CS144
An Introduction to Computer Networks

Packet Switching

Queue models

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Outline

1. Simple deterministic queue model
2. Small packets reduce end to end delay
3. Statistical multiplexing

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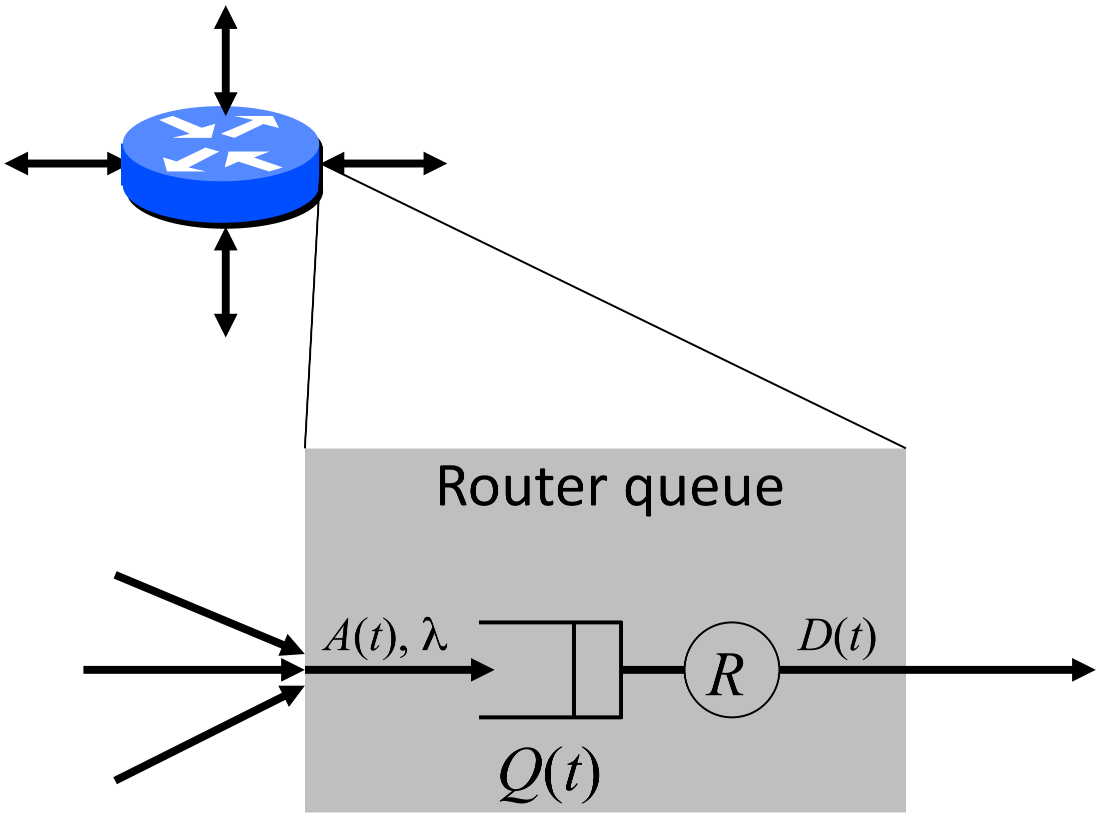
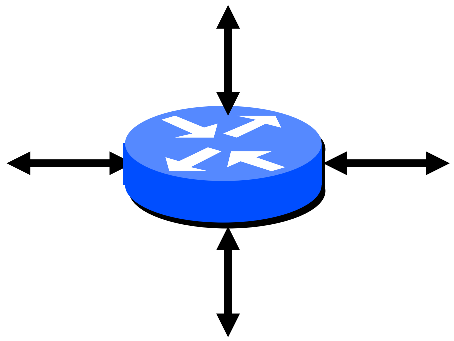
Simple model of a router queue



Properties of $A(t)$, $D(t)$:

- $A(t)$, $D(t)$ are non-decreasing
- $A(t) >= D(t)$

Simple model of a router queue



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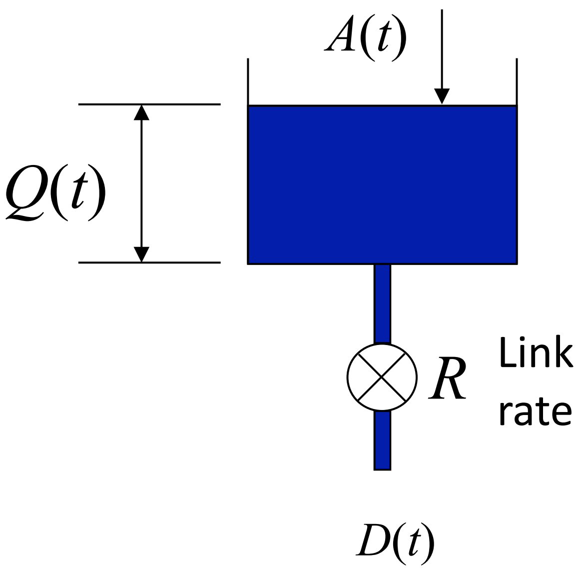
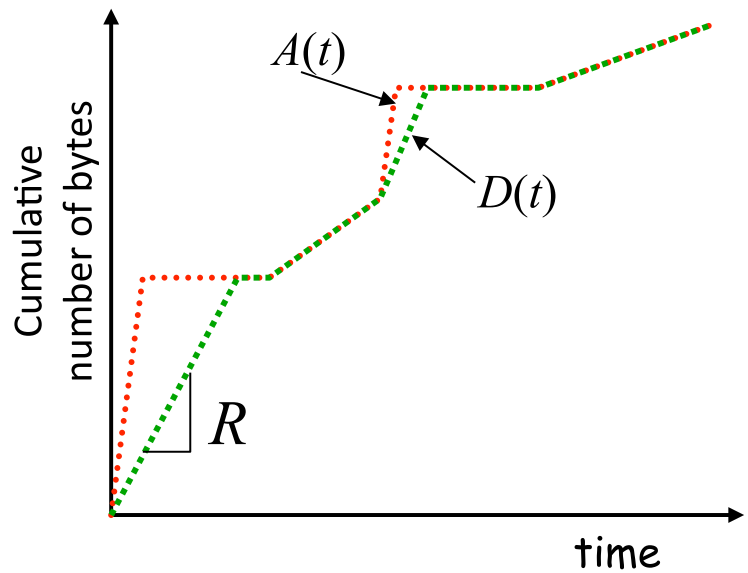
Simple model of a queue

Cumulative number of bytes arrived up until time t.



Cumulative number of bytes departed up until time t.



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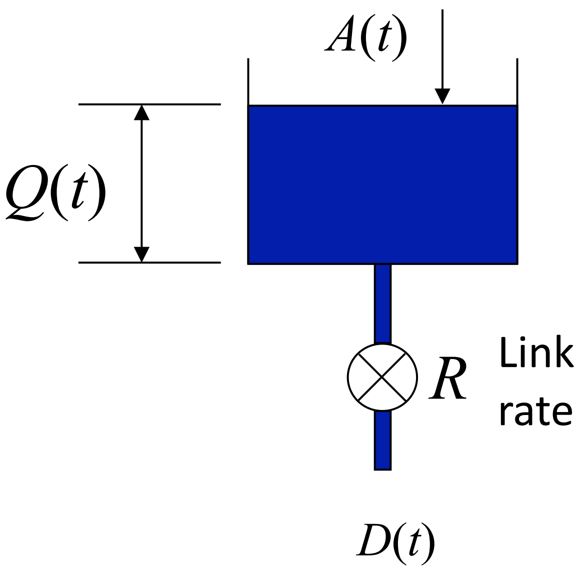

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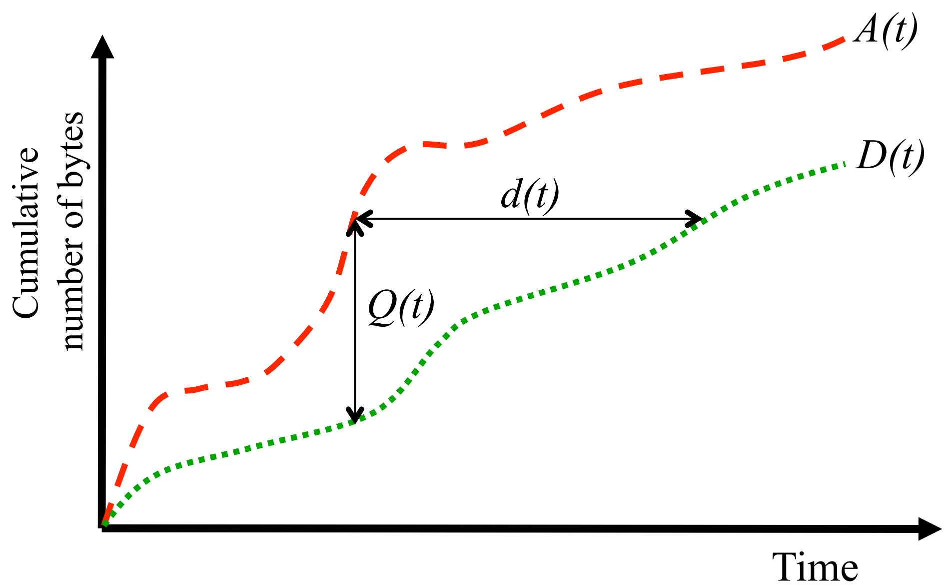
Simple model of a queue



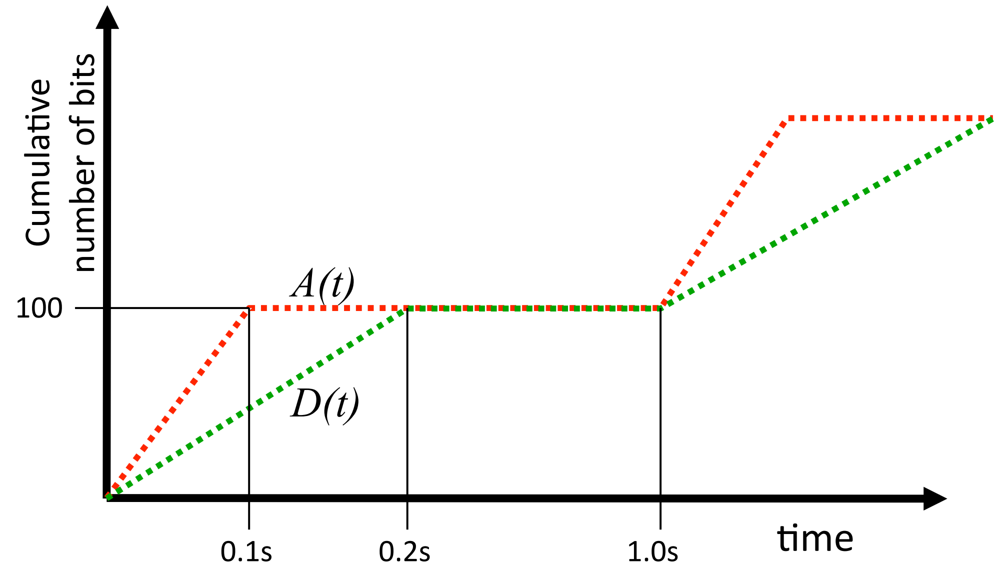
Queue occupancy: $Q(t) = A(t) - D(t)$.

Queueing delay, $d(t)$, is the time spent in the queue by a byte that arrived at time t, assuming the queue is served first-come-first-served (FCFS).

Simple model of a queue

Example

Every second, a 100 bit packet arrives to a queue at rate 1000b/s. The maximum departure rate is 500b/s. What is the average occupancy of the queue?



Solution: During each repeating 1s cycle, the queue fills at rate 500b/s for 0.1s, then drains at rate 500b/s for 0.1s. Over the first 0.2s, the average queue occupancy is therefore $0.5 \times (0.1 \times 500) = 25$ bits.
The queue is empty for 0.8s every cycle, and so average queue occupancy: $\bar{Q}(t) = (0.2 \times 25) + (0.8 \times 0) = 5$

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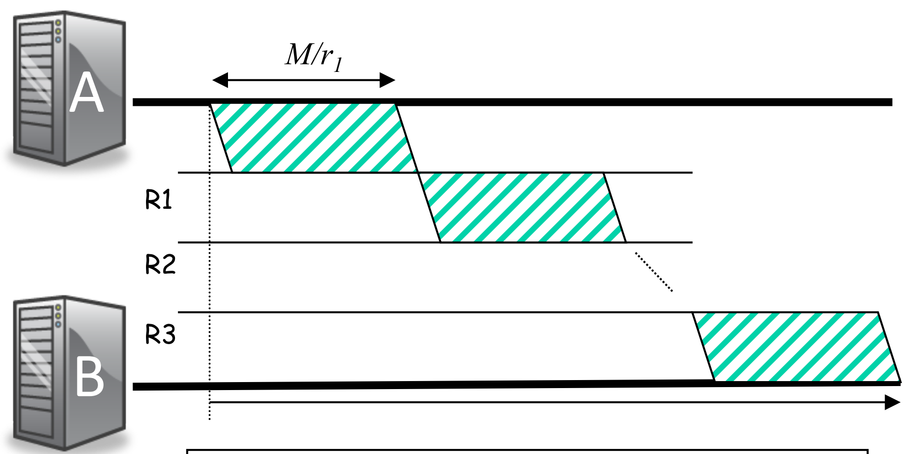
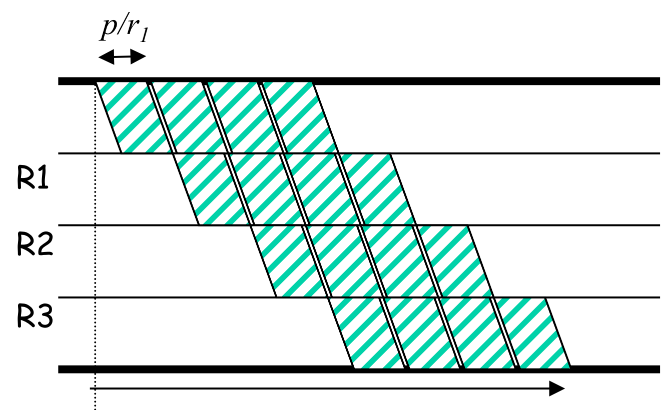
Packet Switching

Why not send the entire message in one packet?





$$\text{End-to-end delay}, \ t = \sum_i \left(\frac{M}{r_i} + \frac{l_i}{c} \right)$$

$$\text{End-to-end delay}, \ t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} \right) + \frac{M}{p} r_3$$

Breaking message into packets allows parallel transmission across all links, reducing end to end latency.

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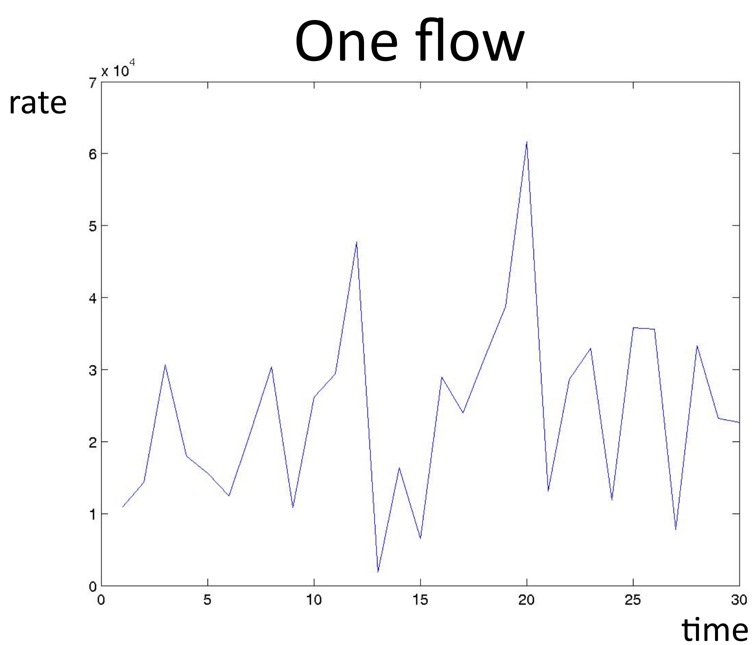
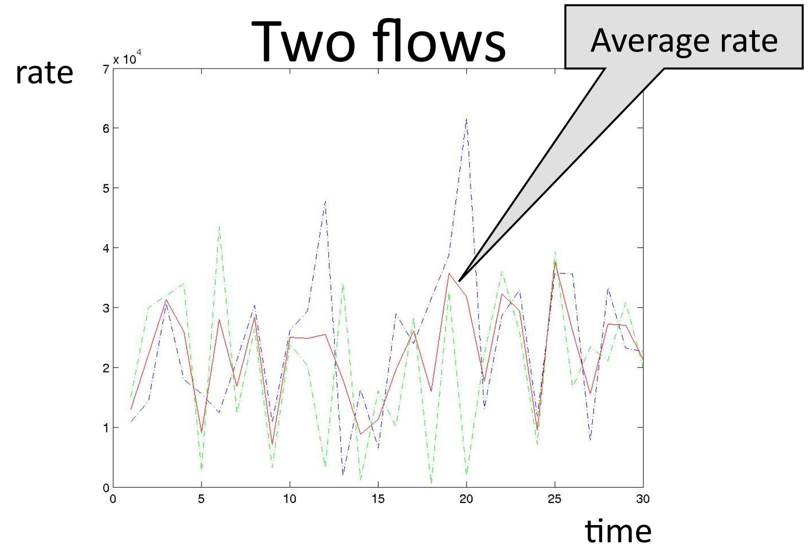
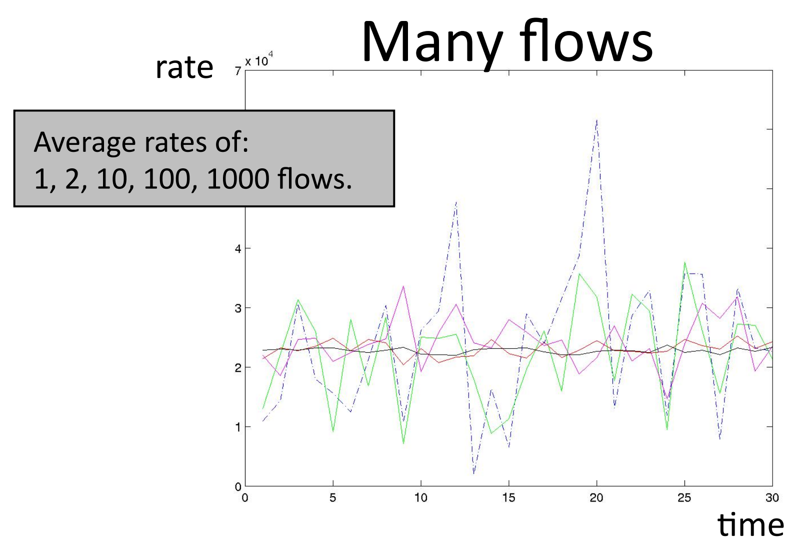
Statistical Multiplexing

Basic idea







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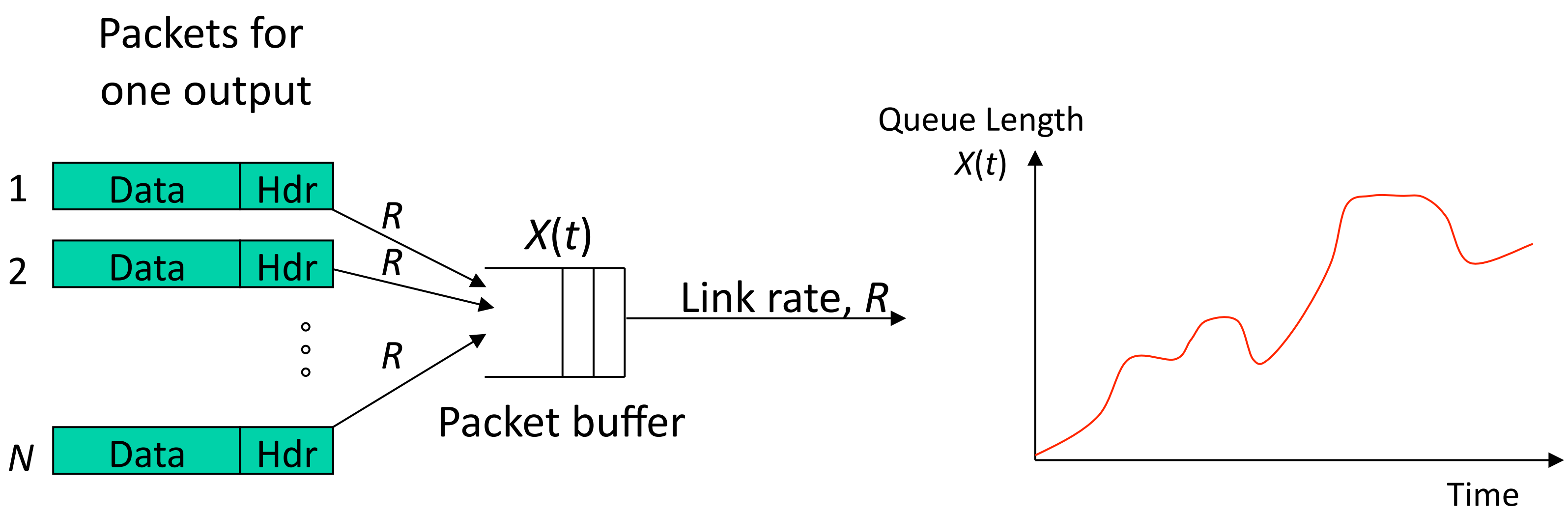
Packet Switching

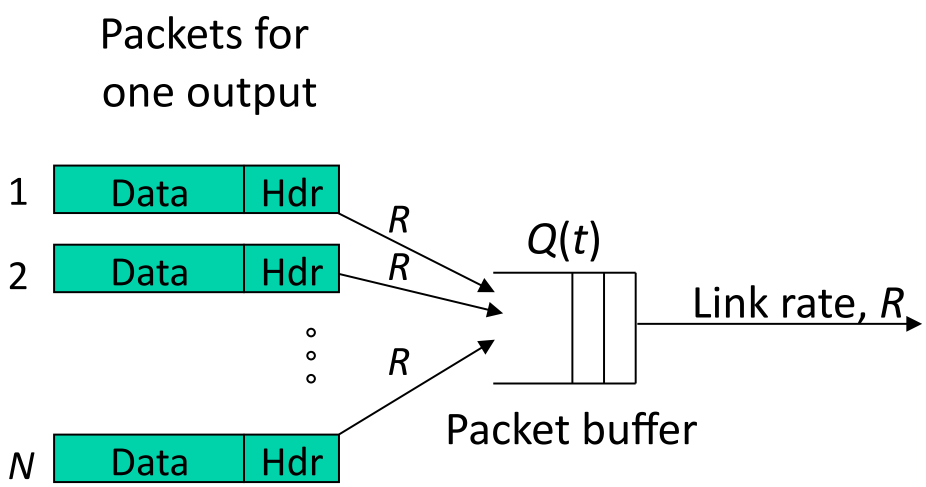
Statistical Multiplexing



- Because the buffer absorbs temporary bursts, the egress link need not operate at rate $N.R$.
- But the buffer has finite size, B, so losses will occur.

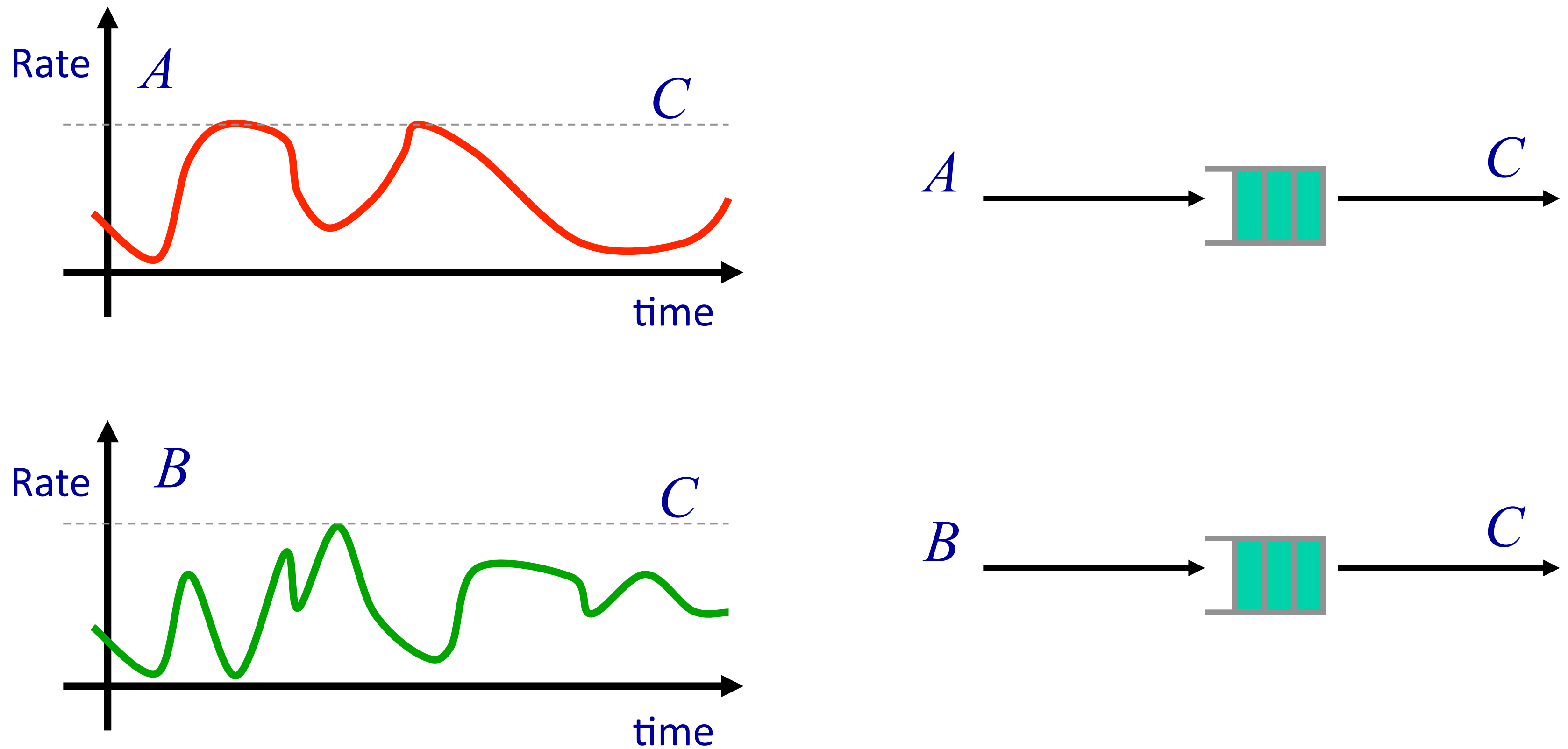
Packet Switching

Statistical Multiplexing

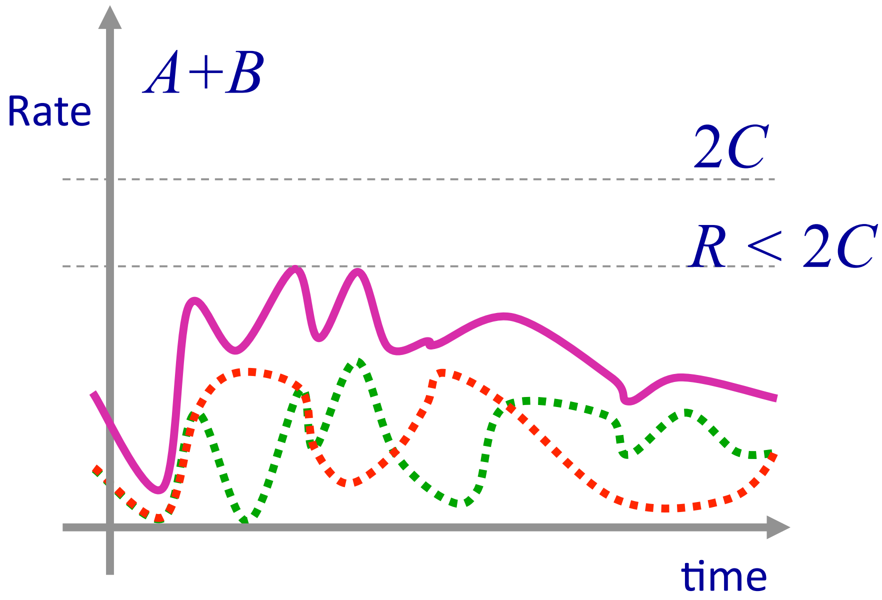


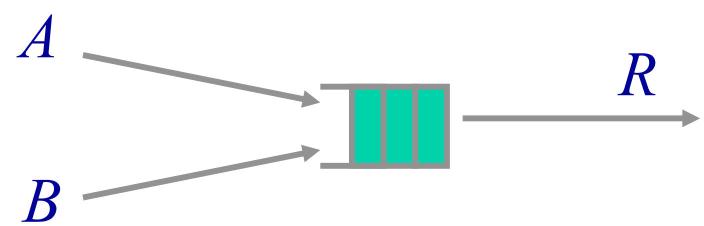
- Statistical multiplexing means the egress link need not run at rate NR.
- The buffer absorbs brief periods when the aggregate rate exceeds R.
- Because the buffer has finite size losses can occur.

Statistical Multiplexing



Statistical Multiplexing Gain





Statistical multiplexing gain = $2C/R$

Summary

Often, we can use a simple deterministic model of a queue to understand the packet dynamics in a network.

We break messages into packets because it lets us pipeline the transfer, and reduce end to end delay.

Statistical multiplexing lets us carry many flows efficiently on a single link.

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