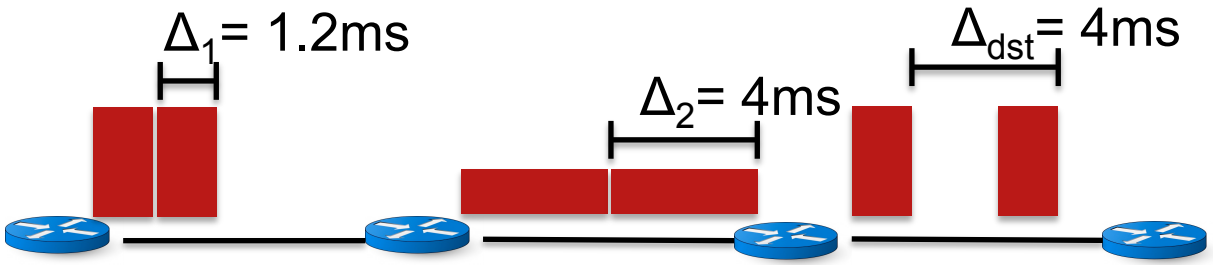
Week 4: Bandwidth

1. Introduction
2. Definitions of bandwidth metrics
3. End-to-end measurement approaches
4. Flooding
5. **Advanced probing**
   A. **Packet pairs**
   B. Size-delay and self-induced congestion
6. Conclusion

Capacity with packet pairs

- Basic method
  - Send a pair of equal-sized packets back-to-back and measure the inter-packet gap at destination



  - $C = \frac{L}{\Delta_{dst}}$

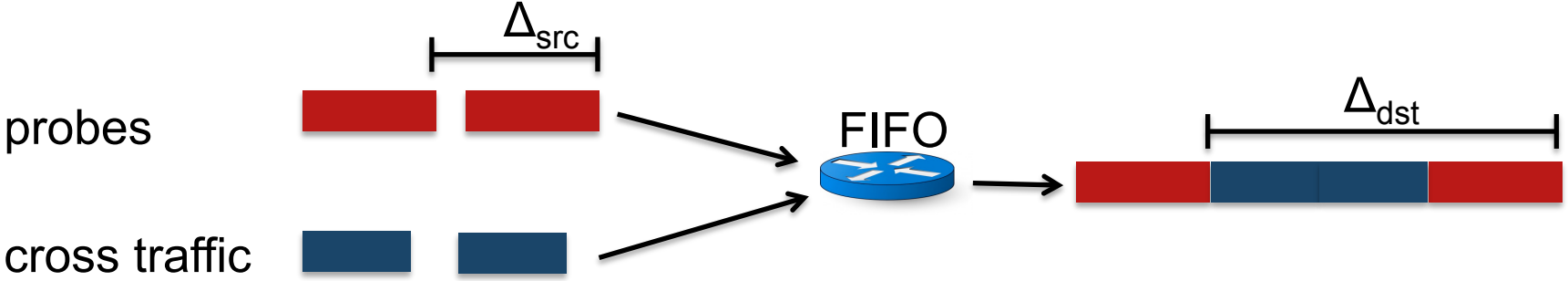
probe size (L) = 1500 bytes

Considerations

- Probe size and interval
  - Probe rate should be greater than capacity of bottleneck link
  - Small probes, back-to-back
- Cross traffic will modify inter-probe gap
  - Send multiple probe pairs
  - Probe pairs with minimum delay give best estimates
- Gaps hard to measure at high capacity
  - E.g. 1500-byte probes at 1 Gbps = 12 μs

Available bandwidth with packet pairs

- Basic method
  - Use pairs of probes to measure capacity and cross traffic



  - $A = C * \left[1 - \frac{\Delta_{dst} - \Delta_{src}}{\Delta_{src}}\right]$

Considerations

- Bottleneck router's queue not empty between probes
  - Send back-to-back probes
- Requires FIFO queuing
  - Not always true, e.g. CoDel

Picture credits

- Slides 2 & 4: **Router clip art** by OCAL, www.clker.com (public domain)