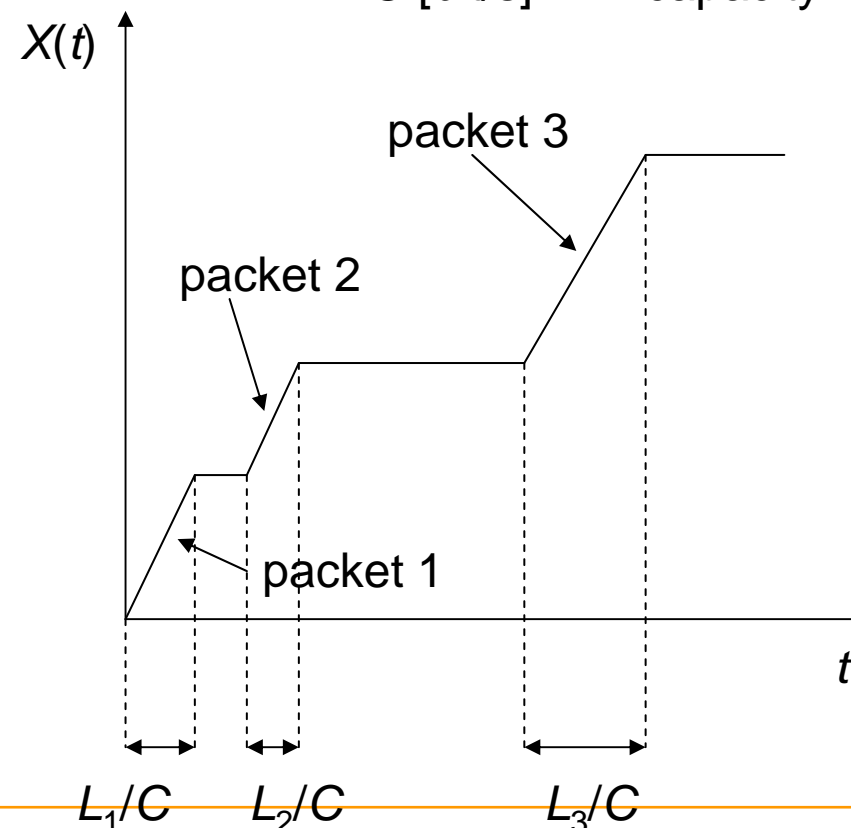
- Consider a specific network interface and assume to be able to count the number of bits  $X(t_1, t_2)$  crossing the interface in a given time interval  $[t_1, t_2]$
- $X(t_1, t_2)$  is the traffic curve at the reference interface
- If, by convention,  $t_1=0$ , the traffic curve is indicated as  $X(t)$



# Traffic curve

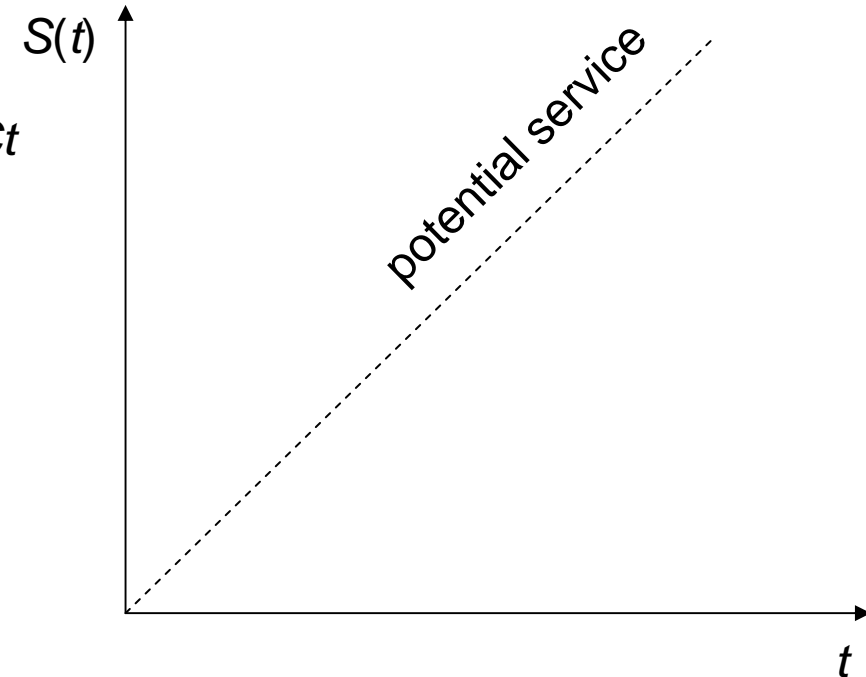
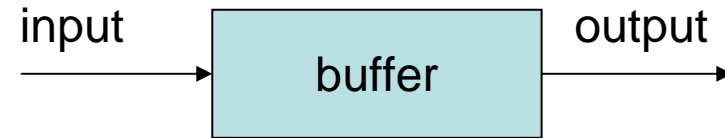
- Since traffic is packetized, the actual shape of a traffic curve is shown in this graph
- When a packet is crossing the reference interface, the curve increases linearly with slope  $C$  [bit/s], where  $x$  is the link capacity
- When no packet is present, the traffic curve is steady

$L_1$  [bit]: length of packet 1  
 $L_2$  [bit]: length of packet 2  
 $L_3$  [bit]: length of packet 3  
 $C$  [bit/s]: link capacity



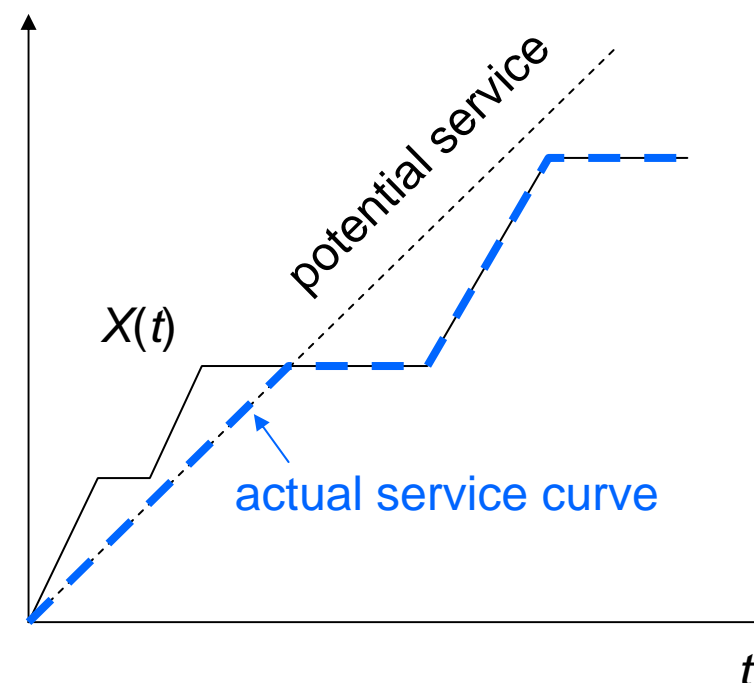
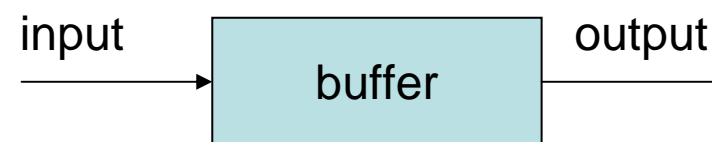
# Potential service curve

- Given a scheduler (in the example, a FIFO scheduler), the potential service curve  $S(t)$  is the maximum number of bits that the scheduler can serve in a time interval of duration  $t$
- Given a FIFO scheduler provided with an output link with capacity equal to  $C$ , the potential service curve is equal to  $Ct$



# Actual service curve

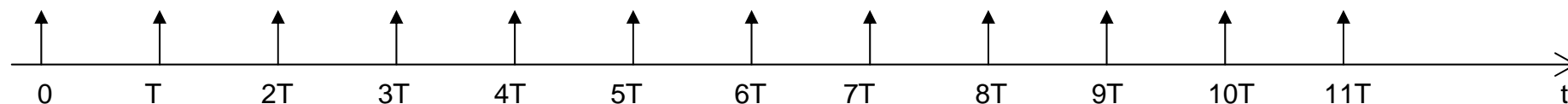
- Given a scheduler (in the example, a FIFO scheduler), the actual service curve is the traffic curve at the output of the scheduler, given an input traffic with traffic curve  $X(t)$





# EF PHB

- Usually, a fresh EF traffic flow is characterized with a periodic arrival process of equal-length packets
- All packets have length  $L$  (bit) and the arrival rate is  $1/T$  (packet/s)

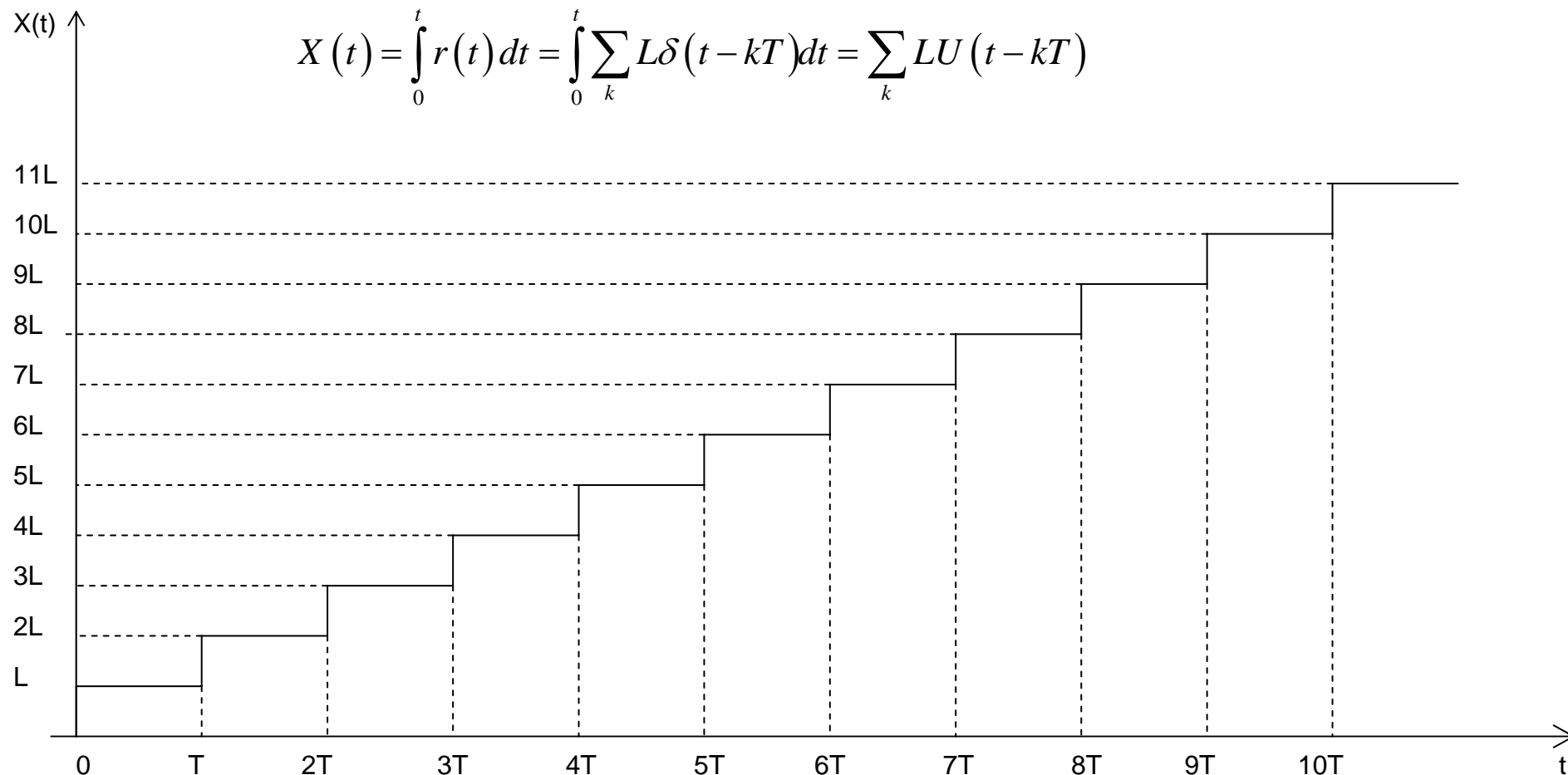


Packet arrival process:

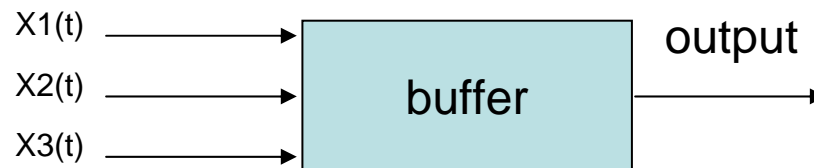
$$r(t) = \sum_k L\delta(t - kT)$$

# EF PHB

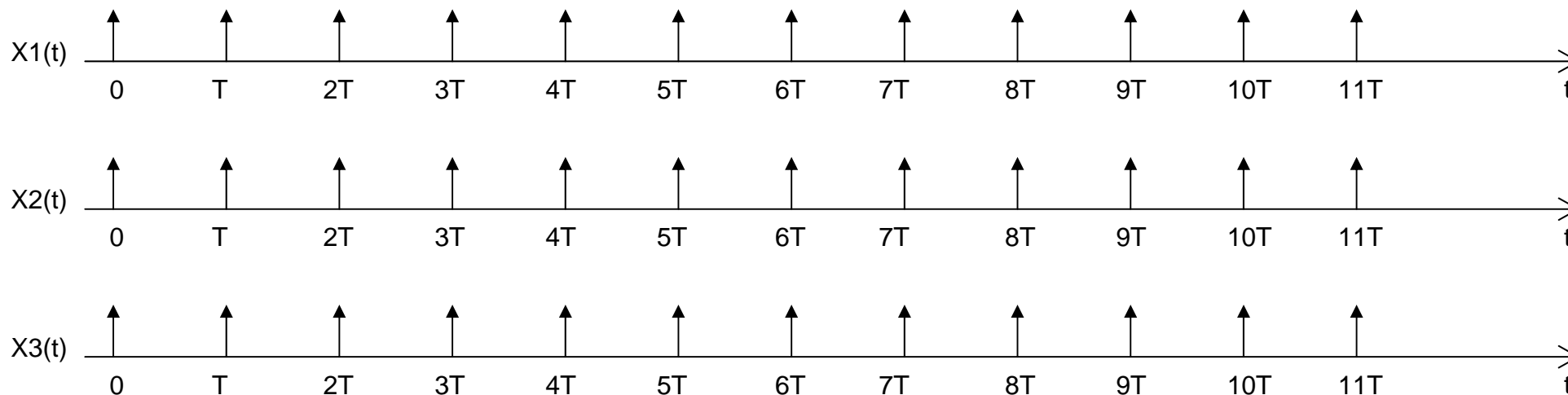
- The traffic curve relative to the previous example is shown in the figure



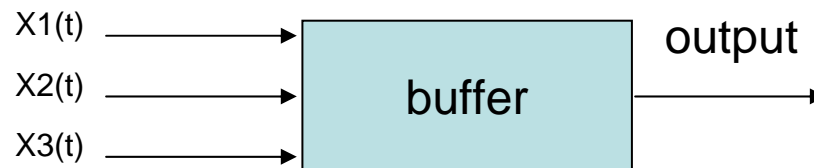
# EF PHB



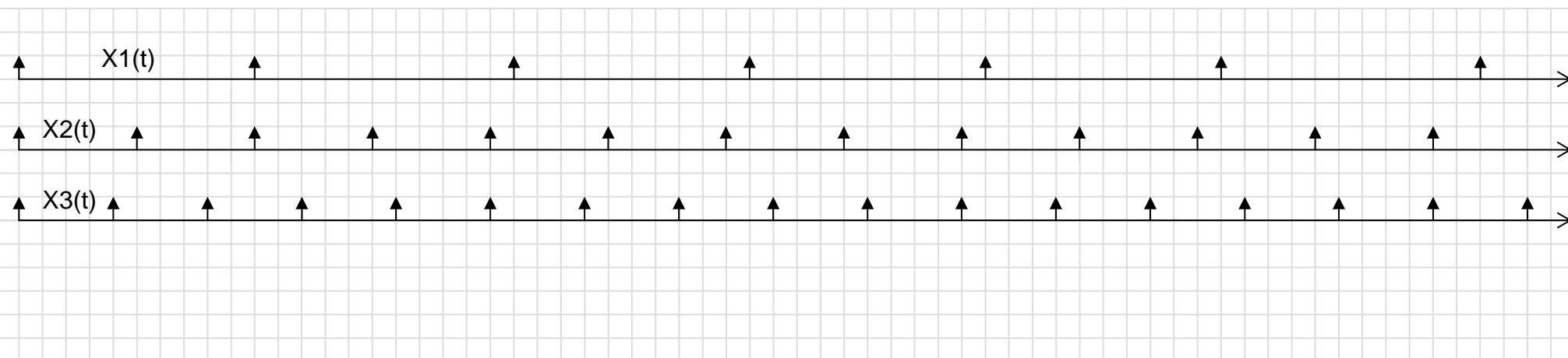
- Let us consider the case of three identical EF flows offered to a FIFO scheduler
- The worst possible case is that in which the phases of the three flows coincide:



# EF PHB

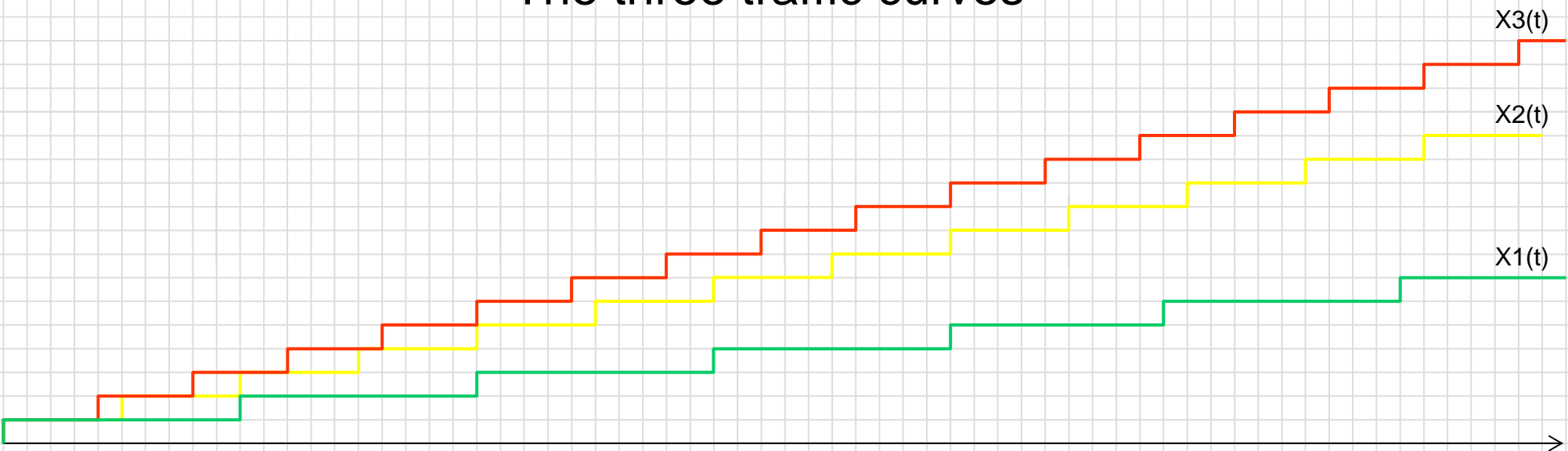


- Let us consider the following example, where the packet length  $L$  is 1000 (bit):
  - $X1(t)$ : 100 kbit/s; 1 packet every 10 ms
  - $X2(t)$ : 200 kbit/s; 1 packet every 5 ms
  - $X3(t)$ : 250 kbit/s; 1 packet every 4 ms



# EF PHB

## The three traffic curves



# EF PHB

The total traffic curve

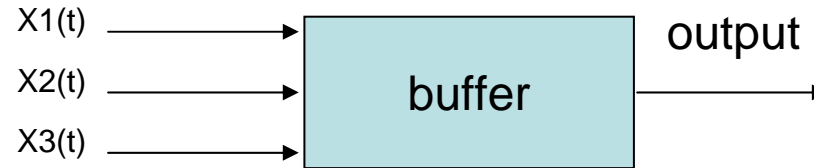
$$X(t) = X_1(t) + X_2(t) + X_3(t)$$

$X_3(t)$

$X_2(t)$

$X_1(t)$

# EF PHB



- Now, assume that the line capacity is equal to 1 Mbit/s
- In this way, the service time of one packet is equal to 1 ms
- The service of one packet is over when the last bit of the packet is transmitted
- Therefore, if the first bit of a packet is transmitted at time  $t$ , the last bit of that packet will be transmitted at time  $t + 1$  ms
- This is why the actual service curve grows by one packet as soon as the packet's service is over (i.e., 1 ms after the start of its service)

# EF PHB

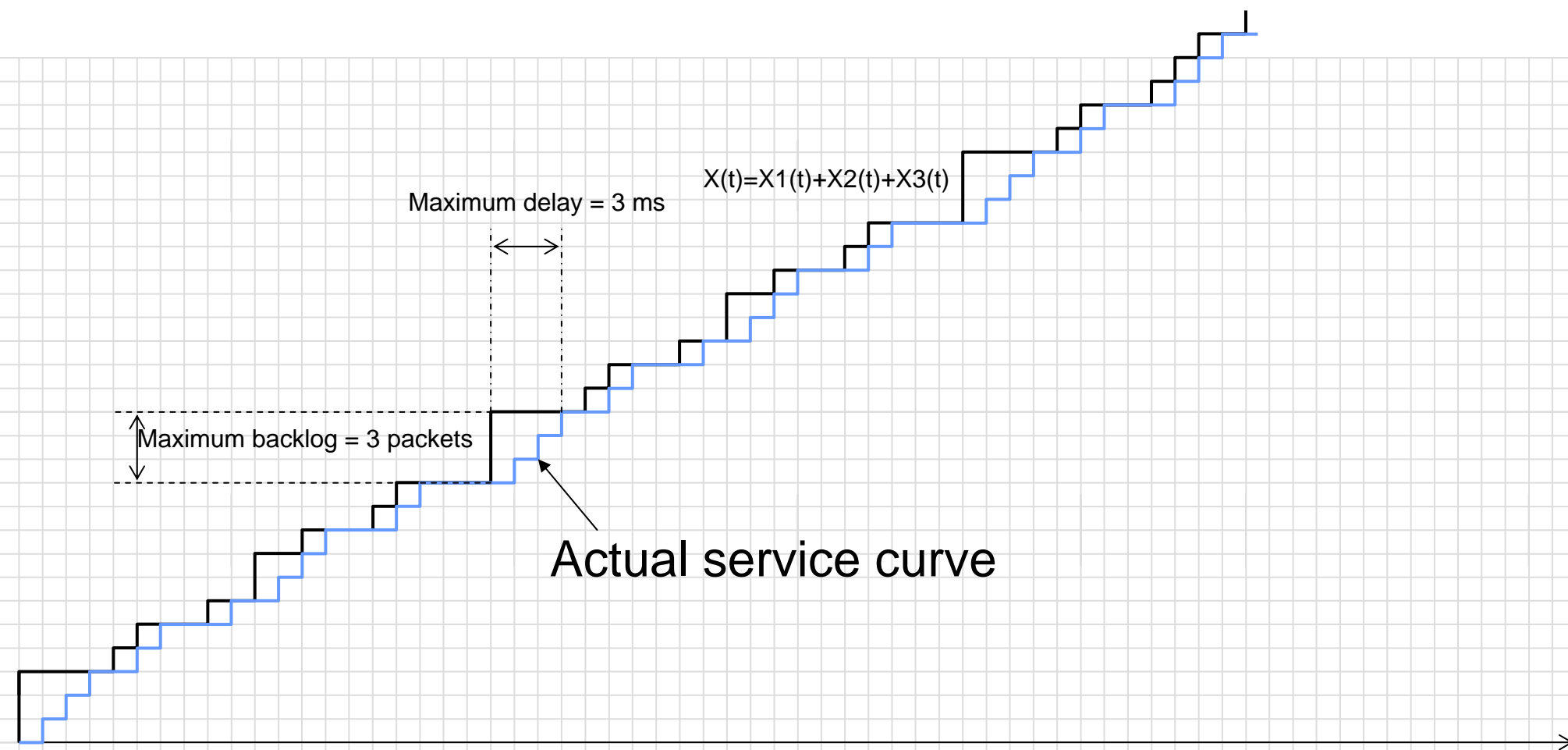
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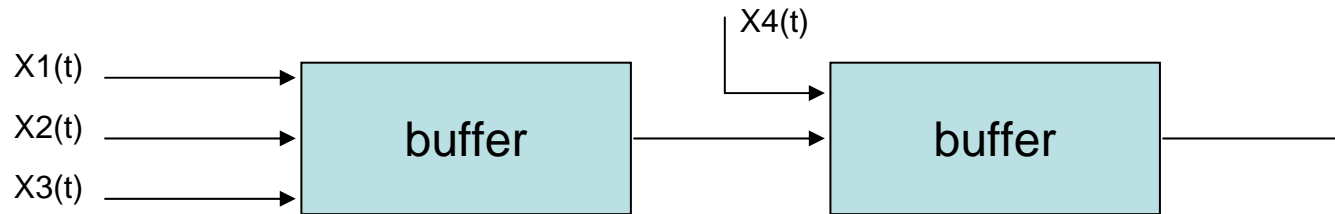
- The maximum delay is calculated as the maximum horizontal difference between the traffic curve and the actual service curve
- The maximum backlog is calculated as the maximum vertical difference between the traffic curve and the actual service curve



# EF PHB

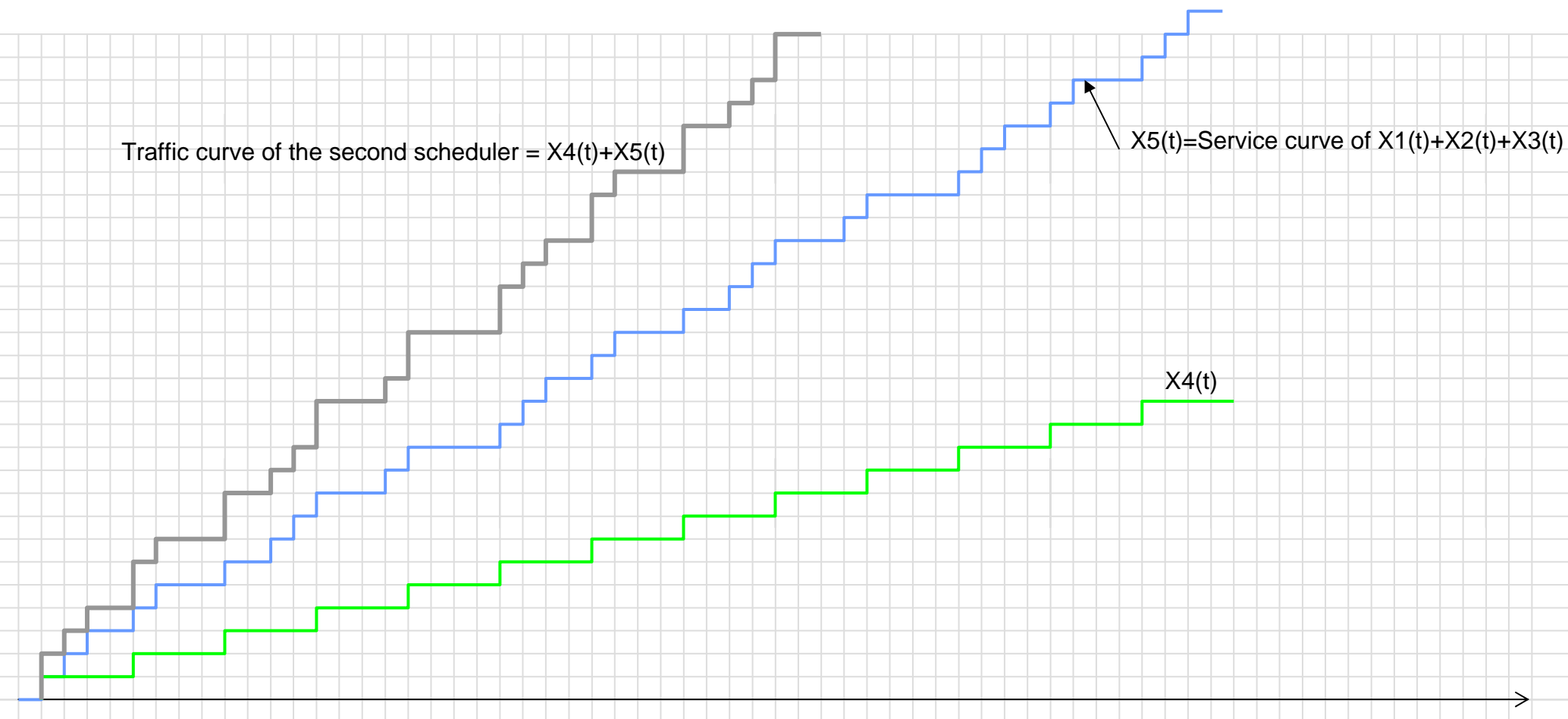


## EF PHB

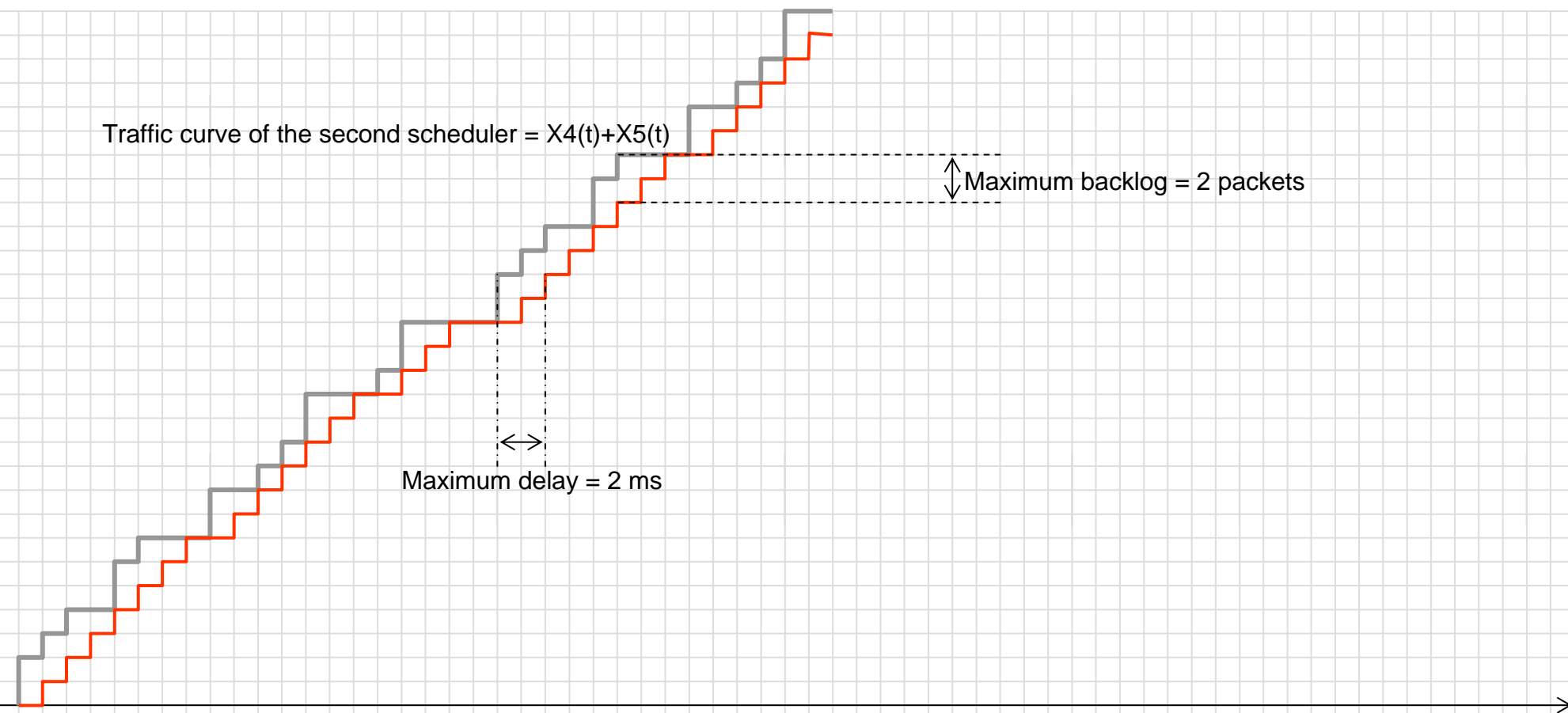


- Now, let us consider a multihop case, in which the output of the first scheduler is fed to a second scheduler, that receives an additional flow,  $X4(t)$
- $X4(t)$  has the same statistical features of the fresh flow  $X3(t)$
- We want to calculate the maximum end-to-end delay
- The curve of the traffic  $X1(t) + X2(t) + X3(t)$ , fed to the second scheduler, is the actual service curve of the first scheduler, previously calculated

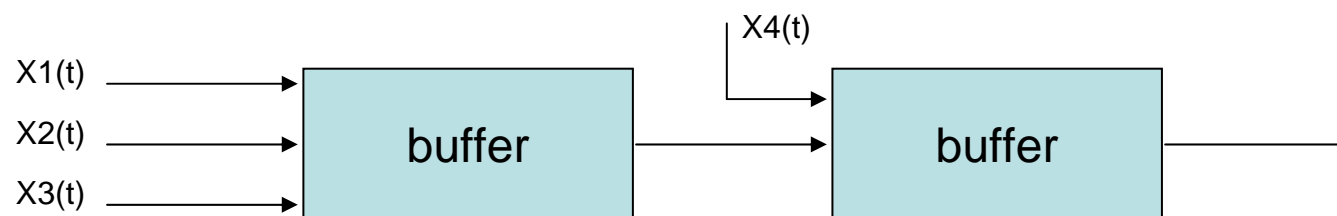
# EF PHB



# EF PHB

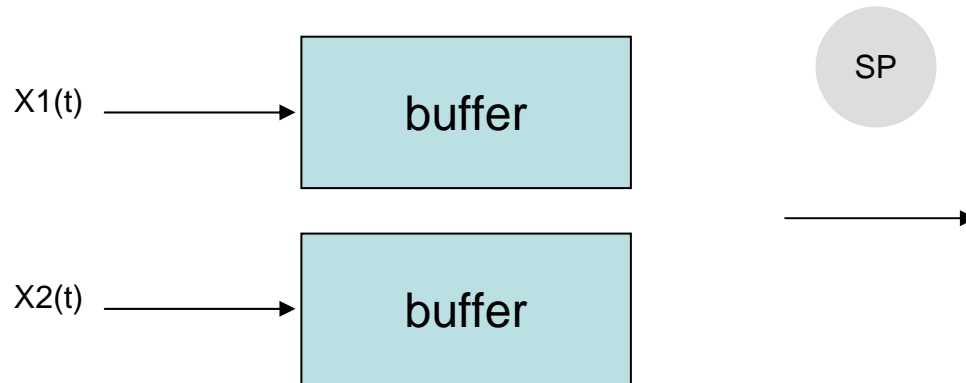


# EF PHB



- Thus, the maximum end-to-end delay of flows  $X1(t)$ ,  $X2(t)$ ,  $X3(t)$  is equal to  $3 \text{ ms} + 2 \text{ ms} = 5 \text{ ms}$

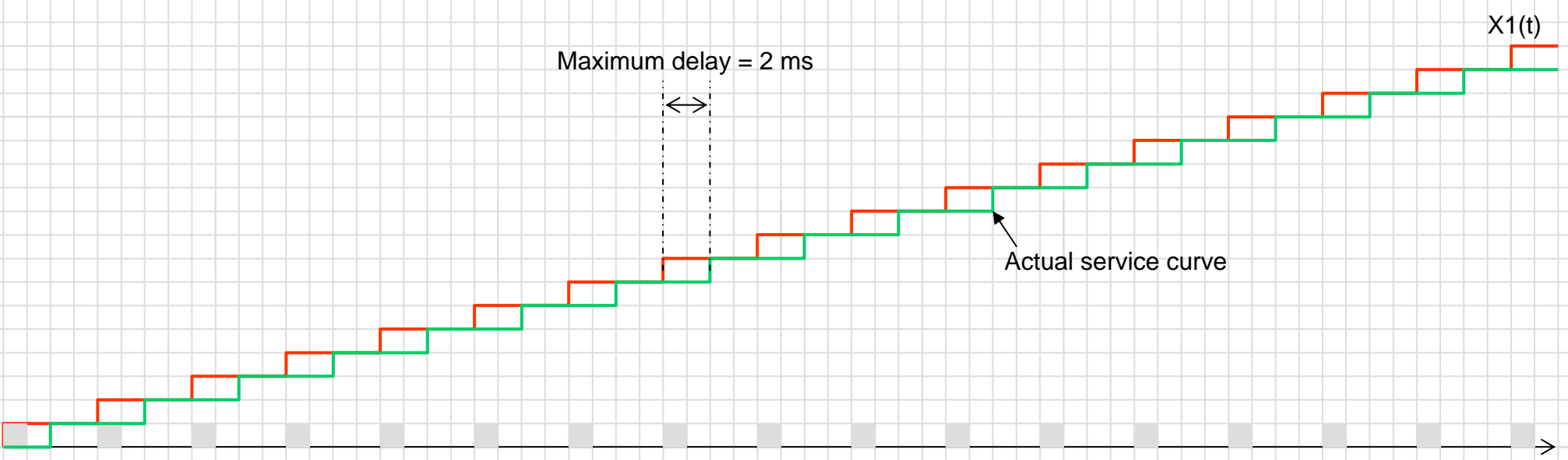
# EF PHB



- Now, consider a multi-class scheduler (in particular, a Strict Priority scheduler) where a fresh EF flow ( $X1(t)$ ) has higher service priority than a not-EF flow,  $X2(t)$
- $X2(t)$  might be a Best Effort flow
- In this case, the worst case delay for EF traffic is calculated by assuming that, when an EF packet is offered to the scheduler, a not-EF packet has just started its service
- The EF packet must wait the end of the not-EF packet's service, before starting transmission
- In the following example, let us assume that  $X1(t)$  has the same features of the  $X3(t)$  flow of the previous example
- Moreover, we assume that the packet length is constant and identical for the two flows

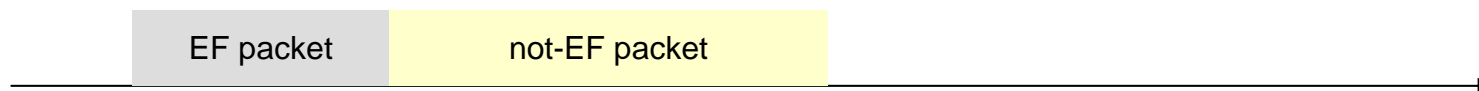
# EF PHB

■ = interfering not-EF packet



# Maximum configurable rate of EF traffic

- There exists a maximum configurable rate of EF traffic that can be allocated on a node's output line
- This is because all EF packets may find, at their arrival, another non-EF MTU-sized packet, this halves the sustainable EF rate
- In general, given an EF flow with packet length  $L_1$  and an interfering not-EF flow with packet length  $L_2$ , with a line rate equal to  $C$ , the maximum configurable rate of EF traffic is obtained by considering the diagram below, where for each EF packet a non-EF interfering packet causes an additional delay





# Maximum configurable rate of EF traffic

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- The maximum configurable rate of EF traffic is  $C_{EF}$
- The largest the not-EF packet length, the smaller the maximum configurable rate of EF traffic

$$C_{EF} = \frac{L_1}{L_1 + L_2} C$$

# Final (tiny) detail: the DS codepoint of the EF PHB

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- Codepoint 101110 is recommended in RFC 3246 for the EF PHB