University of Southampton
School of Electronics and Computer Science

Network Layer 3

ELEC3227/ELEC6255

Alex Weddell
asw@ecs.soton.ac.uk

Source: ThinkStock

Overview

- Application requirements
- Traffic shaping
- Routing (revisited)
- Differentiated services
- Tunneling
- Internetworking

Application Requirements

- Different applications care about different properties
  - We want all applications to get what they need

Application	Bandwidth	Delay	Jitter	Loss
Email	Low	Low	Low	Medium
File sharing	High	Low	Low	Medium
Web access	Medium	Medium	Low	Medium
Remote login	Low	Medium	Medium	Medium
Audio on demand	Low	Low	High	Low
Video on demand	High	Low	High	Low
Telephony	Low	High	High	Low
Videoconferencing	High	High	High	Low

"High" means a demanding requirement, e.g., low delay

Application Requirements

- Network provides service with different kinds of QoS (Quality of Service) to meet application requirements
- QoS is part of the routing policy decisions of an Autonomous System (AS). Routers within an AS are configured to reflect the policies of that specific AS. QoS provides an optional mechanism for routers to tailor their behaviour based upon the differing needs of specific applications.

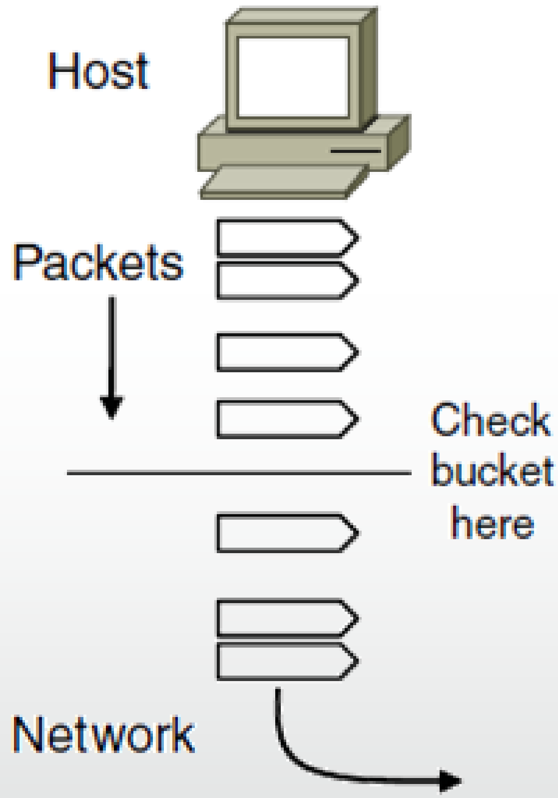
Network Service	Application
Constant bit rate	Telephony
Real-time variable bit rate	Videoconferencing
Non-real-time variable bit rate	Streaming a movie
Available bit rate	File transfer

Example of QoS categories from ATM networks

UNIVERSITY OF Southampton
School of Electronics
and Computer Science

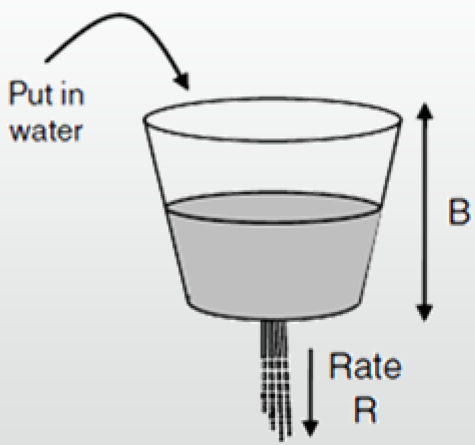
Traffic Shaping

- Traffic shaping regulates the average rate and burstiness of data entering the network
  - Lets us make Service Level Agreement (SLA) guarantees
  - For example, packets in excess of the agreed upon pattern might be dropped by the network or marked as having a lower priority
  - Traffic Policing = monitoring Traffic Flow
- Algorithms are used to limit long-term rate of flow, but allow short-term bursts up to a certain length.

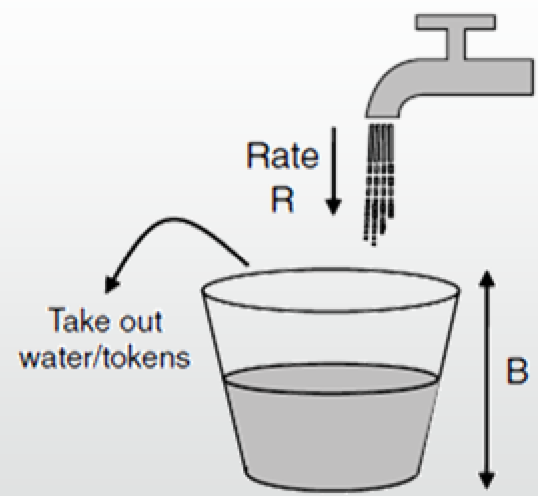


Traffic Shaping

- Token/Leaky bucket limits both the average rate (R) and short-term burst (B) of traffic
  - Leaky bucket algorithm – No matter what rate the packets enter the bucket, the outflow is at a constant rate (R) or less
  - Token bucket algorithm – to send a packet must be able to take tokens out of bucket. No more than a fixed # of tokens (B) can accumulate in bucket.
- For token, bucket size is B, water enters at rate R and is removed to send; opposite for leaky.



Leaky bucket
(need not be full to send)



Token bucket
(need some water to send)

Traffic Shaping

UNIVERSITY OF Southampton
School of Electronics and Computer Science

- Token buckets

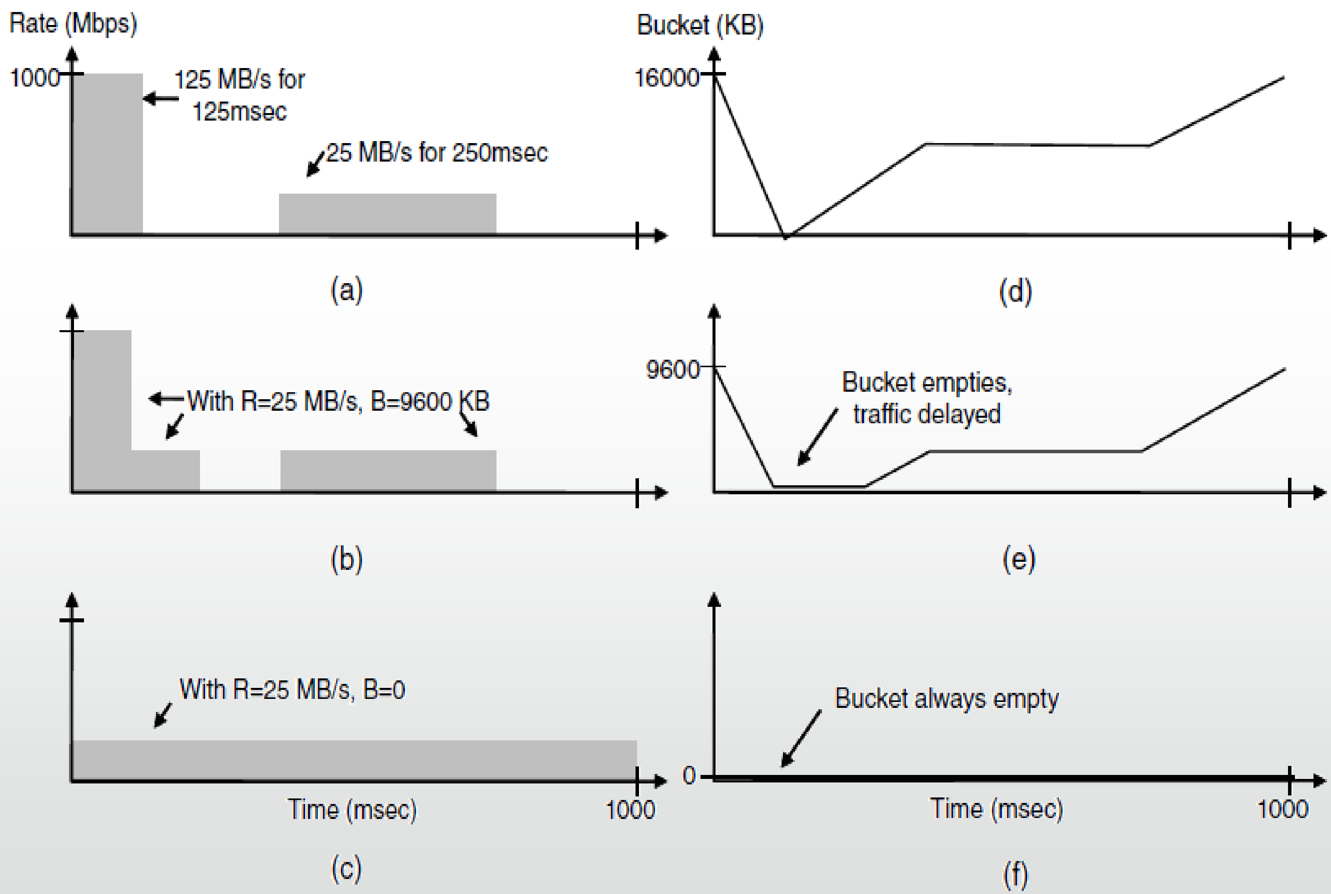
Host traffic
R=200 Mbps
B=16000 KB

↓

Shaped by
R=200 Mbps
B=9600 KB

↓

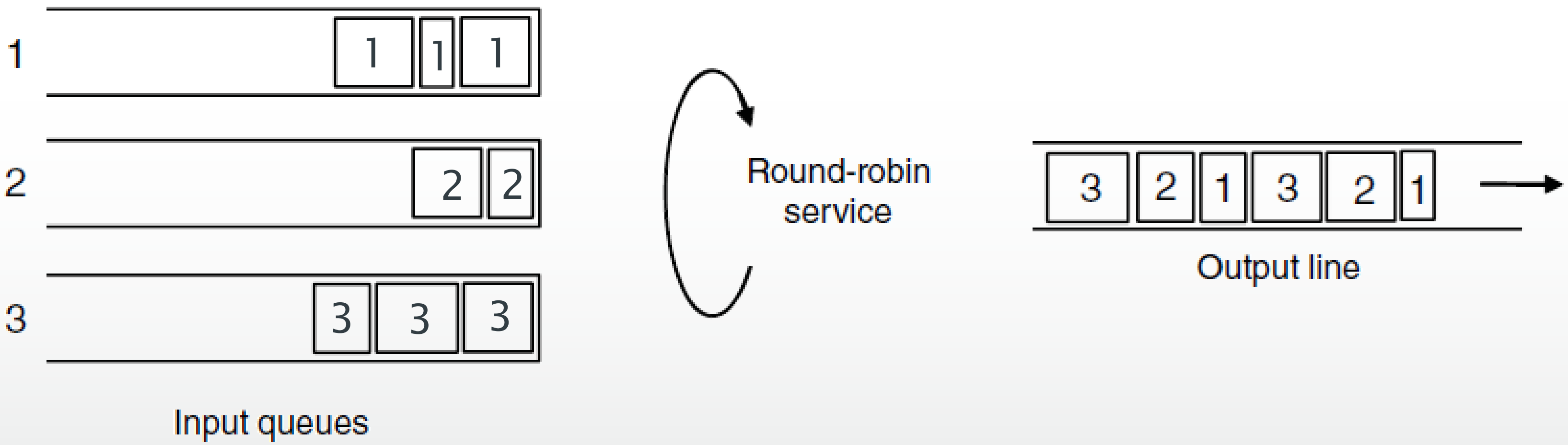
Shaped by
R=200 Mbps
B=0 KB



Smaller bucket size delays traffic and reduces burstiness

Packet Scheduling

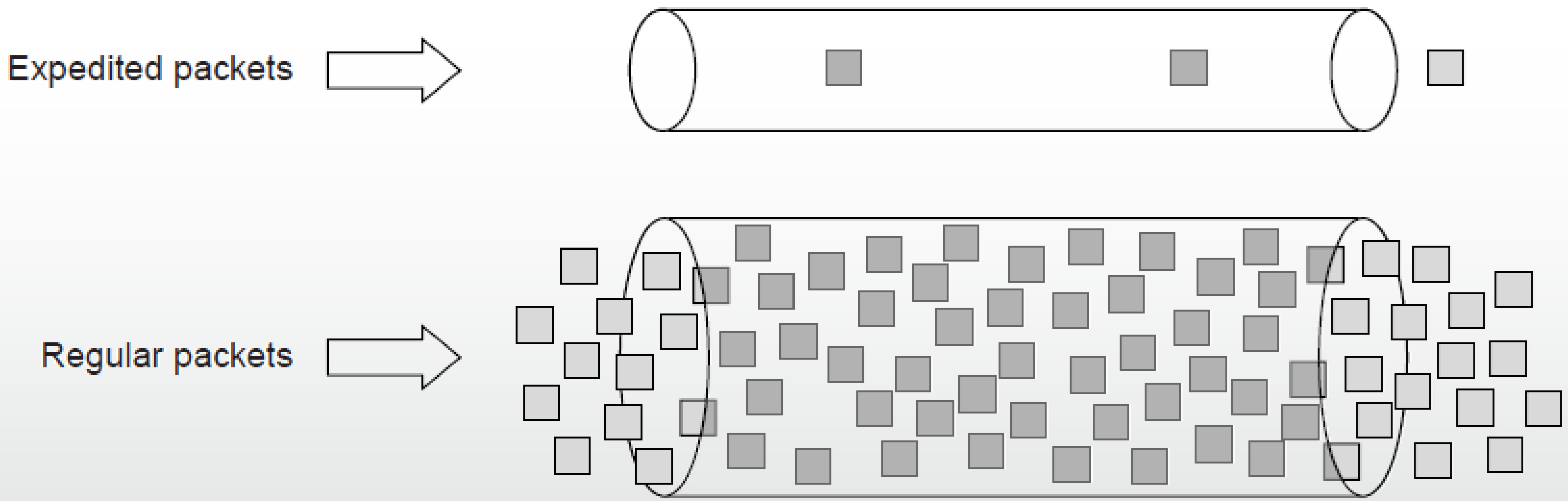
- Packet scheduling divides router/link resources among traffic flows with alternatives to FIFO (First In First Out)



Example of round-robin queuing

Differentiated Services

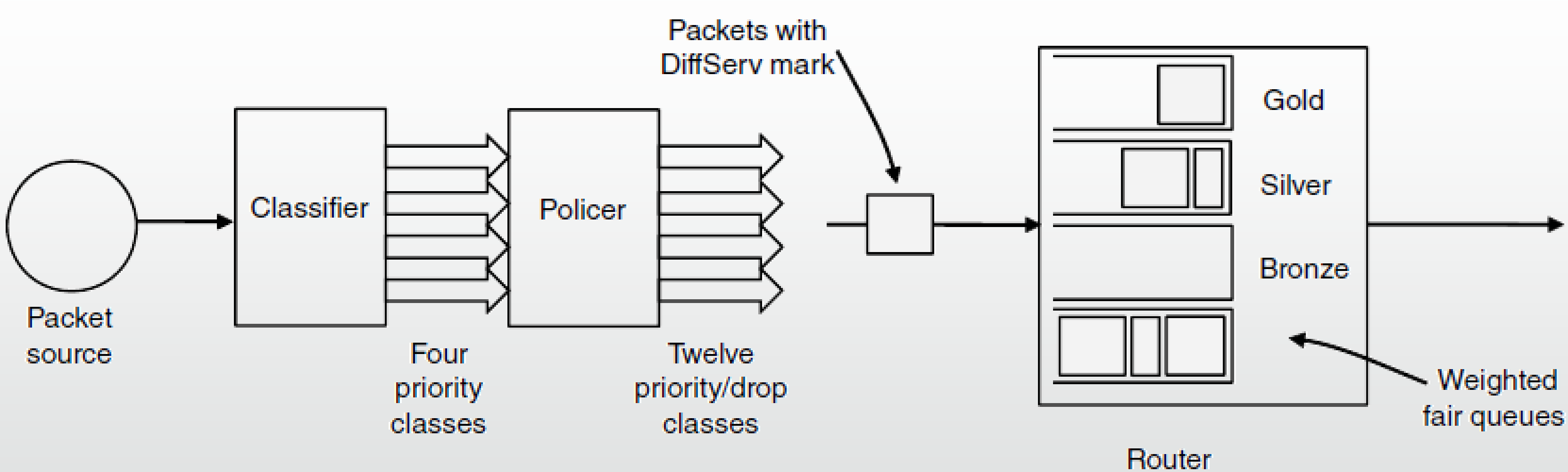
- Design with classes of QoS; customers buy what they want
  - Expedited class is sent in preference to regular class
  - Less expedited traffic but better quality for applications



UNIVERSITY OF Southampton
School of Electronics
and Computer Science

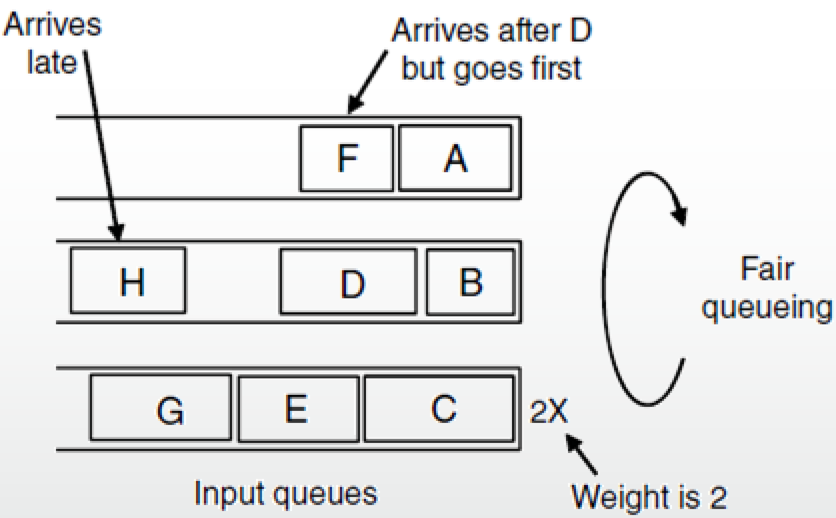
Differentiated Services

- Implementation of DiffServ:
  - Customers mark desired class on packet
  - ISP shapes traffic to ensure markings are paid for
  - Routers use Weighted Fair Queuing to give different service levels



Packet Scheduling

- Fair Queueing approximates bit-level fairness with different packet sizes; weights change target levels
  - Result is WFQ (Weighted Fair Queueing)



Packets may be sent out of arrival order

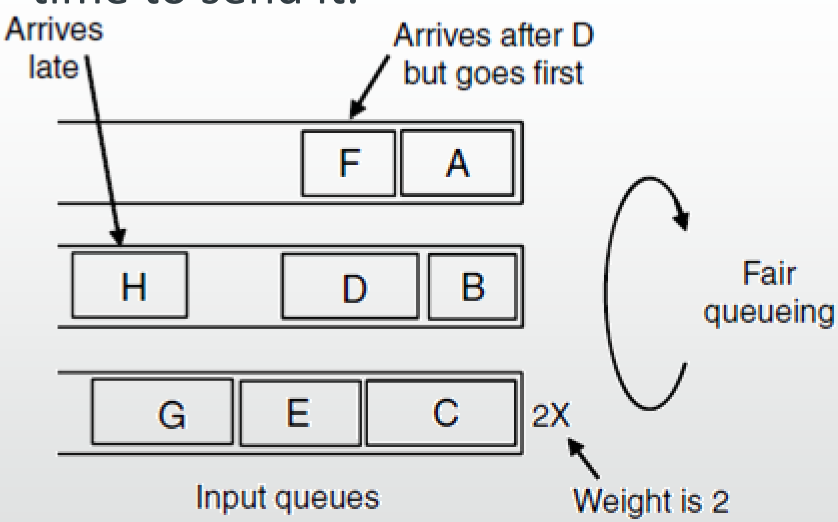
Packet	Arrival time	Length	Finish time	Output order
A	0	8	8	1
B	5	6	11	3
C	5	10	10	2
D	8	9	20	7
E	8	8	14	4
F	10	6	16	5
G	11	10	19	6
H	20	8	28	8

$$F_i = \max(A_i, F_{i-1}) + L_i/W$$

Finish virtual times determine transmission order

Packet Scheduling

- Virtual times are measured in rounds, where a round lets each input queue send 1 bit for weight 1, or W bits for weight W.
- The time to send a packet of length L is thus L/W. The formula says that the finish virtual time for a packet is the larger of its arrival time plus the time to send it, or the finish time of the previous packet in the same queue plus the time to send it.



Packet	Arrival time	Length	Finish time	Output order
A	0	8	8	1
B	5	6	11	3
C	5	10	10	2
D	8	9	20	7
E	8	8	14	4
F	10	6	16	5
G	11	10	19	6
H	20	8	28	8

$$F_i = \max(A_i, F_{i-1}) + L_i/W$$

Packets may be sent out of arrival order

Finish virtual times determine transmission order

Admission Control

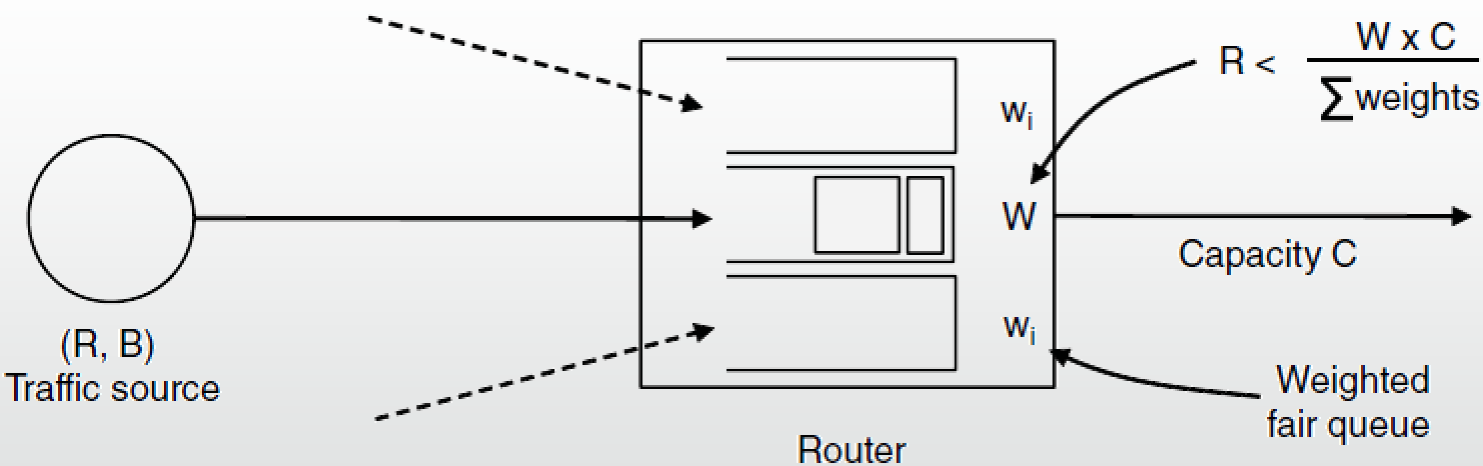
- Admission control takes a traffic flow specification and decides whether the network can carry it
  - Sets up packet scheduling to meet QoS

Parameter	Unit
Token bucket rate	Bytes/sec
Token bucket size	Bytes
Peak data rate	Bytes/sec
Minimum packet size	Bytes
Maximum packet size	Bytes

Example flow specification

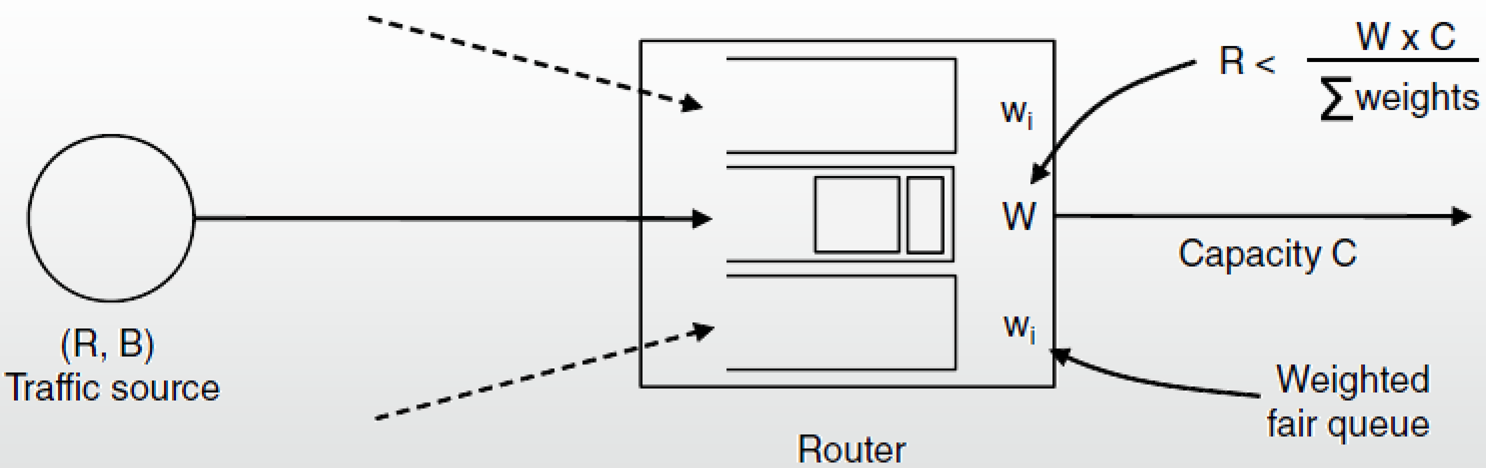
Admission Control

- Construction to guarantee bandwidth B and delay D:
  - Shape traffic source to a (R, B) token bucket
  - Run WFQ with weight W / all weights > R/capacity
  - Holds for all traffic patterns, all topologies
- Bandwidth is guaranteed at each router by setting a high enough weight on the flow; if this cannot be done then the flow must not be admitted.



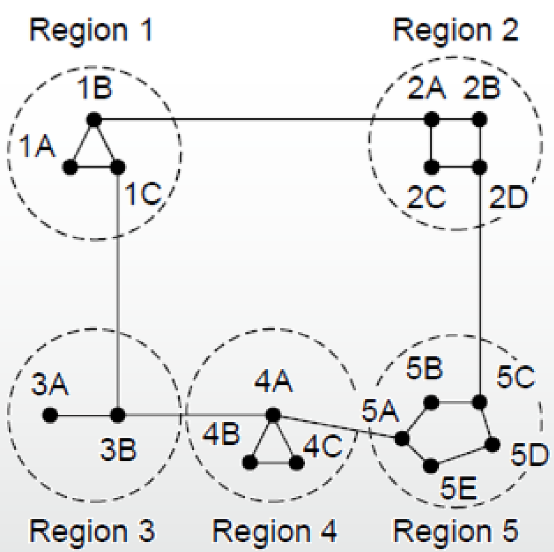
Admission Control

- Delay guarantees are more subtle and the bound is not given here.
- A burst of traffic can arrive at one router and be delayed, but then it will not be delayed at other routers because it has already been shaped to be less bursty. So the total delay is something like the propagation delay plus B/R.



Hierarchical Routing

- Hierarchical routing reduces the work of route computation but may result in slightly longer paths than flat routing



Full table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2A	1B	2
2B	1B	3
2C	1B	3
2D	1B	4
3A	1C	3
3B	1C	2
4A	1C	3
4B	1C	4
4C	1C	4
5A	1C	4
5B	1C	5
5C	1B	5
5D	1C	6
5E	1C	5

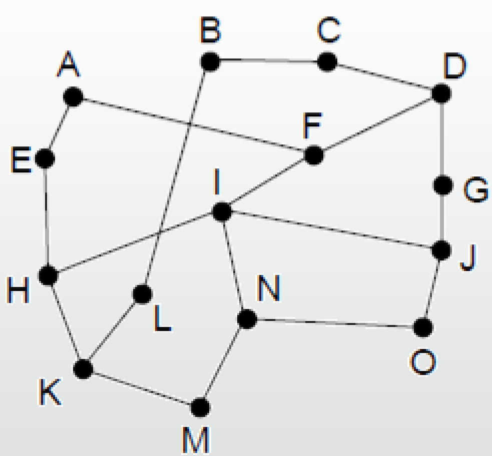
Hierarchical table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2	1B	2
3	1C	2
4	1C	3
5	1C	4

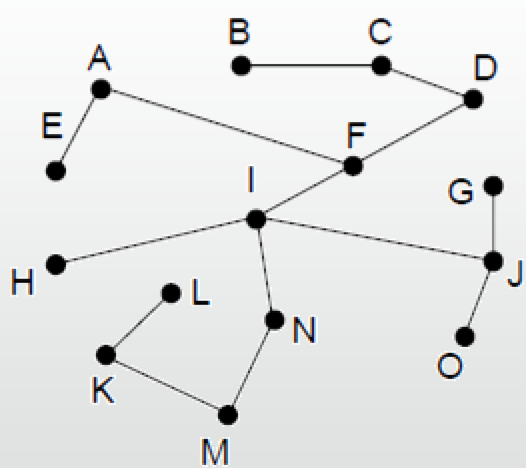
Best choice to reach nodes in 5 except for 5C

Broadcast Routing

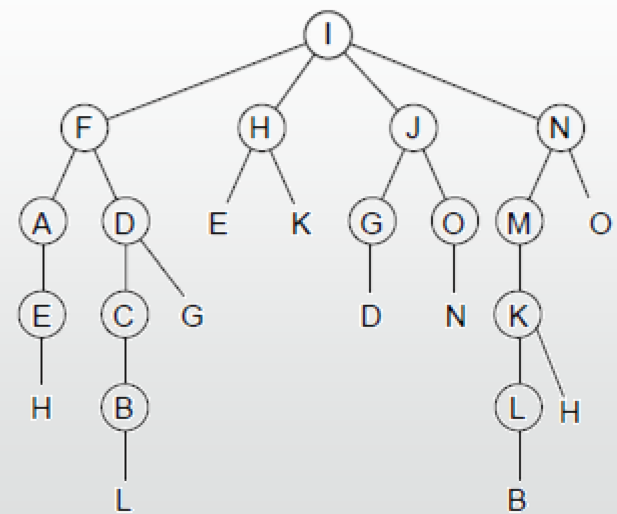
- **Broadcast** sends a packet to all nodes
  - RPF (Reverse Path Forwarding): send broadcast received on the link to the source out to all remaining links
  - When broadcast packet arrives at router, router checks if it arrived on a link normally used to send packets **towards** source of broadcast. If so, likely it followed best route from router.
  - Therefore, likely to be first copy to arrive at router, and forwards copy on to all links except the one it arrived on.
  - If arrived on non-preferred link, discard as likely a duplicate!



Network



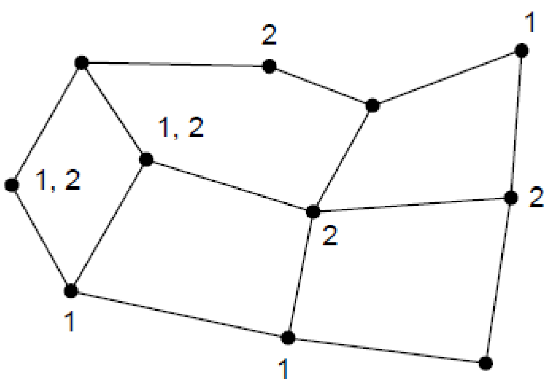
Sink tree for *I* is efficient broadcast



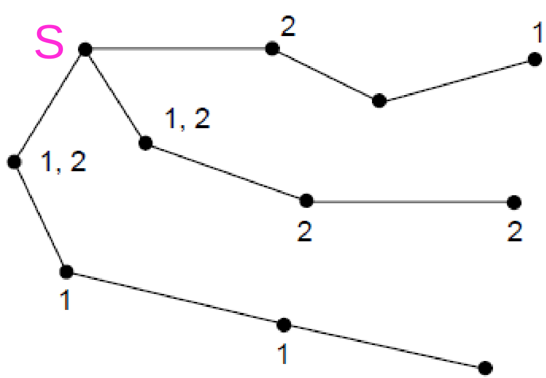
RPF from *I* is larger than sink tree

Multicast Routing

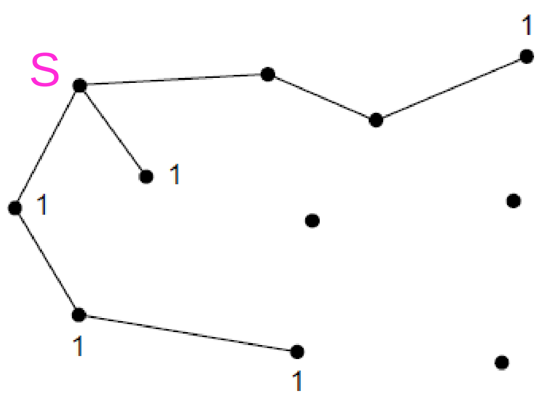
- **Multicast** sends to a subset of the nodes called a **group**
  - Uses a different tree for each group and source



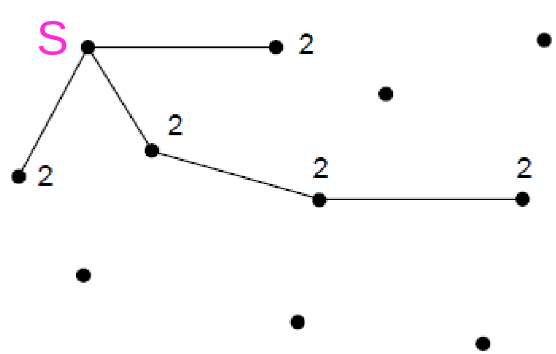
Network with groups 1 & 2



Spanning tree from source S



Multicast tree from S to group 1

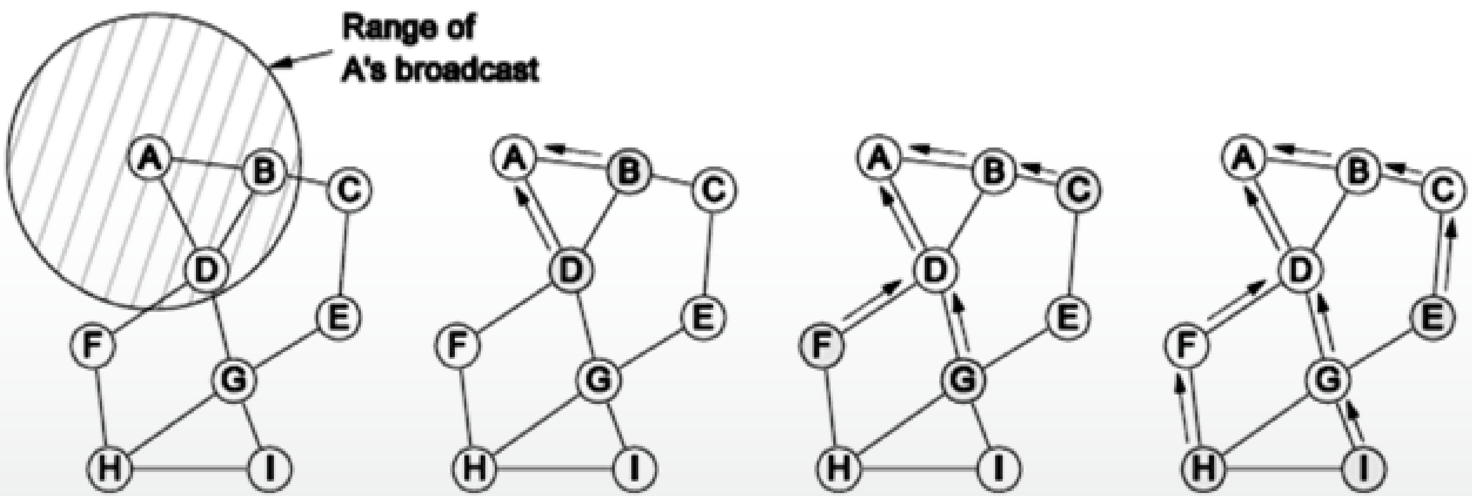


Multicast tree from S to group 2

UNIVERSITY OF Southampton
School of Electronics and Computer Science

Routing in Ad-Hoc Networks

- The network topology changes as wireless nodes move
  - Routes are often made on demand, e.g., AODV (below)



A’s starts to find route to *I*

A’s broadcast reaches *B* & *D*

B’s and *D*’s broadcast reach *C*, *F* & *G*

C’s, *F*’s and *G*’s broadcast reach *H* & *I*

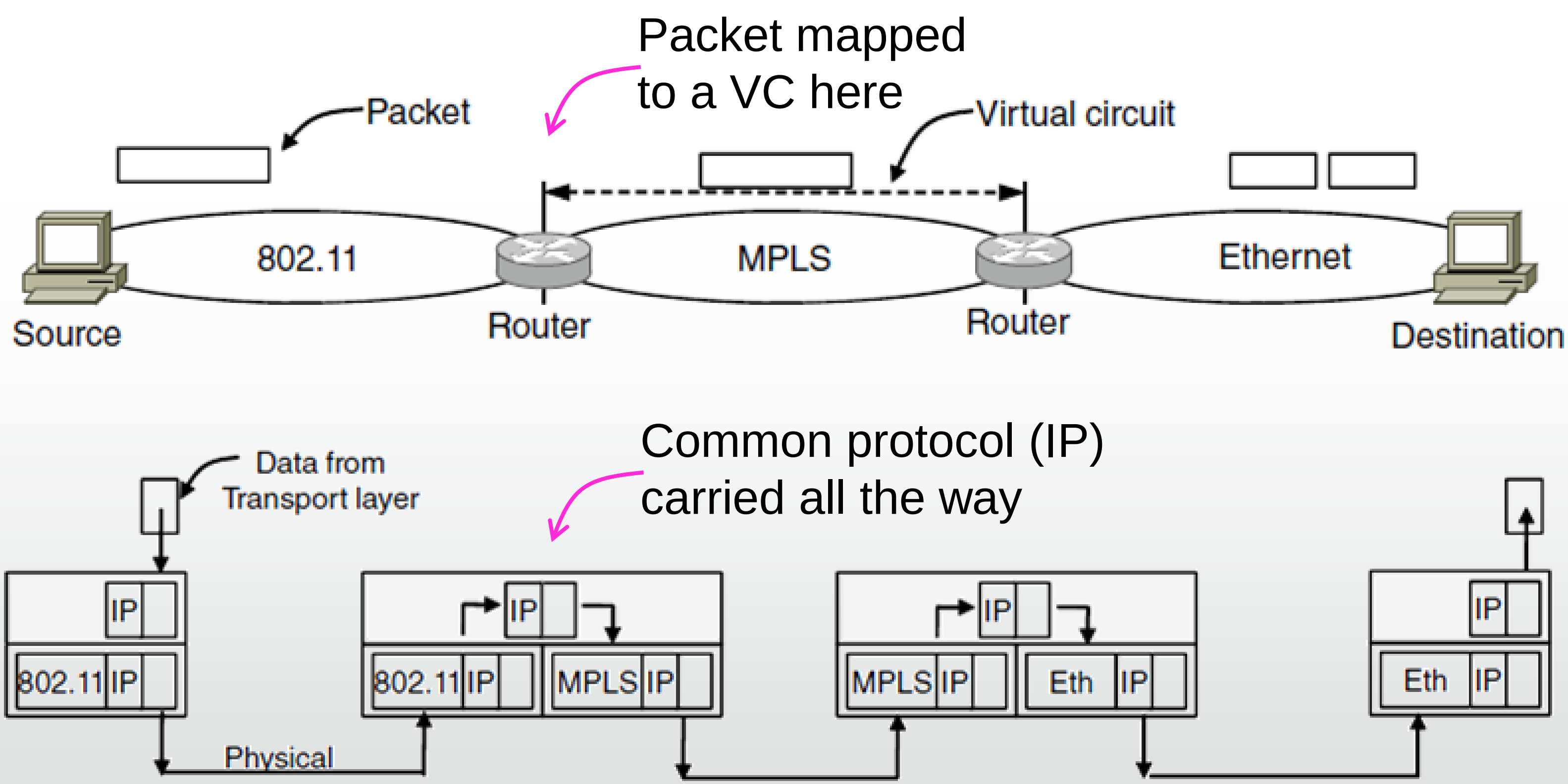
University of Southampton
School of Electronics and Computer Science

Internetworking

- Internetworking joins multiple, different networks into a single larger network
- The word “network” may mean several very different things in data communications. Here the meaning is data link – *networks* in this section refer to differences between different kinds of data link layer protocols.
- IP regularizes and hides these differences from the Transport Layer, which is the layer it provides services for.

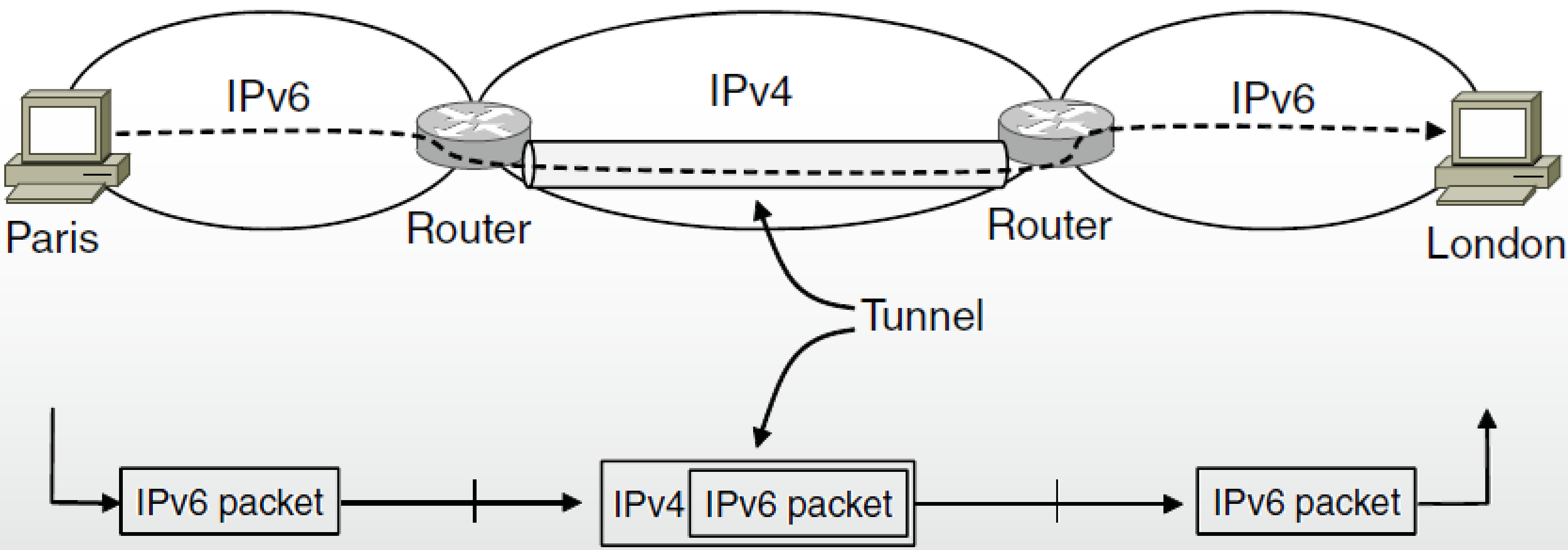
How Networks can be Connected

- Internetworking based on a common network layer – IP



Tunnelling

- Connects two networks through a middle one
  - Packets are encapsulated over the middle

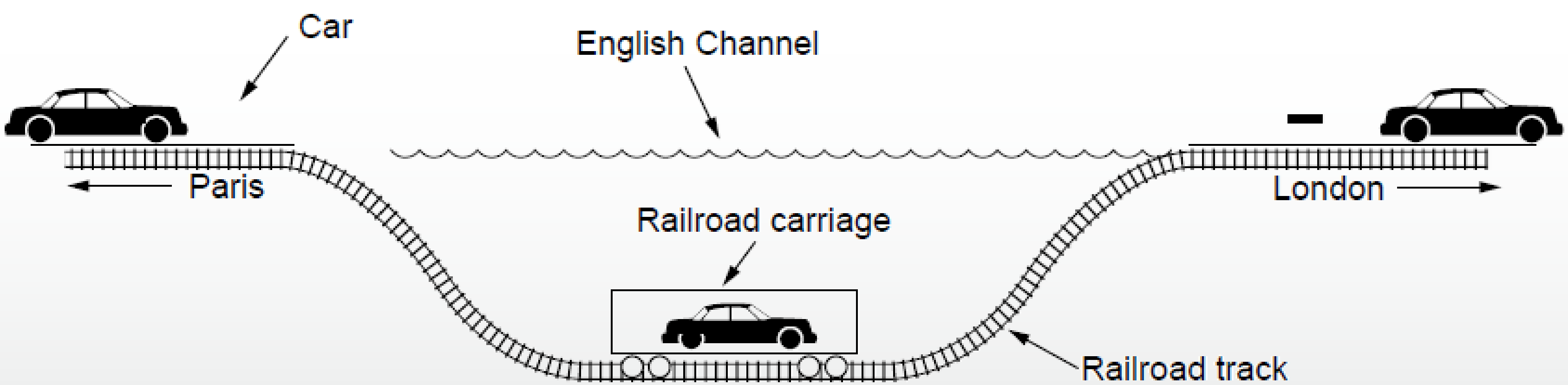


Tunneling can also be IPv4 in IPv4 and IPv6 in IPv6
IPsec (IP Security) in tunnel mode

Tunnelling

UNIVERSITY OF Southampton
School of Electronics and Computer Science

- Tunneling analogy:
  - tunnel is a link; packet can only enter/exit at ends



UNIVERSITY OF Southampton
School of Electronics and Computer Science

Summary

- Application requirements
- Traffic shaping
- Routing (revisited)
- Differentiated services
- Tunneling
- Internetworking