

CS 725/825 & IT 725

Lecture 14

Transport Layer

October 20, 2025

Filling the pipe...

- ▶ **Stop and Wait** protocol
 - wait for acknowledgment before sending next packet
- ▶ **Sliding Window** protocols
 - send up to W (window size) packets/bytes before waiting for acknowledgment
 - when a packet is lost:
 - retransmit the packet (*Selective-Reject ARQ*)
 - retransmit all un-acknowledged packets (*Go-Back-N ARQ*)
- ▶ Measure: **utilization** (a.k.a. normalized throughput)
 - the ratio between *goodput* and *maximum theoretical capacity*

Two bottlenecks

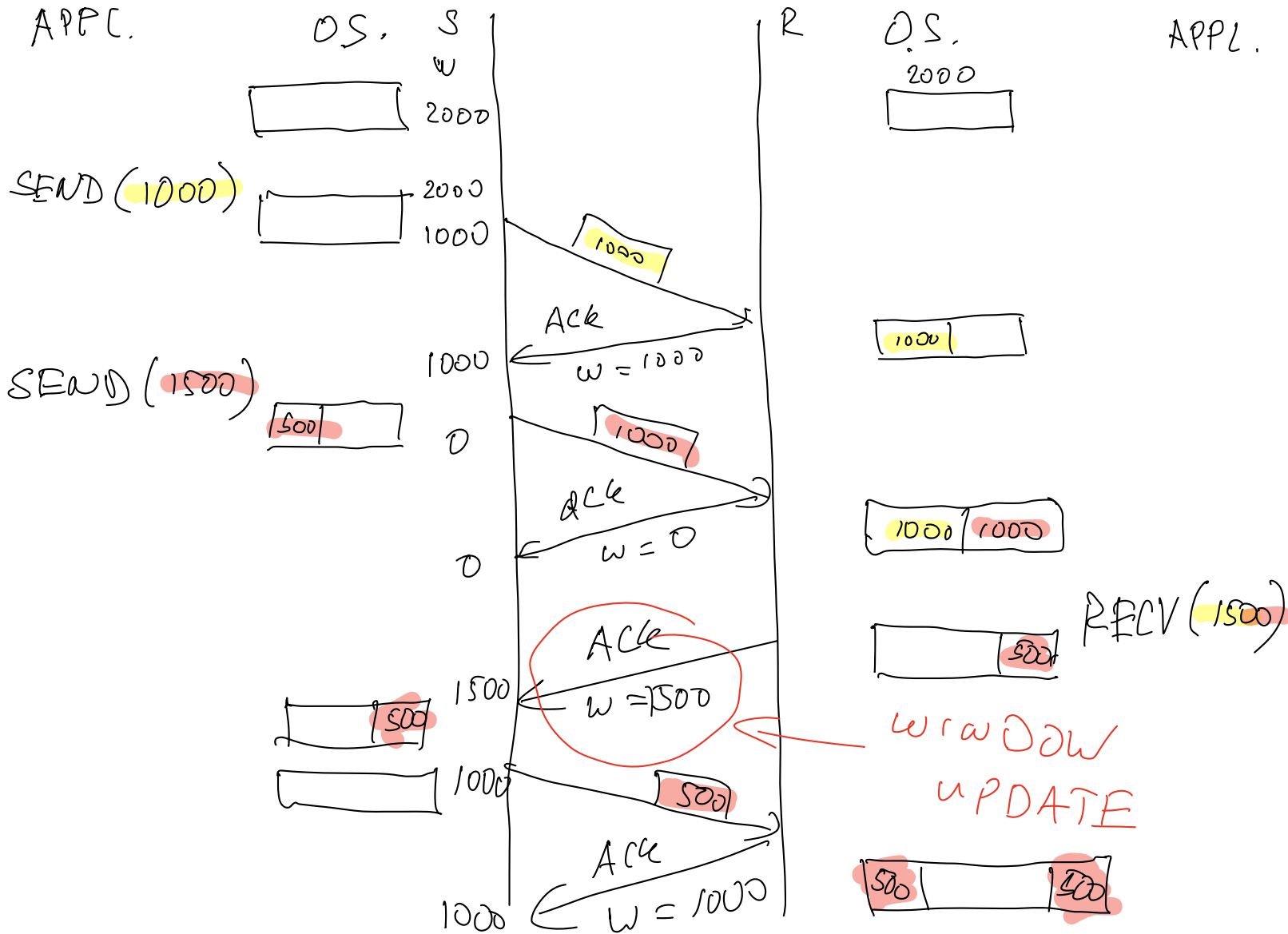
► Receiver

- receiver is unable to keep up with incoming data
- addressed by **flow control** mechanisms
- typically uses **explicit** feedback from receiver to sender

► Network

- nodes or links of the network are overloaded
- addressed by **congestion control** mechanism
- **explicit** congestion notification (few technologies)
- **implicit** congestion notification (Internet)

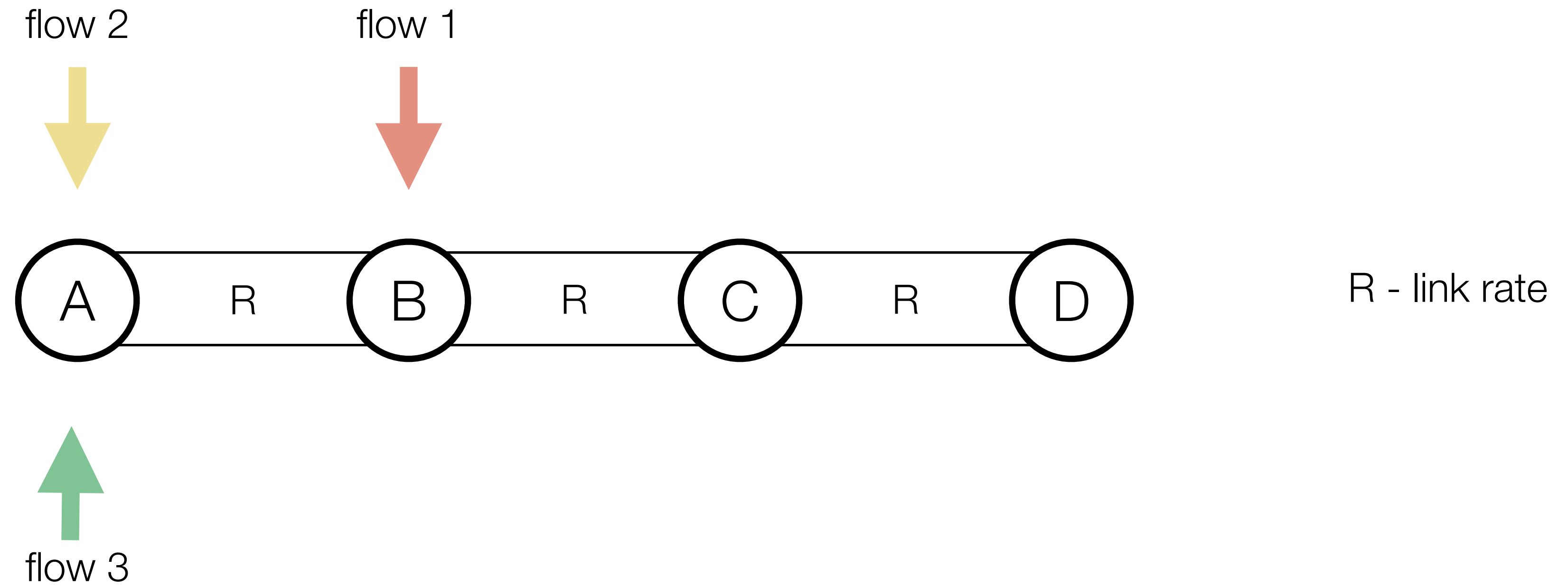
Flow Control



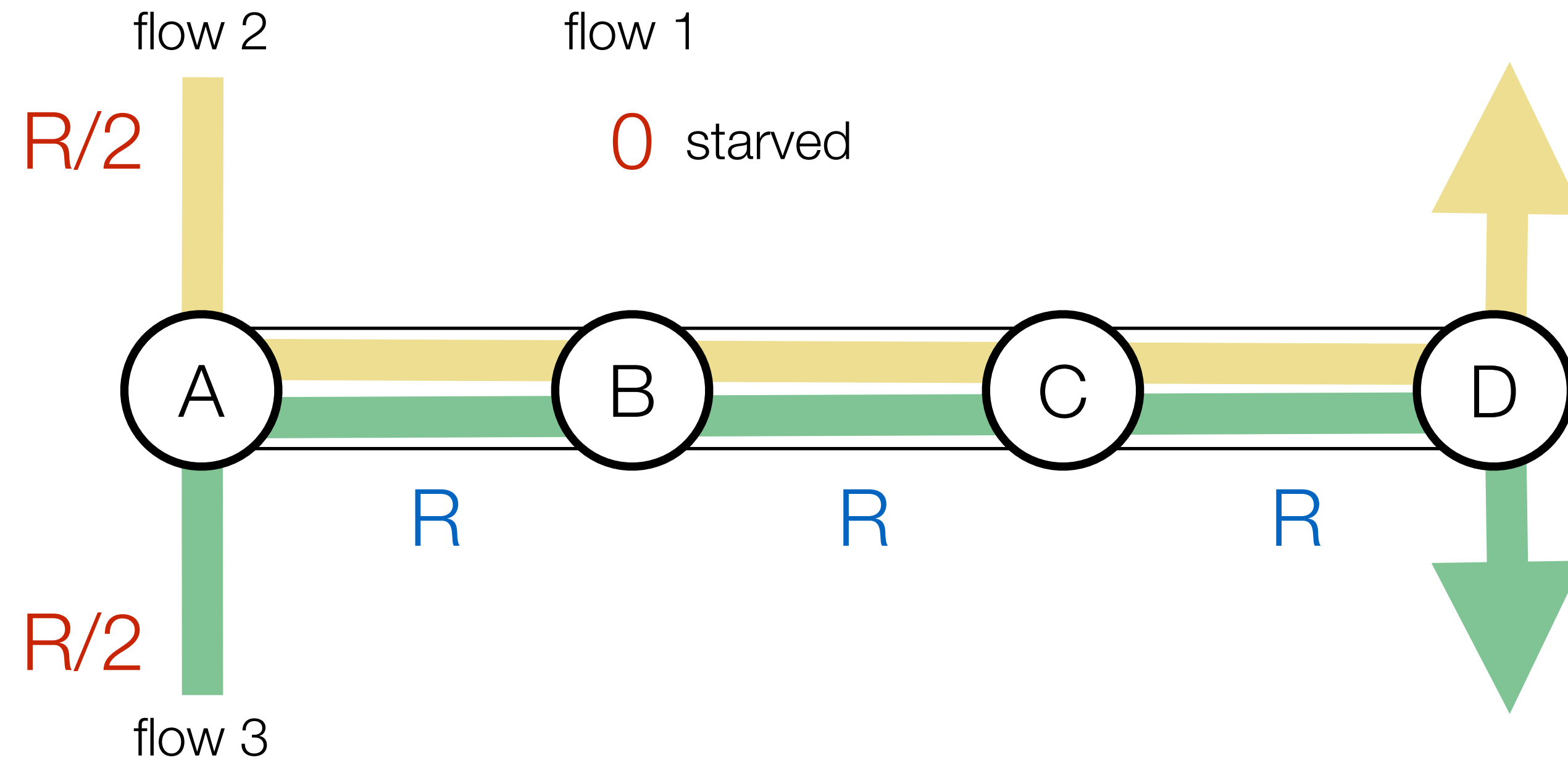
Congestion control

- ▶ **Goal:** Make the most effective use of the network capacity
 - avoid congestion
 - maximize utilization
 - maintain fairness (or deliver promised service level)
- ▶ **Method:** Controlling the rate with which traffic is injected into the network by the transmitter

Utilization vs fairness



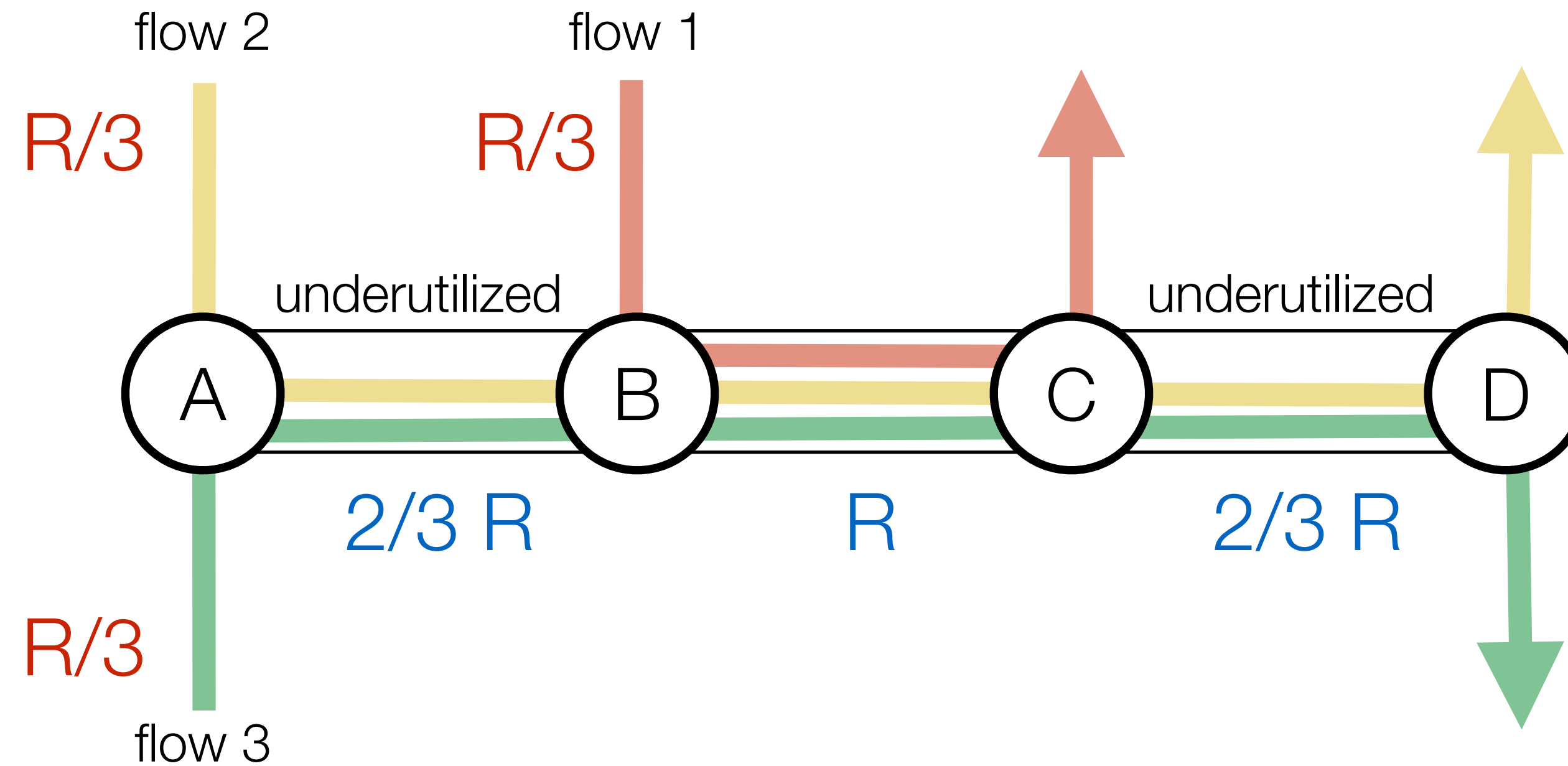
Max utilization



	Max utilization	Max fairness
flow 1	0	$R/3$
flow 2	$R/2$	$R/3$
flow 3	$R/2$	$R/3$

R - link rate

Max fairness



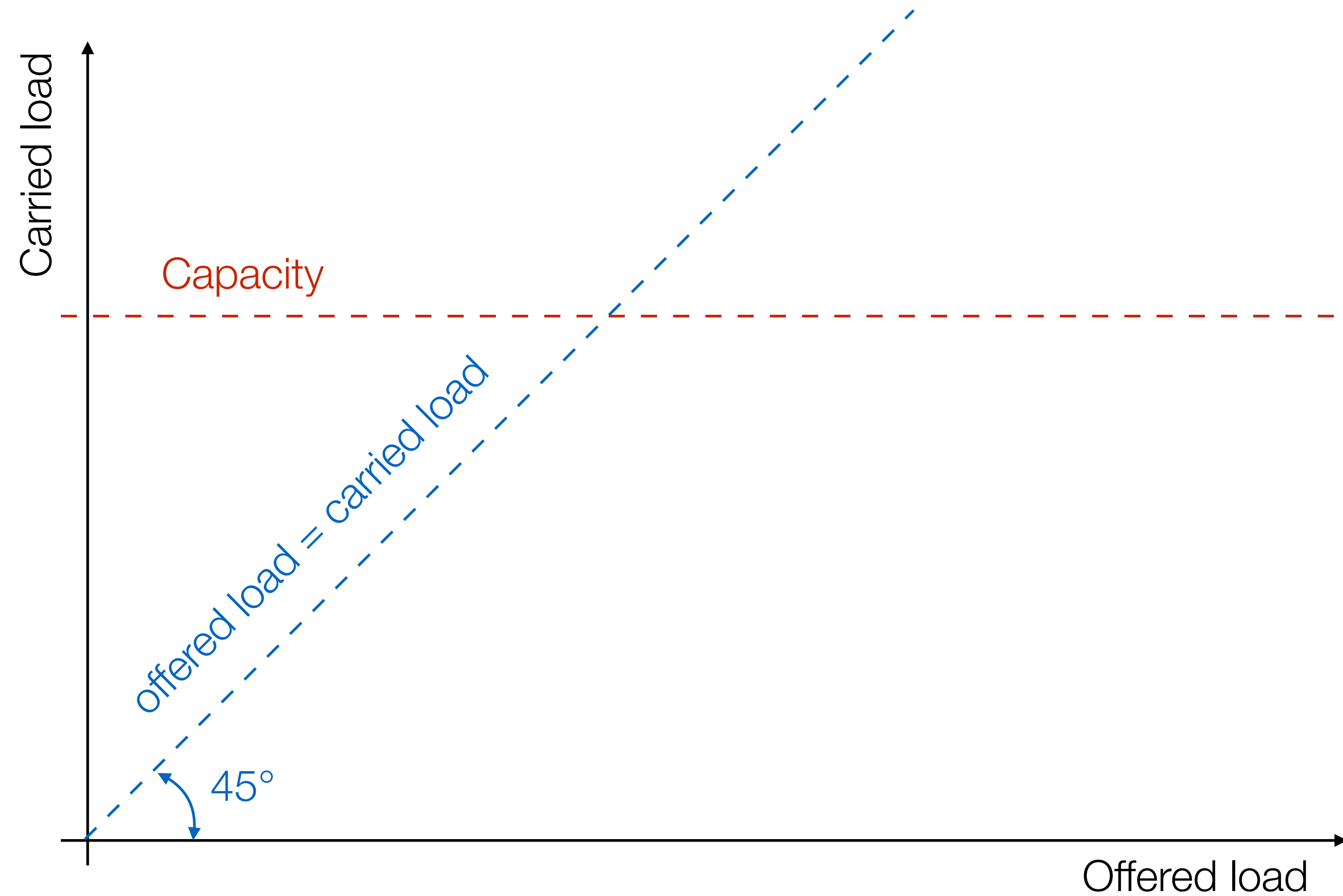
		Max utilization	Max fairness
flow 1	→	0	$R/3$
flow 2	→	$R/2$	$R/3$
flow 3	→	$R/2$	$R/3$

R - link rate

Network congestion control

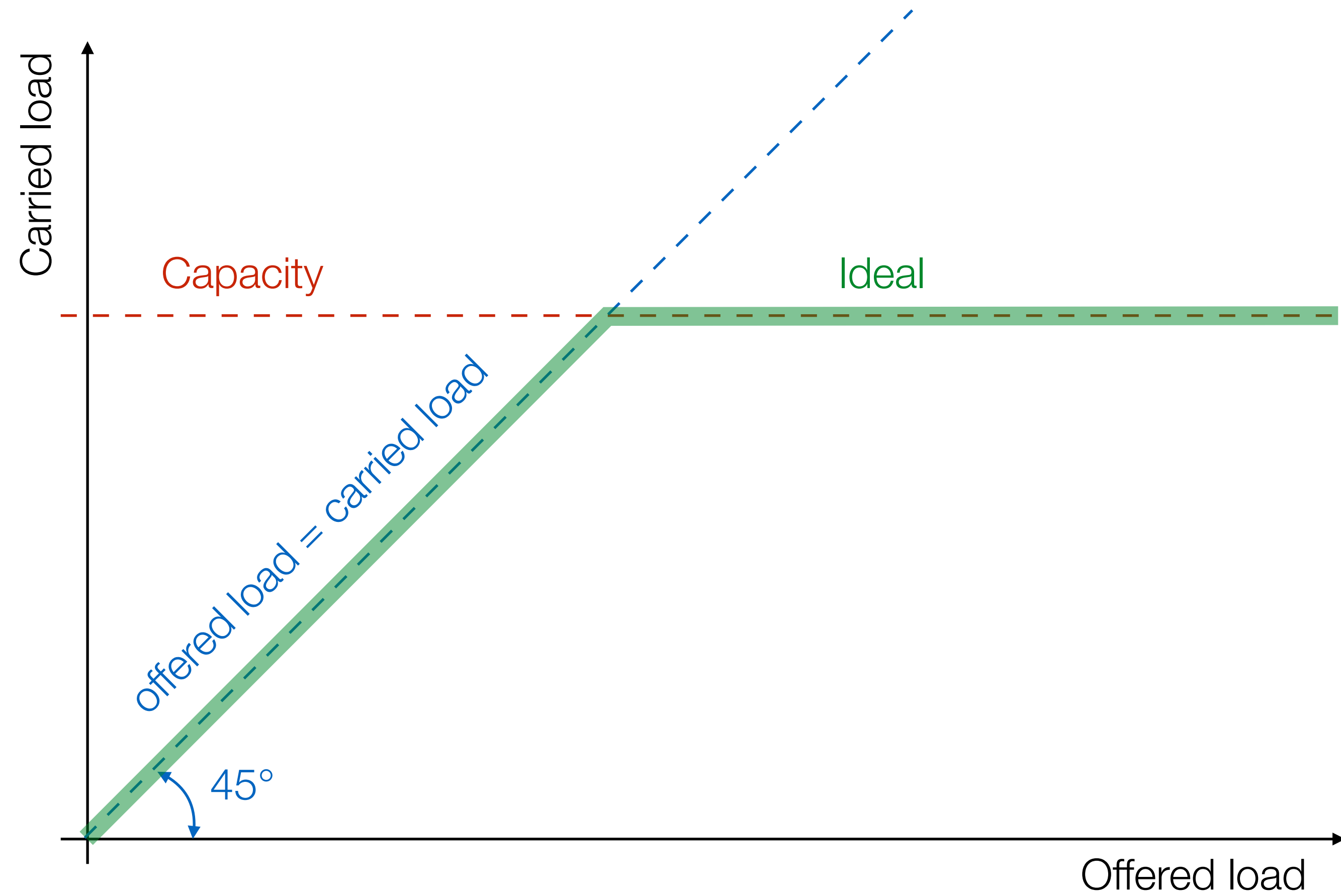
- ▶ Reasons why congestion control mechanisms are critical for the stable operation of the Internet [RFC 8085]:
- ▶ Prevention of congestion collapse
 - i.e., a state where an increase in network load results in a decrease in useful work done by the network
- ▶ Establishment of a degree of fairness
 - i.e., allowing multiple flows to share the capacity of a path reasonably equitably.

Impact of Congestion

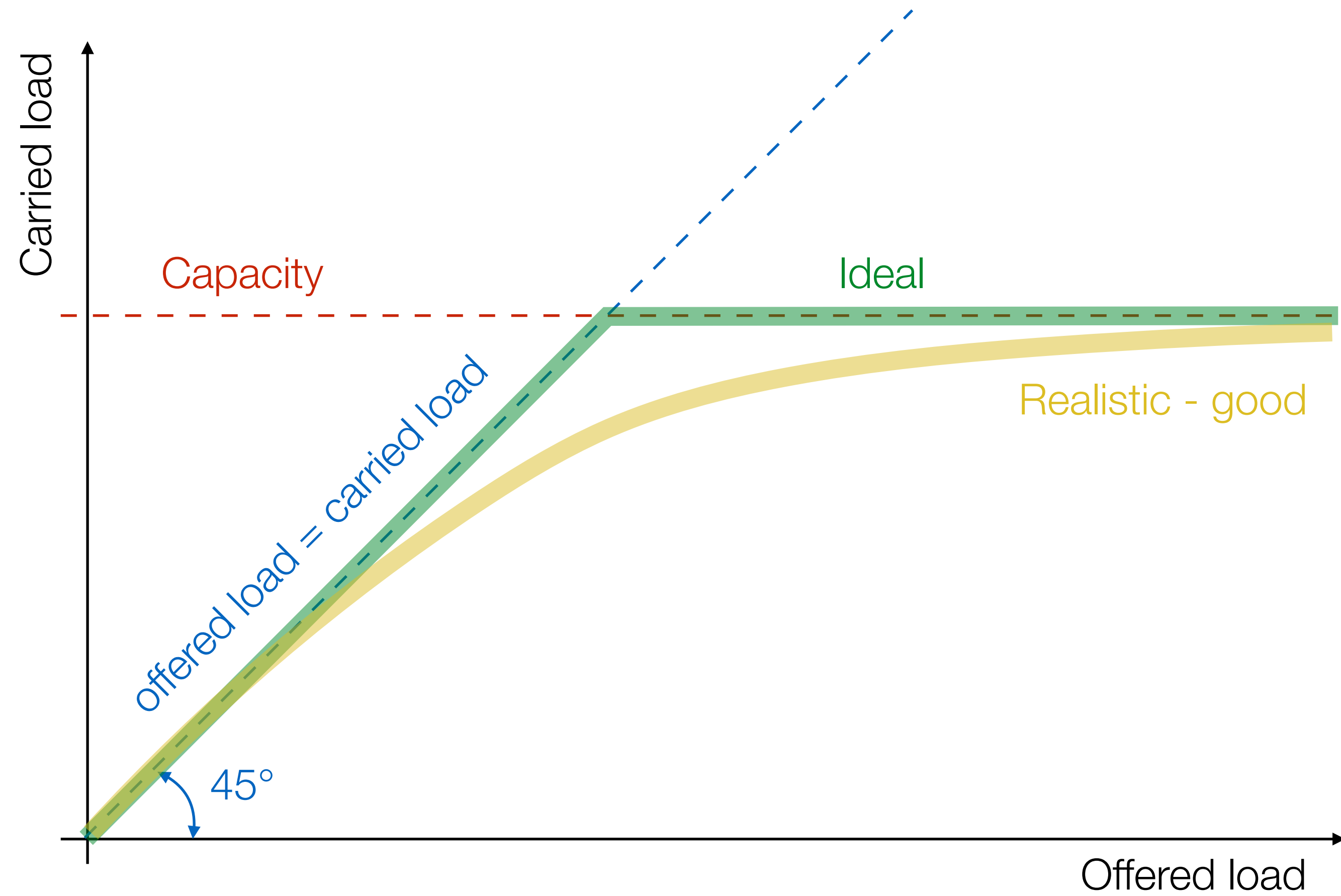


Offered vs carried load graph

Impact of Congestion



Impact of Congestion



Impact of Congestion

