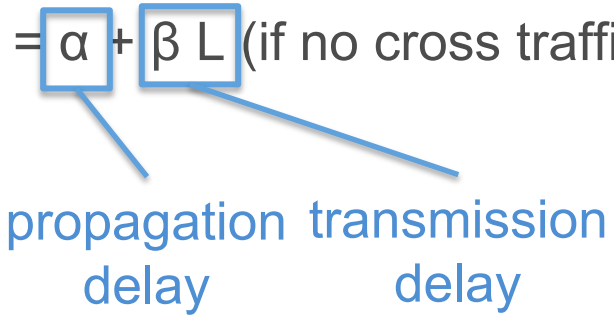
Week 4: Bandwidth

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 size-delay: Intuintion

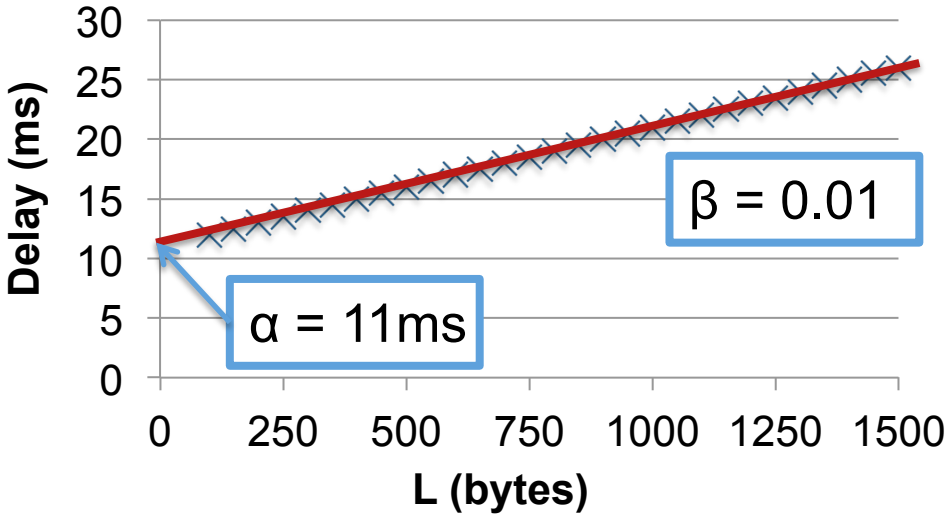
- Probe delay: queuing, transmission, propagation
  - $T(L) = \alpha + \beta L$ (if no cross traffic)



  - Only transmission delay affected by capacity and probe size

Capacity with size-delay: Basic method

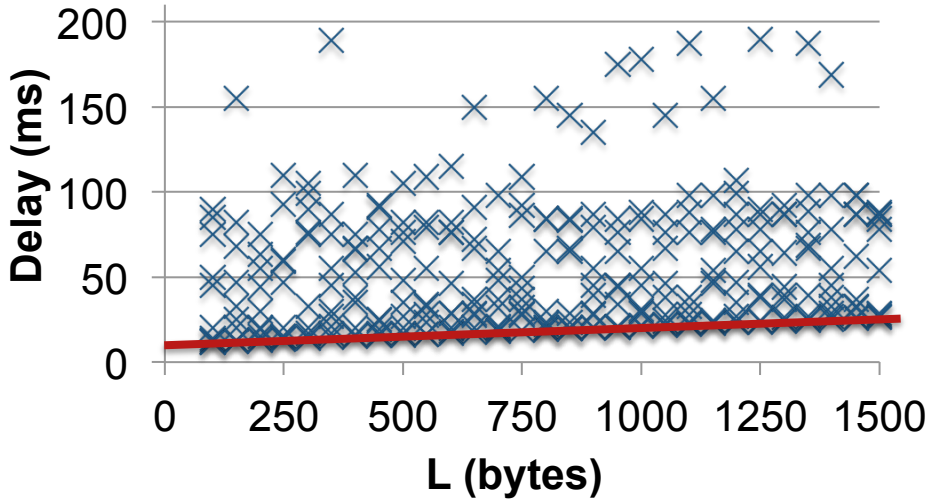
- Send RTT probes with varying packet sizes
  - Estimate α and β



$$C = \frac{1}{\beta}$$

Considerations

- Presence of cross traffic will break assumptions
  - Send many probes per L and take minimum

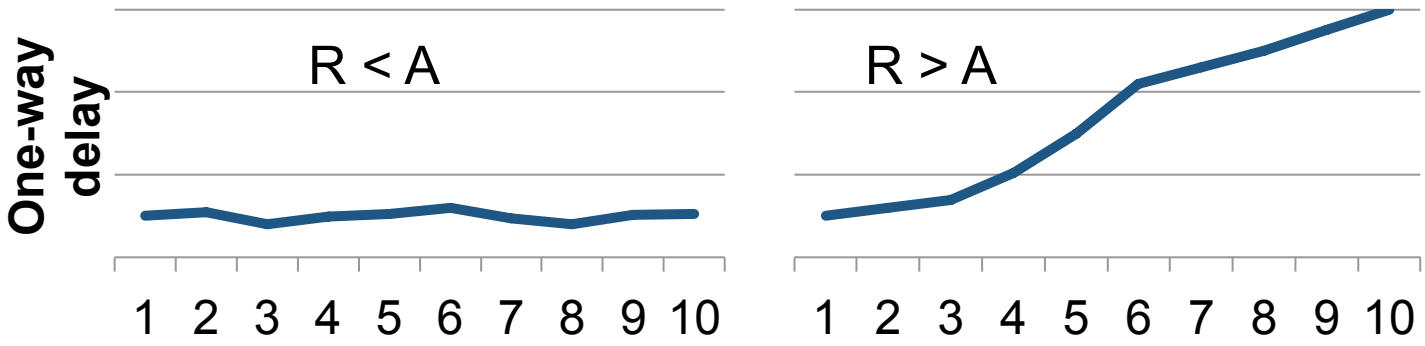


Considerations

- Presence of cross traffic will break assumptions
  - Send many probes per hop and take minimum
- Packet size may vary in the network
  - Layer-2 header sizes are different across technologies

Available bandwidth with self-induced congestion

- Basic method
  - Send train of equal-sized probes with rate *R*



  - Search *R* (binary or exponentially increasing)

Considerations

- Cross traffic is often bursty
  - Increasing train length increases robustness to burst
  - But method won’t converge with long trains if cross traffic is not stable
- Probe train may affect cross traffic
  - Affecting quantity that it is trying to measure