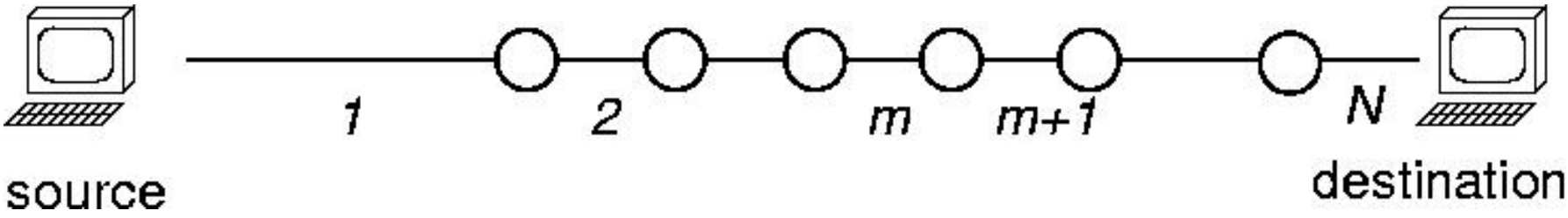
Spatio-Temporal Available Bandwidth Estimation

Vinay Ribeiro

Rolf Riedi, Richard Baraniuk

Rice University

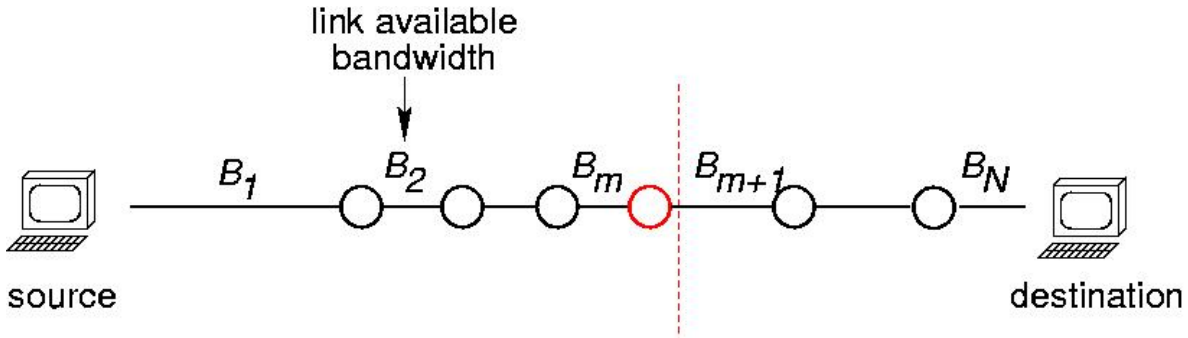
Network Path Model



- End-to-end paths
  - Multi-hop
  - No packet reordering
- Router queues
  - FIFO
  - Constant service rate

Packet delay = ***constant term***
(propagation,
service time)
+
variable term
(queuing delay)

Key Definitions

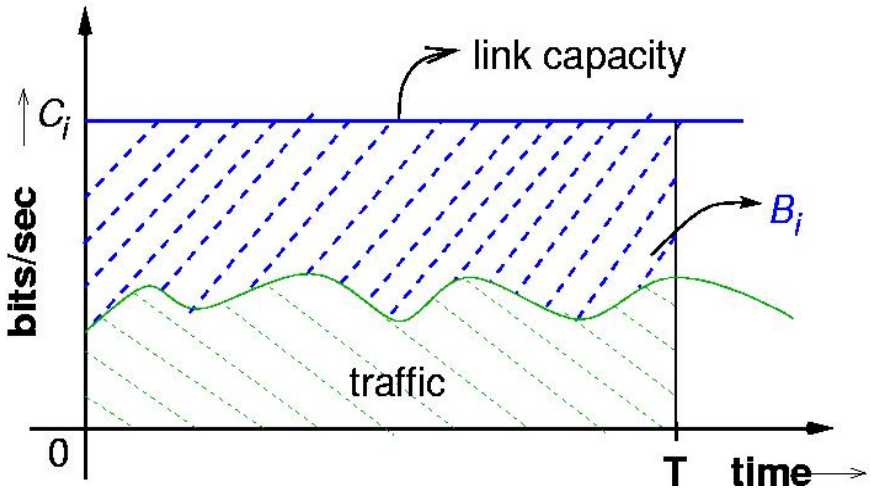


Path available bandwidth

$$A = \min_i B_i$$

Sub-path available bandwidth

$$A[1,m] = \min_{1 \le i \le m} B_i$$



Tight link: link with least available bandwidth

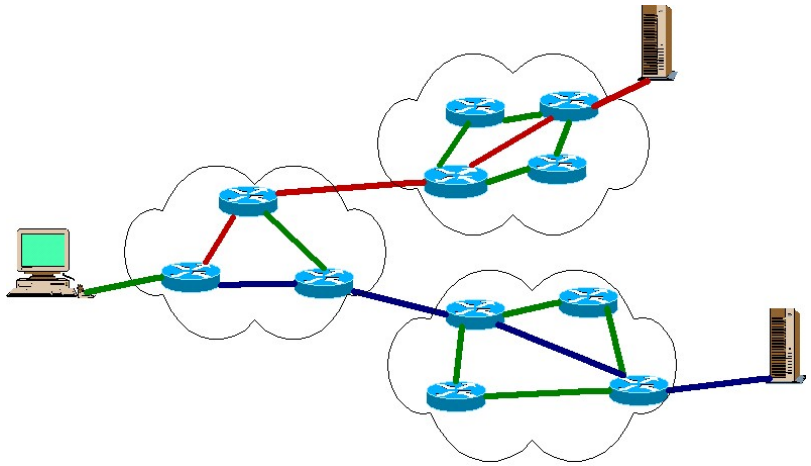
- **Goal**: use end-to-end probing to locate tight link in space and over time

Applications

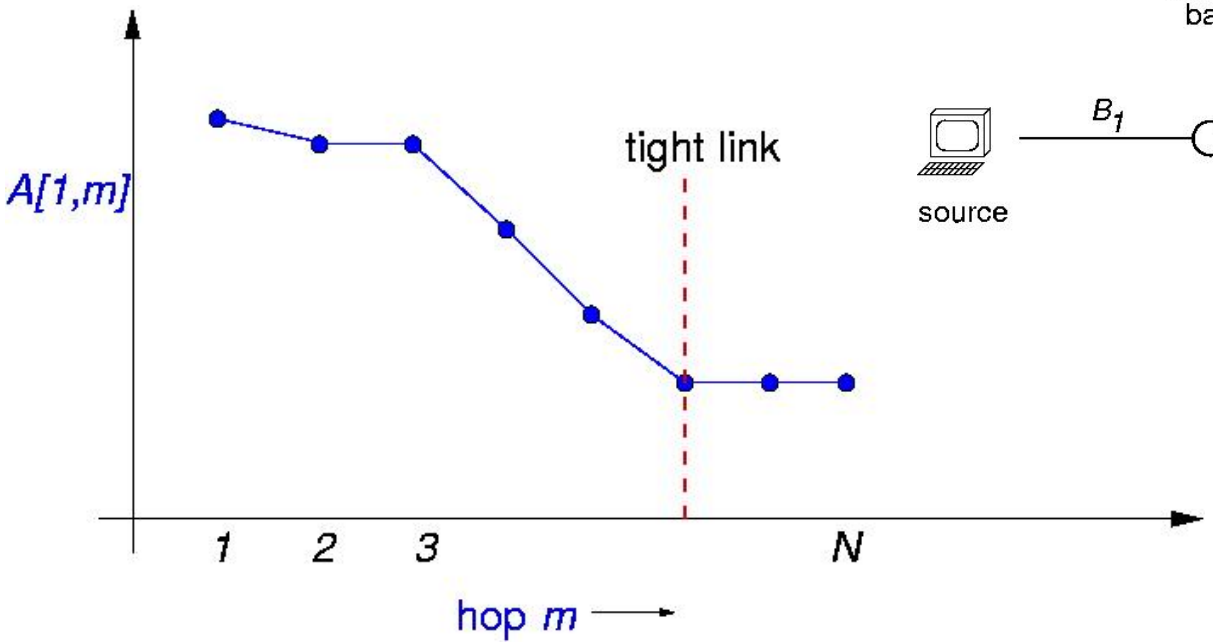
- Science: *where* do Internet tight links occur and *why*?

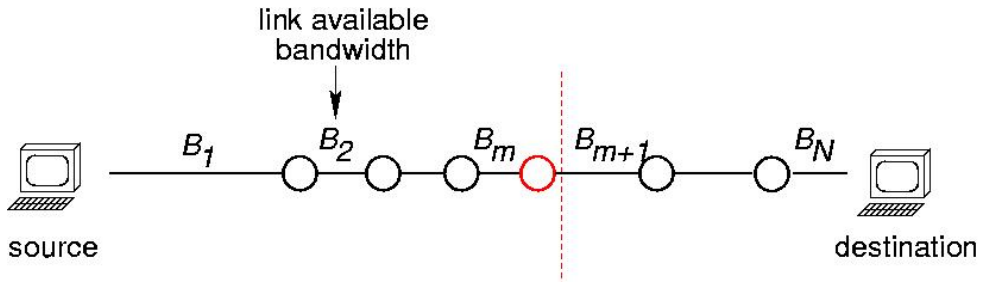
- Network aware applications
  - server selection

- Network monitoring
  - locating hot spots



Methodology





$$A[1,m] = \min_{1 \le i \le m} B_i$$

- Estimate *A[1,m]*
- For *m* > tight link, *A[1,m]* remains constant

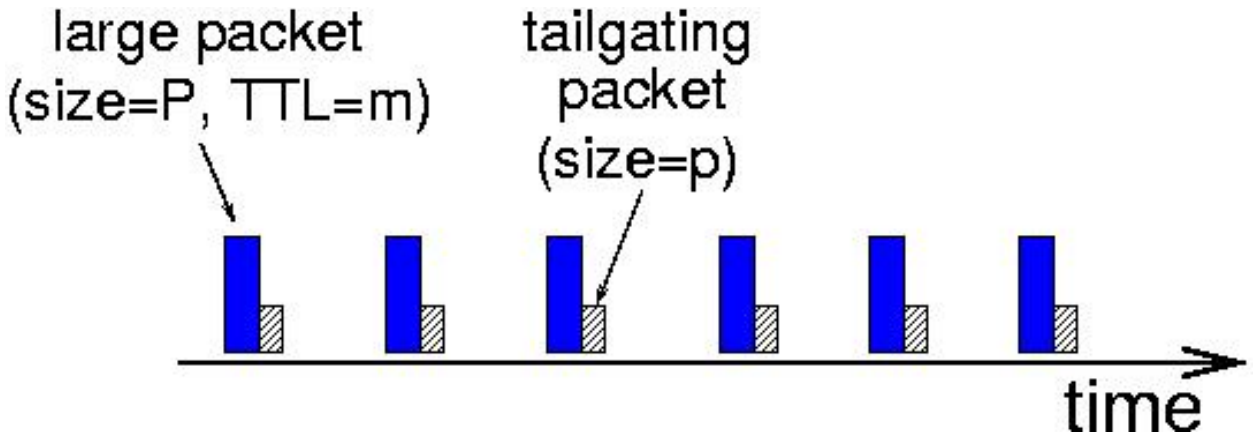
Principle of Self-Induced Congestion

- Probing rate = *R*, path available bandwidth = *A*

> *R* < *A* → no delay increase
>
> *R* > *A* → delay increases

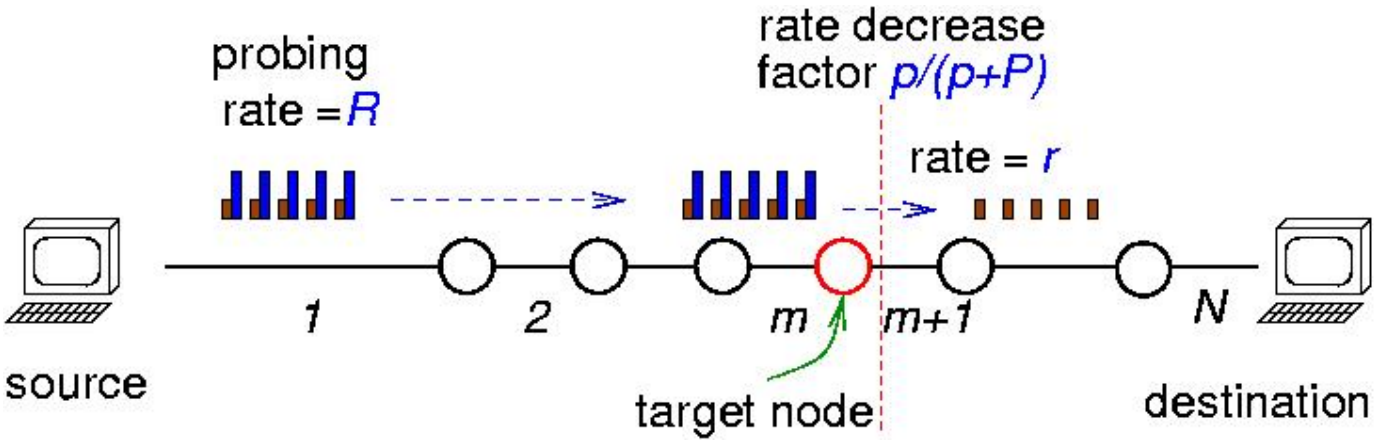
- Advantages
  - No topology information required
  - Robust to multiple bottlenecks

Packet Tailgating



- Large packets of size *P* (TTL=*m*)
  small packets of size *p*
- Large packets exit at hop *m*
- Small packets reach receiver with timing information
- Previously employed in capacity estimation

Estimating *A[1,m]*

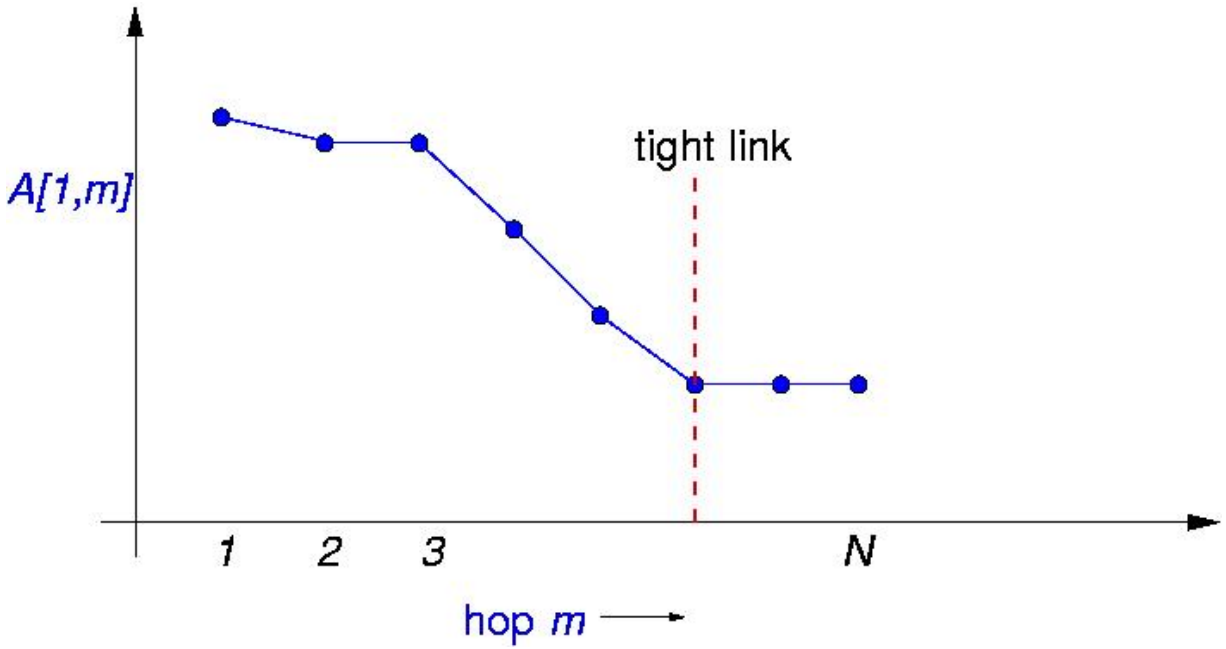


- Key: Probing rate decreases by *p/(p+P)* at link *m*
- Assumption: *r<A[m+1,N]*, no delay change after link *m*

R < A[1,m] → no delay increase

R > A[1,m] → delay increases

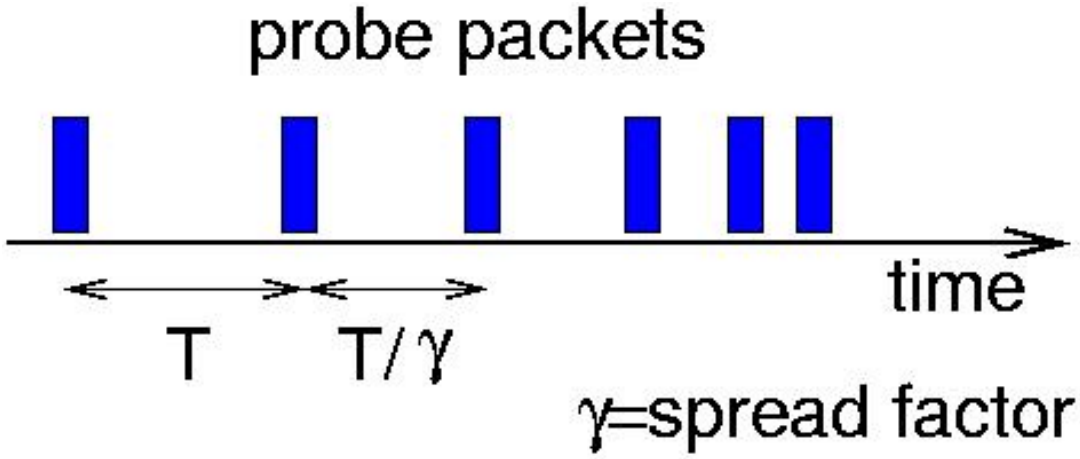
Tight Link Localization



- *Tight link*: link after which *A[1,m]* remains constant

- Applicable to any self-induced congestion tool: pathload, pathChirp, IGI, netest etc.

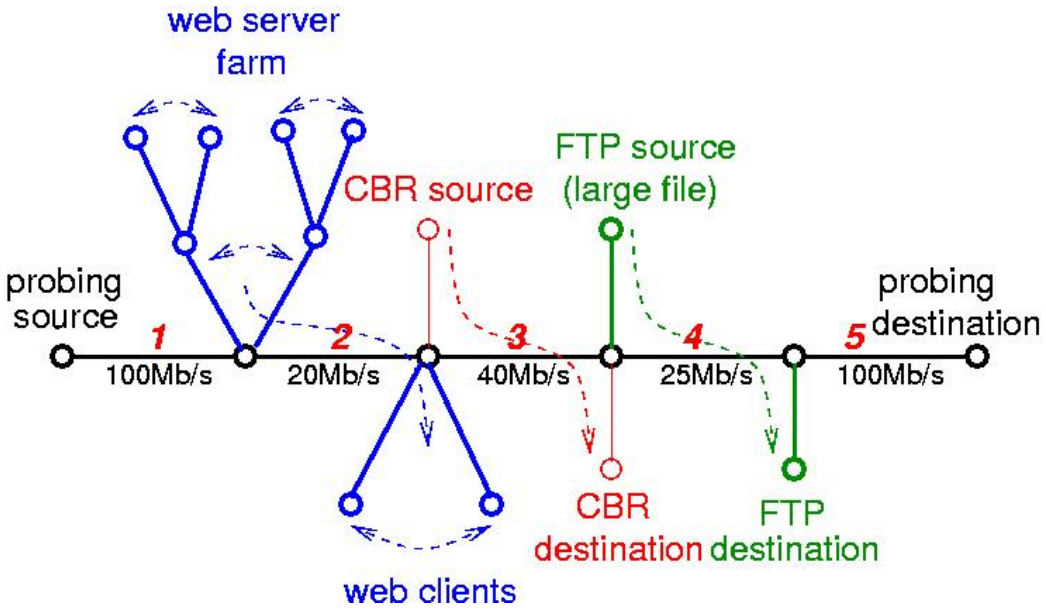
pathChirp

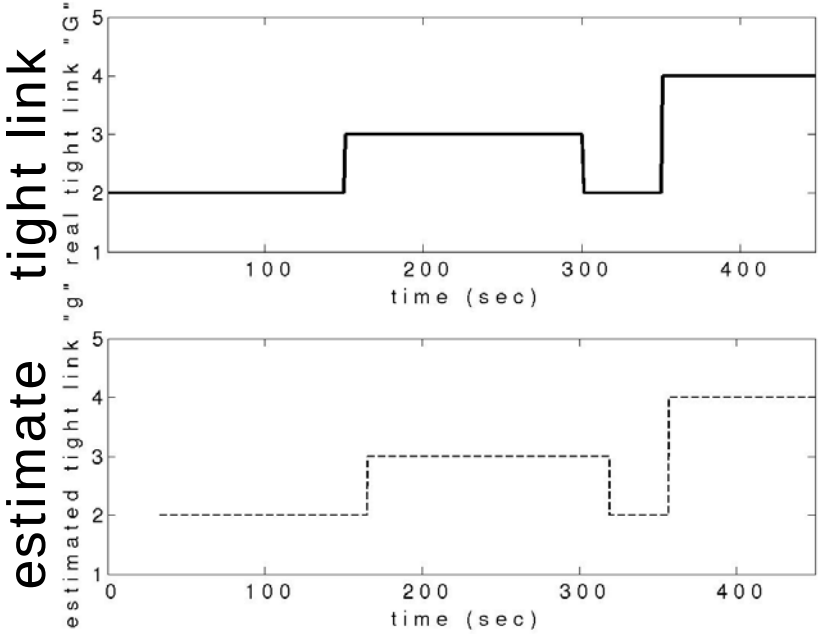


- Chirps: exponentially spaced packets
- Wide range of probing rates
- Efficient: few packets

$$\gamma = 1.4 \Rightarrow 13 \text{ packets, } 1\text{-}100\text{Mbps}$$

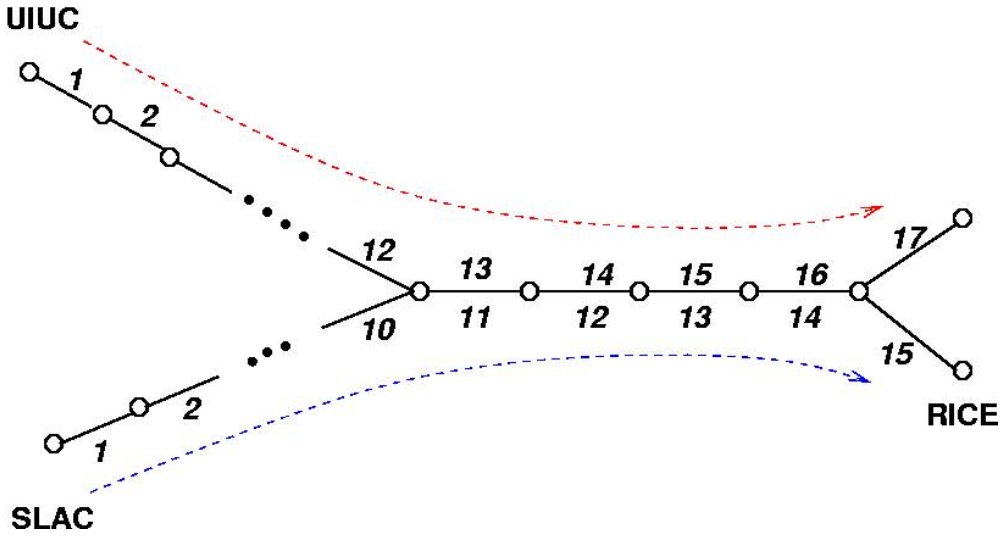
ns-2 Simulation



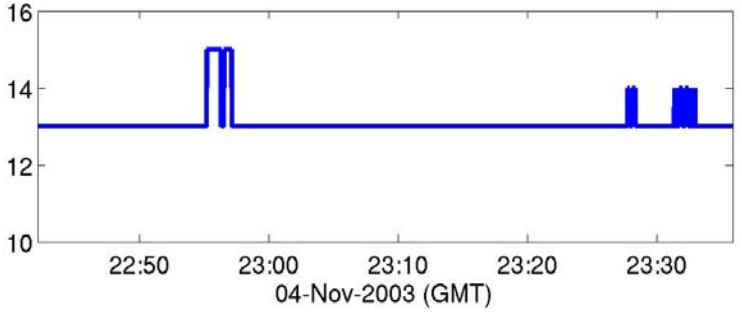


- Heterogeneous sources
- Tight link location changes over time
- pathChirp tracks tight link location change accurately

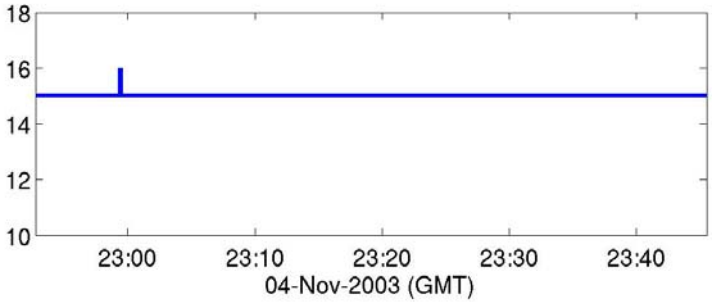
Internet Experiment



SLAC→Rice tight link



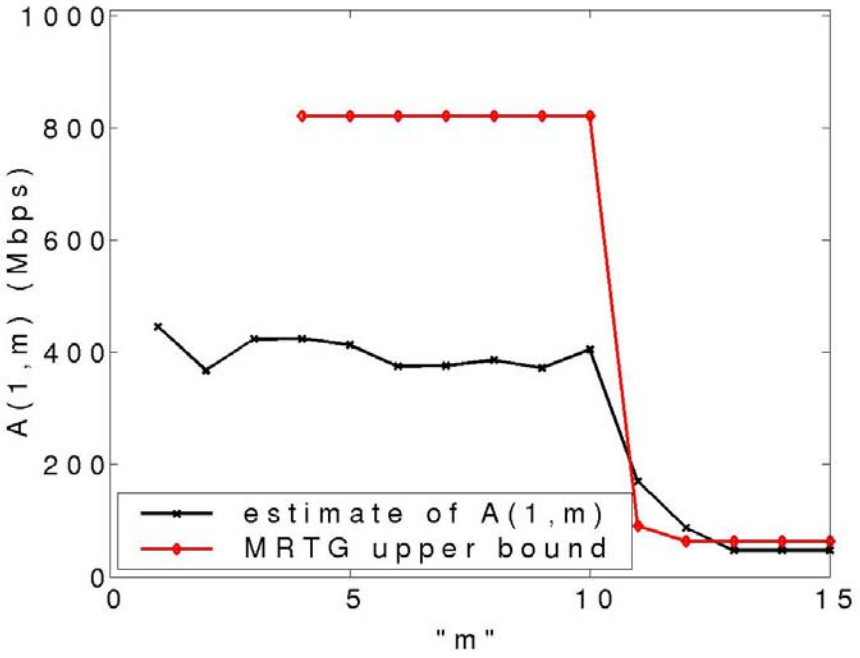
UIUC→Rice tight link



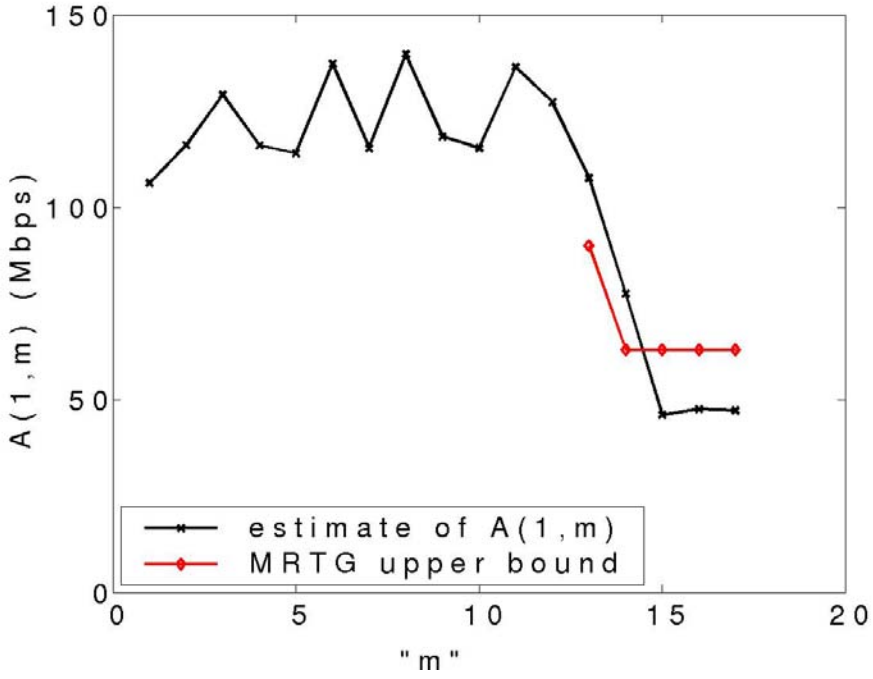
- Two paths:
  UIUC →Rice and SLAC→Rice
- Paths share 4 common links
- Same tight link estimate
  for both paths

Comparison with MRTG Data

SLAC→Rice

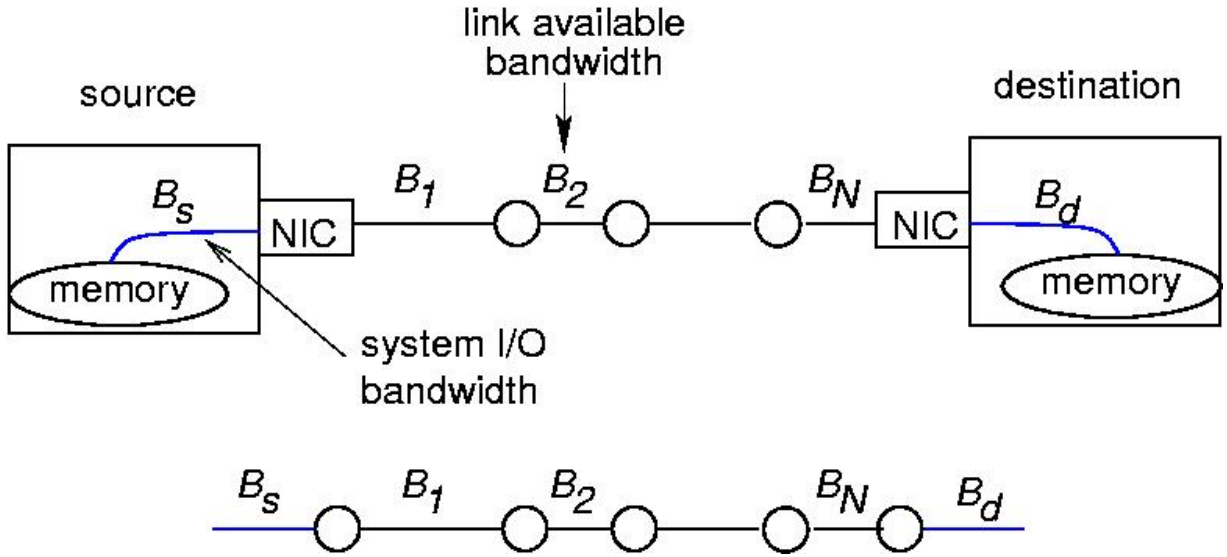


UIUC→Rice



- *A[1,m]* decreases as expected
- Tight link location differs from MRTG data by 1 hop

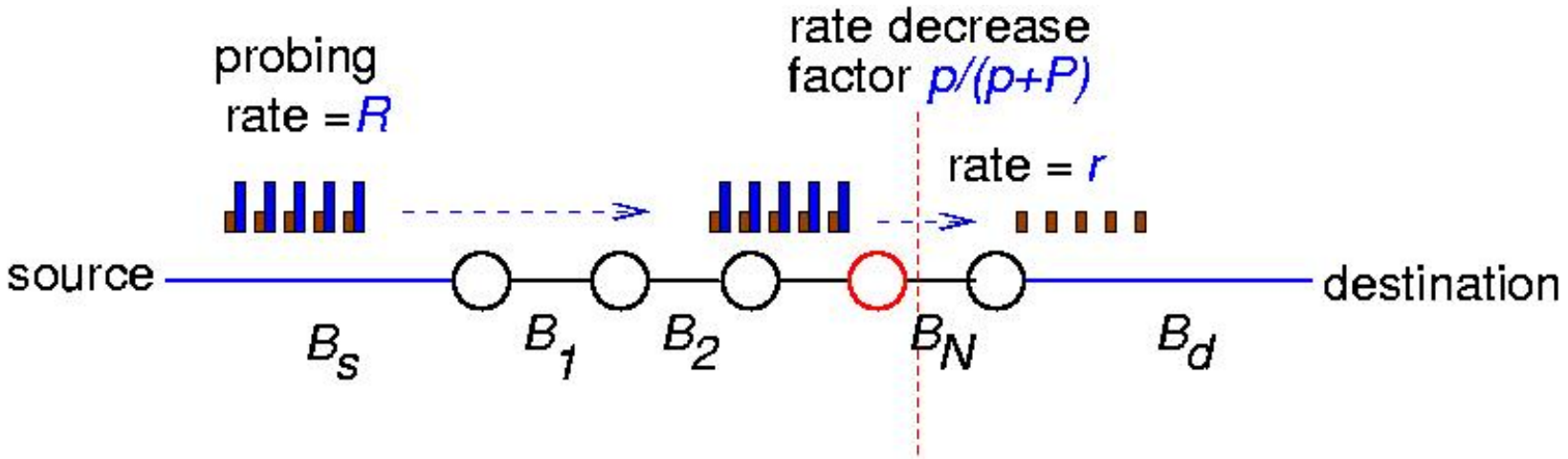
High Speed Probing



- *System I/O limits probing rate*
- On high speed networks:

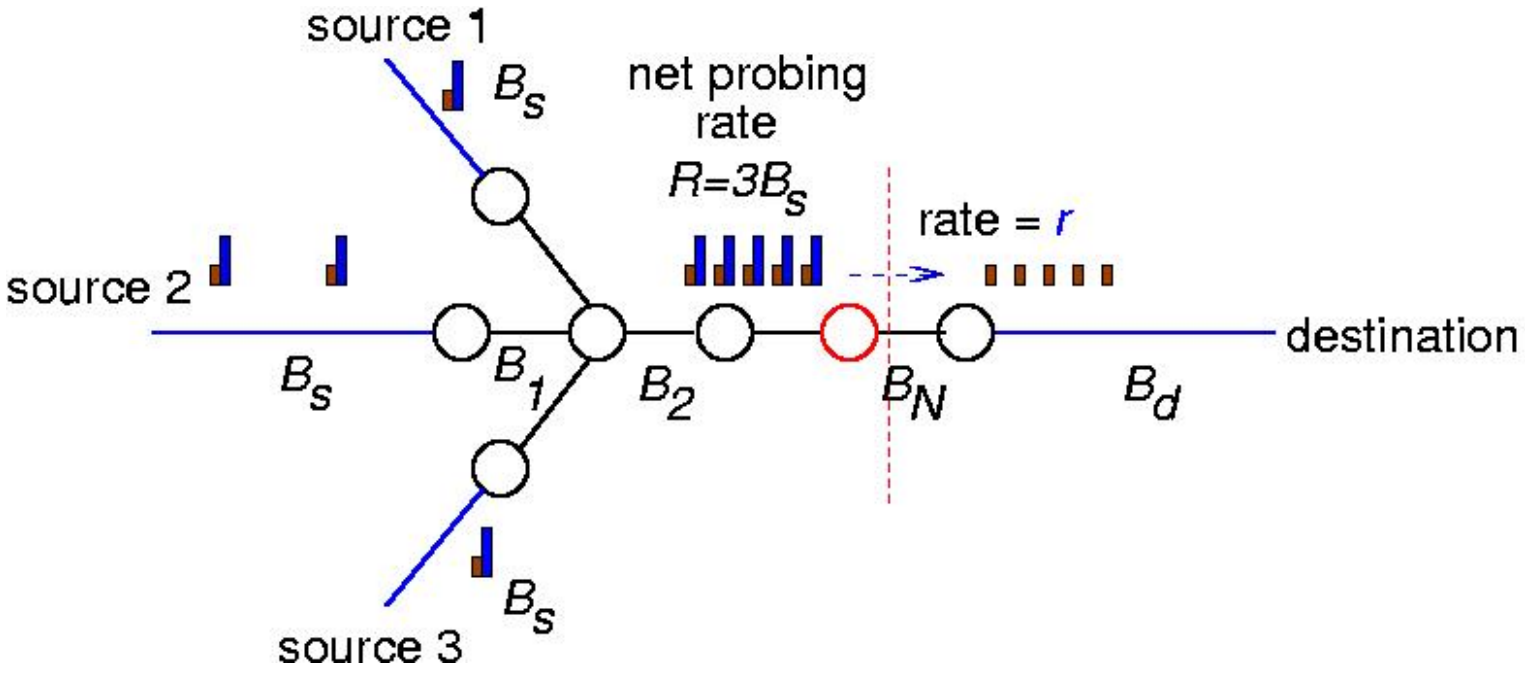
$$A > \min(B_s, B_d)$$ → cannot estimate *A* using self-induced congestion

Receiver System I/O Limitation



- Treat receiver I/O bus as an extra link
- Use packet tailgating
- If $r < B_d$ then we can estimate *A[1,N-1]*

Sender System I/O Limitations



- Combine sources to increase net probing rate
- Issue: machine synchronization

Conclusions

- Towards spatio-temporal available bandwidth estimation
- Combine self-induced congestion and packet tailgating
- Tight link localization in space and over time
- ns-2 and Internet experiments encouraging
- Solutions to system I/O bandwidth limitations

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