What do Packet Dispersion Techniques Measure?

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Overview

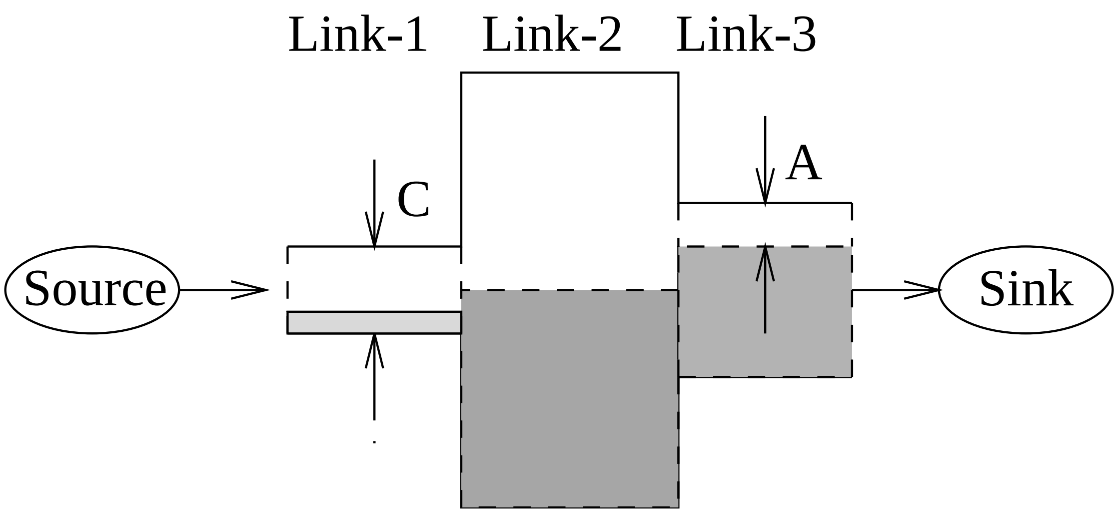
- Background: capacity and available bandwidth
- Dispersion of packet-pairs
- Dispersion of packet-trains
- A capacity estimation methodology: *pathrate*

Part I

Background

Definition of capacity

- Maximum IP-layer throughput that a flow can get, without any cross traffic

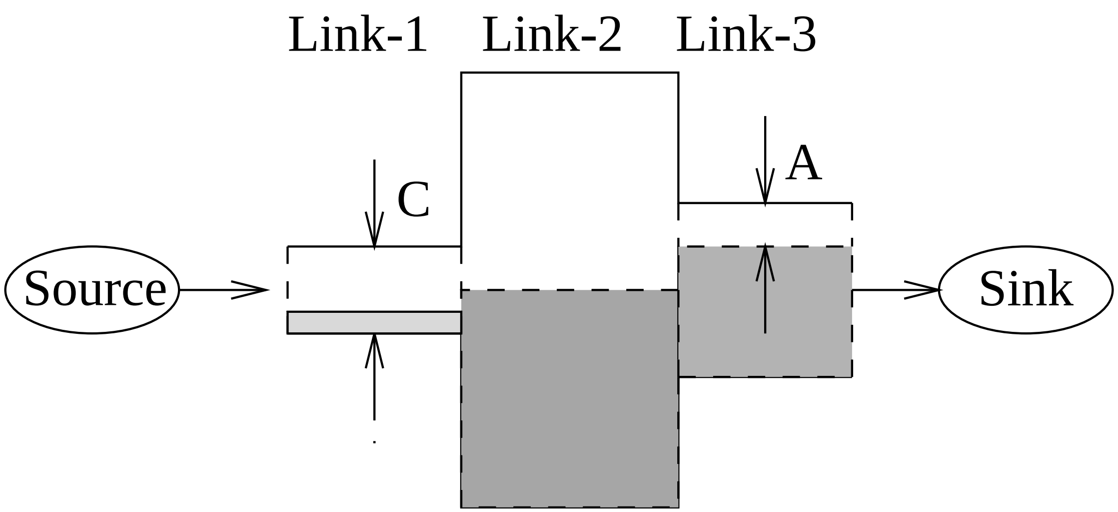


- C_i: capacity of link i ($i = 1, \ldots, H$)
- Path capacity C is limited by *narrow link* n:

$$C = \min_{i=0 \ldots H} \{C_i\} = C_n$$

Definition of available bandwidth

- Maximum IP-layer throughput that a flow can get, given (stationary) cross traffic



- u_i: utilization of link i
- Available bandwidth A limited by *tight link* t:

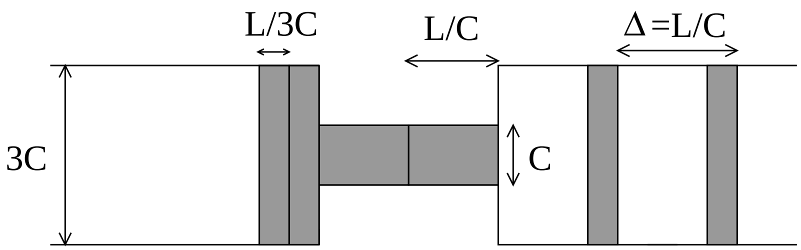
$$A = \min_{i=0 \ldots H} C_i \left(1 - u_i\right) = C_t \left(1 - u_t\right)$$

Part II

Packet-pair dispersion

Packet-pair: basic idea

- Packet transmission time: $\tau = \frac{L}{C}$
- Send two packets back-to-back
- Measure *dispersion* Δ at receiver
- Estimate C as $\frac{L}{\Delta}$



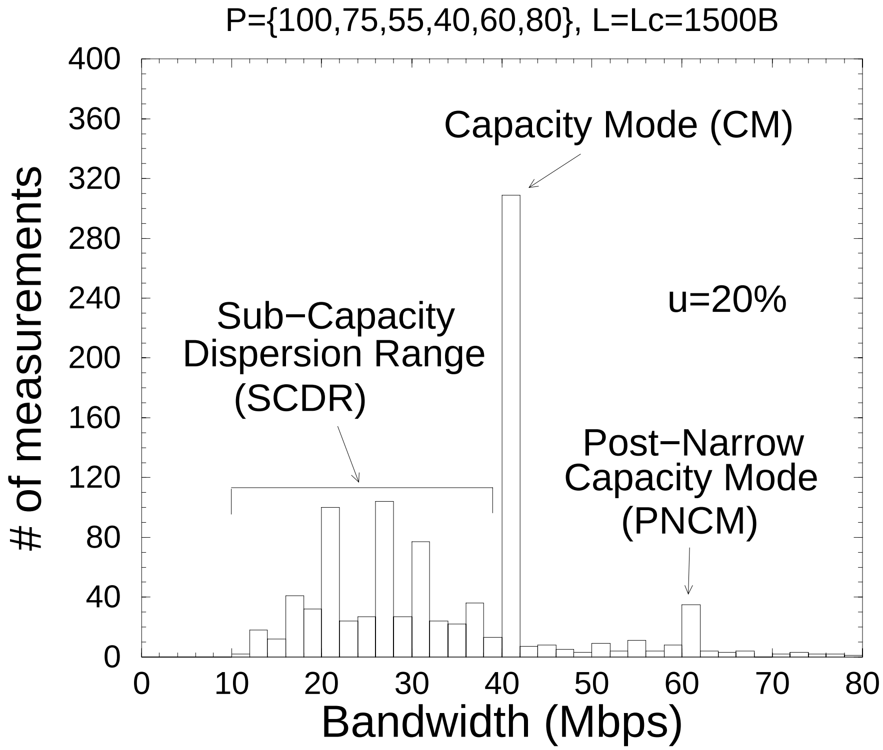
- But.. cross traffic 'noise' can affect the packet dispersion Δ

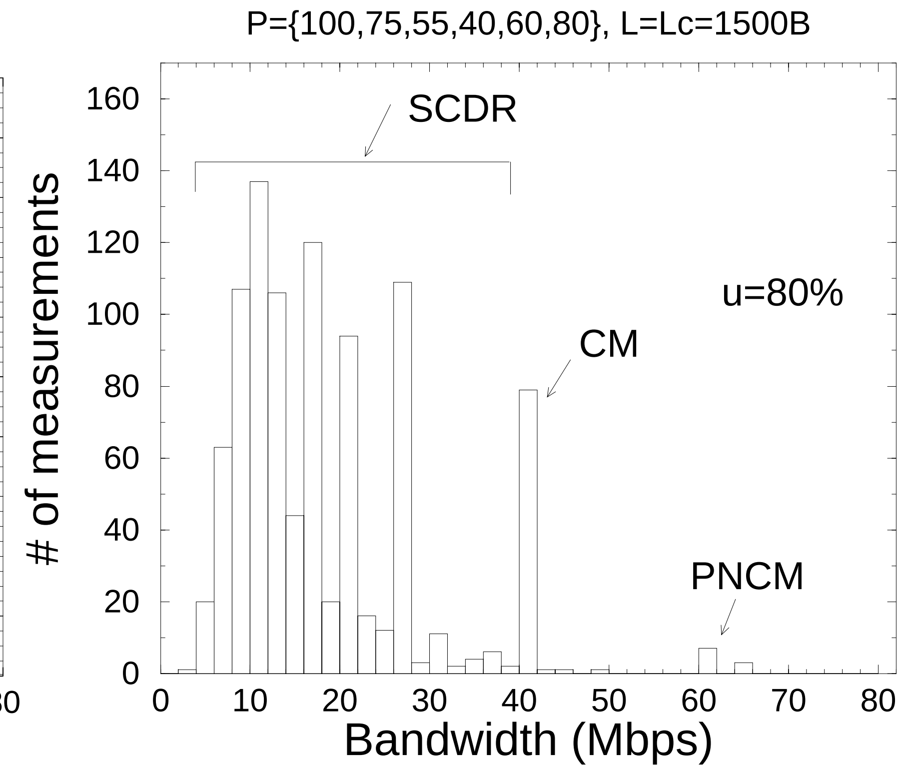
Previous works on packet-pair dispersion

- Largely considered cross traffic effects as 'random noise'
- Carter and Crovella (Infocom 1997), Lai and Baker (Infocom 1999): Statistical techniques to extract most common measurement range (mode)
- Paxson (Sigcomm 1997): observed multimodalities but did not relate them with cross traffic
- They suggest use of maximum-size packet-pair packets

Multimodality of packet-pair estimates

- Cross-traffic causes local modes below (SCDR) and above (PNCM) capacity mode (CM)

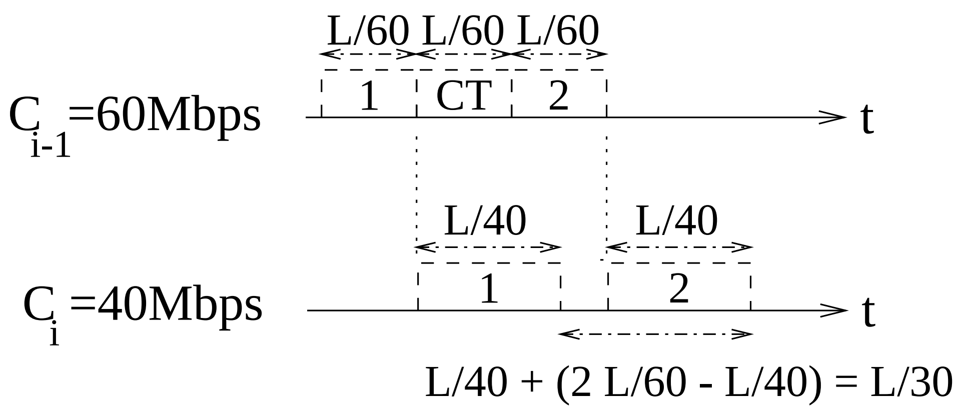




- Heavier cross traffic load makes CM weaker

Creation of SCDR and PNCM modes

- SCDR is caused by cross traffic interfering with packet-pair

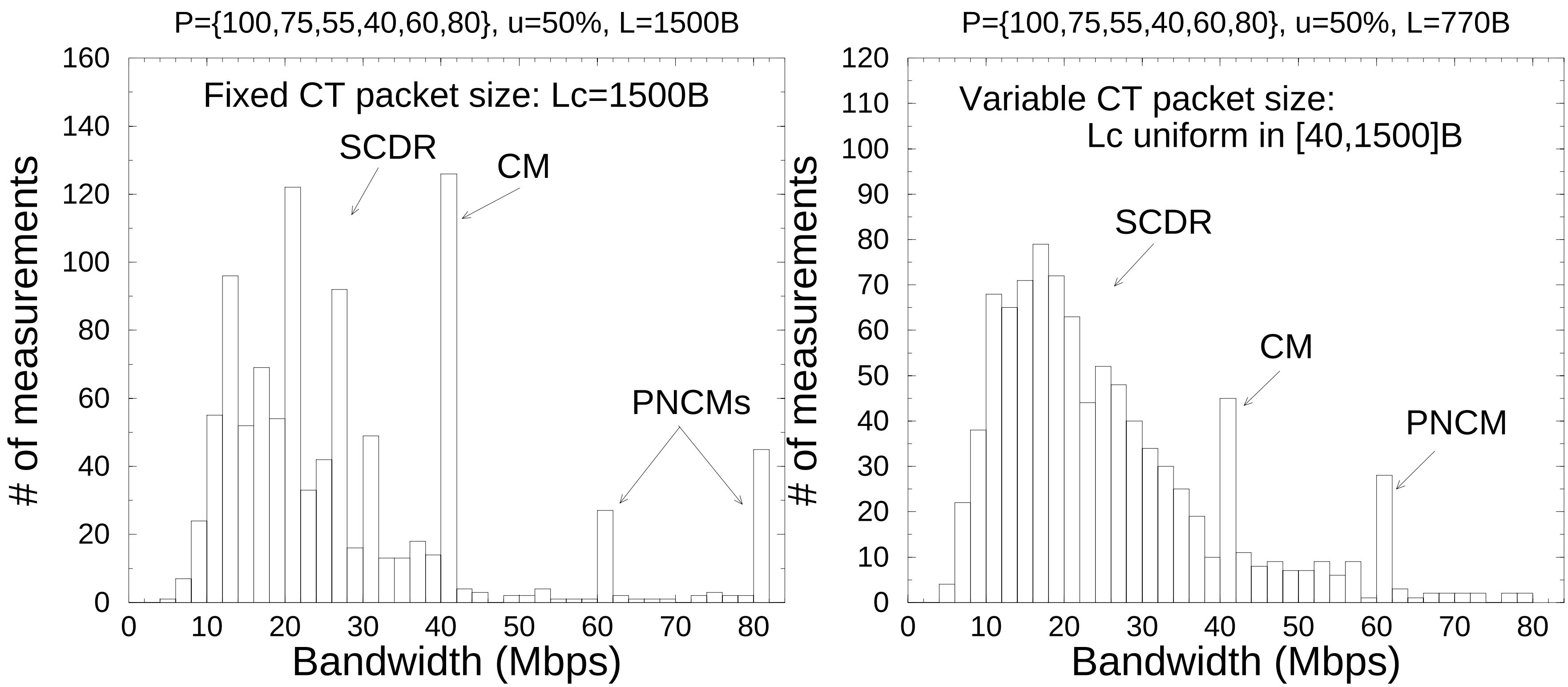


- PNCMs are caused by back-to-back packet-pairs after narrow link (first packet is adequately delayed)

Effect of cross traffic packet size

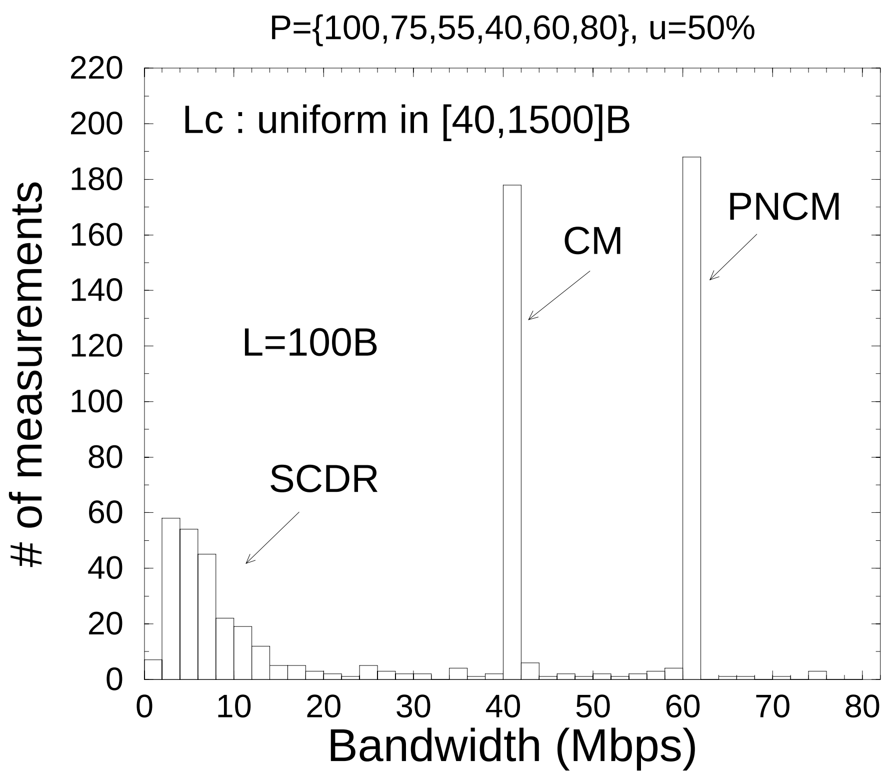
- Distinct cross traffic packet sizes cause SCDR local modes

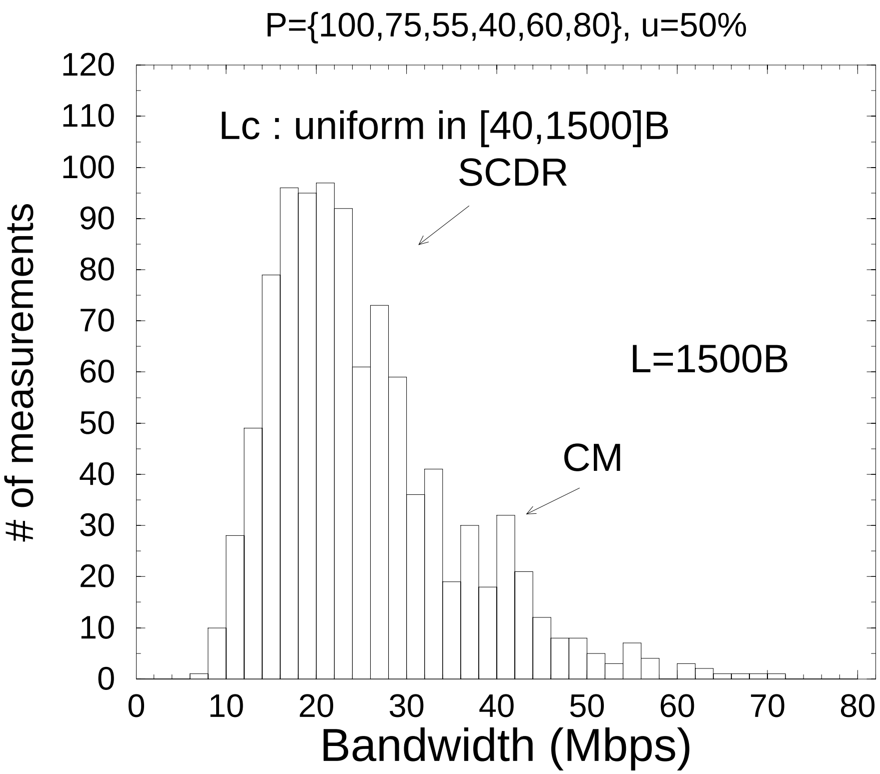
- Common Internet traffic packet sizes: 40B, 550B, 1500B



Effect of packet-pair size

- Previous work suggests use of maximum-sized packets
- But.. this is not optimal for uncovering capacity mode





Packet-pair dispersion: summary

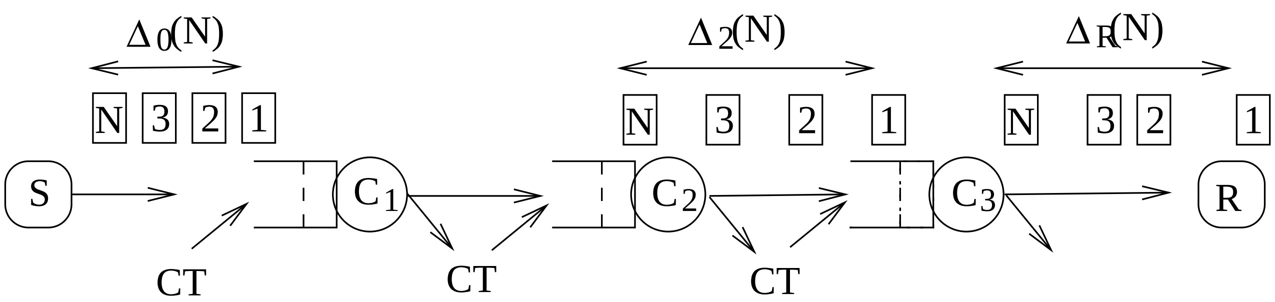
- Packet-pair technique: simple in unloaded paths
- Multimodal bandwidth distribution in loaded paths
- Most common measurement range (mode) is not always the capacity
- Capacity is normally a local mode (CM)
- Interfering cross traffic packets cause local modes or SCDR
- Loaded post-narrow links also cause local modes (PNCMs)
- Maximum packet size is not optimal for uncovering CM
- How can we tell which local mode is related to the capacity?

Part III

Packet-train dispersion

Packet-train dispersion

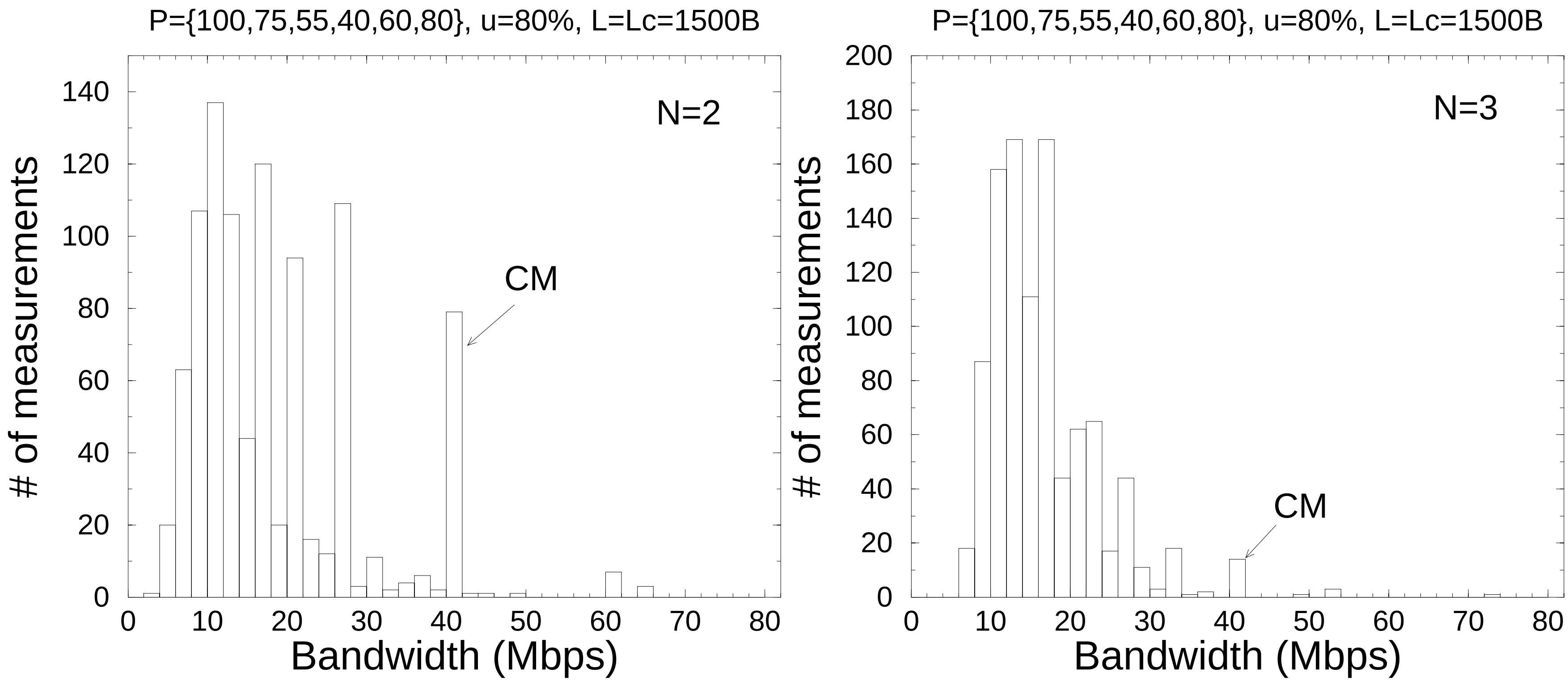
- What do we measure with the dispersion of packet trains?



- Bandwidth estimate: $\frac{(N-1)L}{\Delta(N)}$
- What is the effect of length N on bandwidth estimate?
- Carter & Crovella: packet-train dispersion estimates A

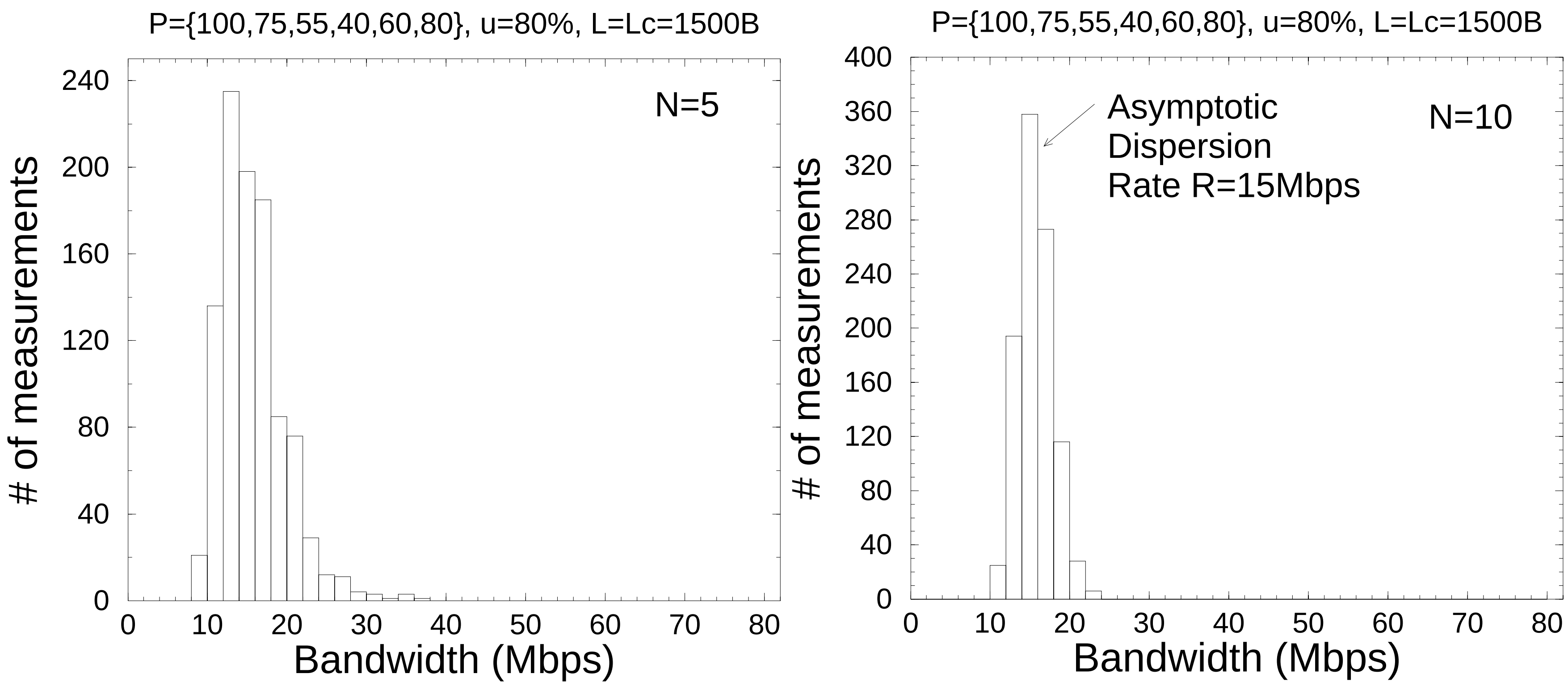
Packet-train experiments

- What happens as we increase the packet-train length N?



Packet-train experiments (cont')

- Range of measurements decreases and becomes unimodal
- Measurements tend to Asymptotic Dispersion Rate (ADR) (less than C)



ADR in single-hop paths

- For sufficiently large N:

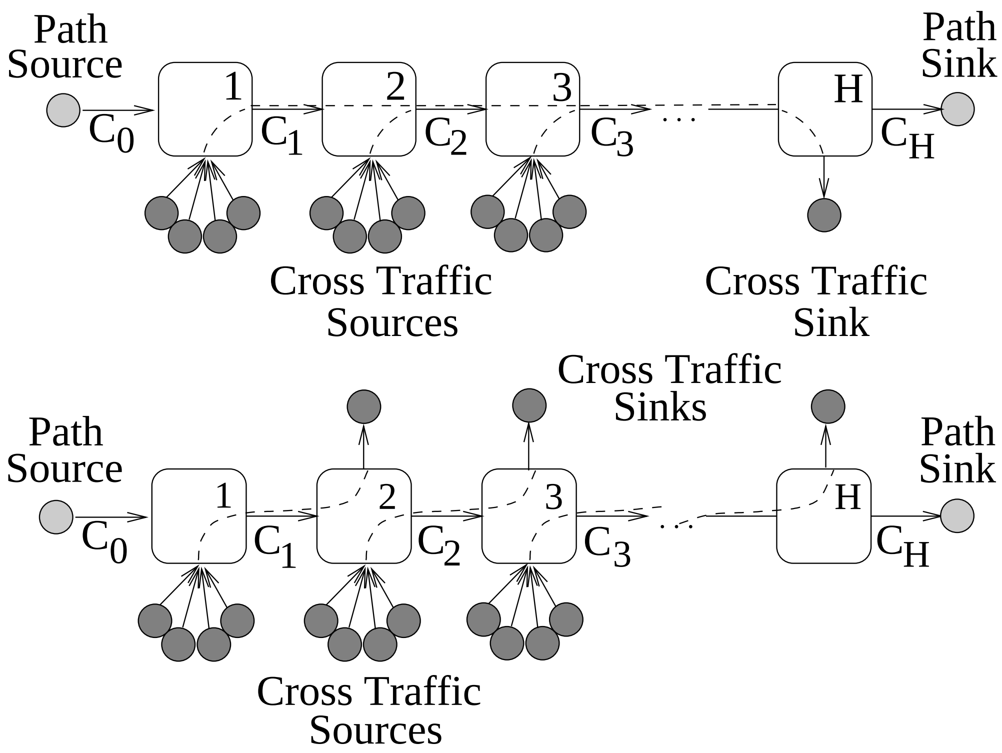
$$R = \frac{(N-1)L}{\bar{\Delta}_1} = \frac{C_1}{1 + u_1 \frac{C_1}{C_0}} < C_1$$

- ADR is *not* the capacity C
- ADR is *not* the available bandwidth A
- For single-hop paths, we can estimate A from R

$$A = C_0 \left(\frac{C_1}{R} - 1 \right)$$

Effect of cross traffic routing

- Path-persistent and one-hop persistent cross traffic



Packet-train dispersion in multi-hop paths

- Can we derive the ADR for general cross traffic routing and paths?
- Cross traffic packets cause 'bubbles' between packet-train packets
- For one-hop path persistent cross traffic with $C_i = C$:

$$\frac{C}{1 + \sum_{i=1}^{H} u_i} \leq R \leq \frac{C}{1 + \max_{i=1...H} u_i}$$

- Lower bound: bubbles are never filled in
- Upper bound: bubbles are determined by tight link

Packet-train dispersion: summary

- Packet-trains: do not lead to more robust capacity estimation
- Packet-trains: do not lead to available bandwidth estimation
- As N increases, measurement range decreases and becomes unimodal
- As N increases, measurements tend to ADR
- ADR is always less than capacity
- Available bandwidth can be computed from ADR in single-hop paths

Part IV

A capacity estimation methodology

Pathrate: a capacity estimation methodology

Phase I:

- Perform many (2000) packet-pair experiments to form distribution $\mathcal{B}$
- Use packet size of about 800 bytes (maximum size: 1500 bytes)
- Determine local modes of distribution $\mathcal{B}$
- Sequence of local modes in increasing order: $\mathcal{M} = \{m_1, m_2, \ldots m_M\}$

Pathrate: a capacity estimation methodology (cont')

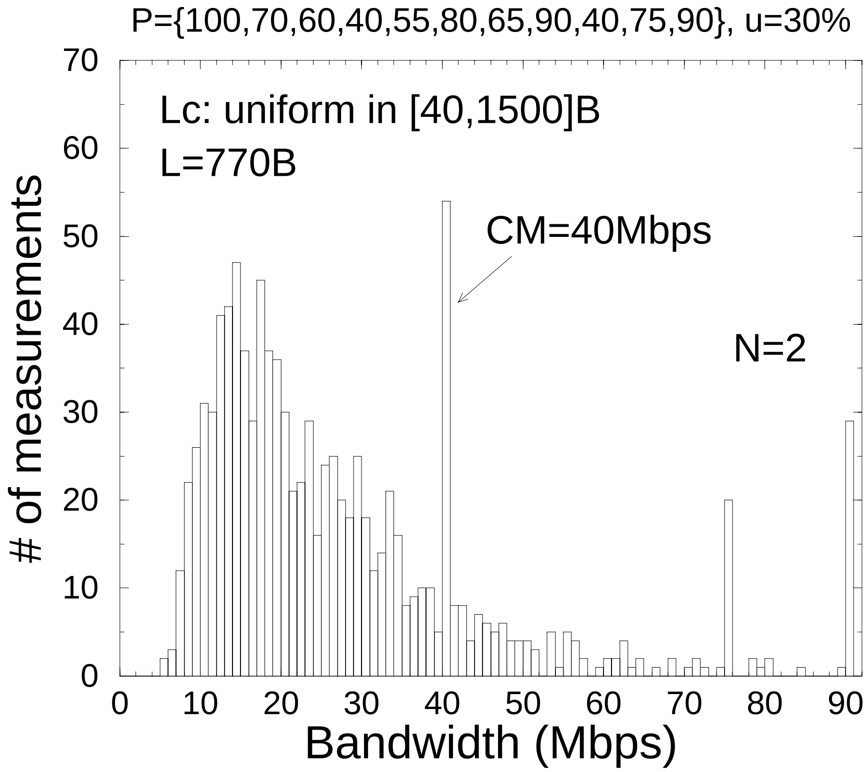
Phase II:

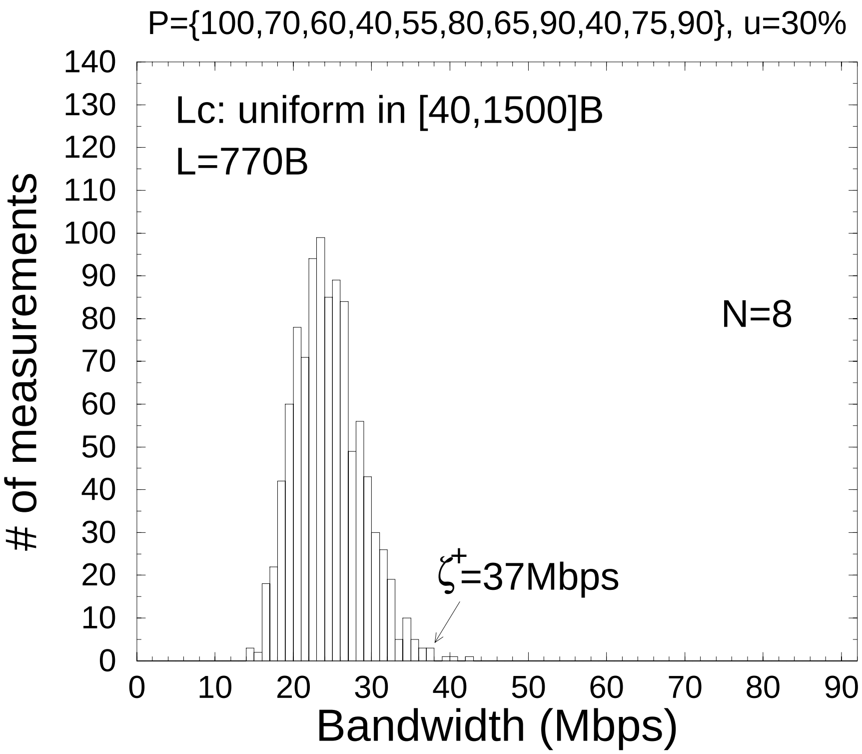
- Perform several packet-train experiments with certain N to get $\mathcal{B}(N)$
- If bandwidth distribution not unimodal, increase N and repeat previous step
- Let $\bar{N}$ be the *minimum* value of N such that $\mathcal{B}(N)$ is unimodal
- Let $[\zeta^-, \zeta^+]$ be range of the unique mode in $\mathcal{B}(N)$
- Estimate capacity as:

$$\hat{C} = m_k = \min\{m_i \in \mathcal{M} : m_i > \zeta^+\}$$

Example: Path $\{100,70,60,40,55,80,65,90,40,75,90\}$

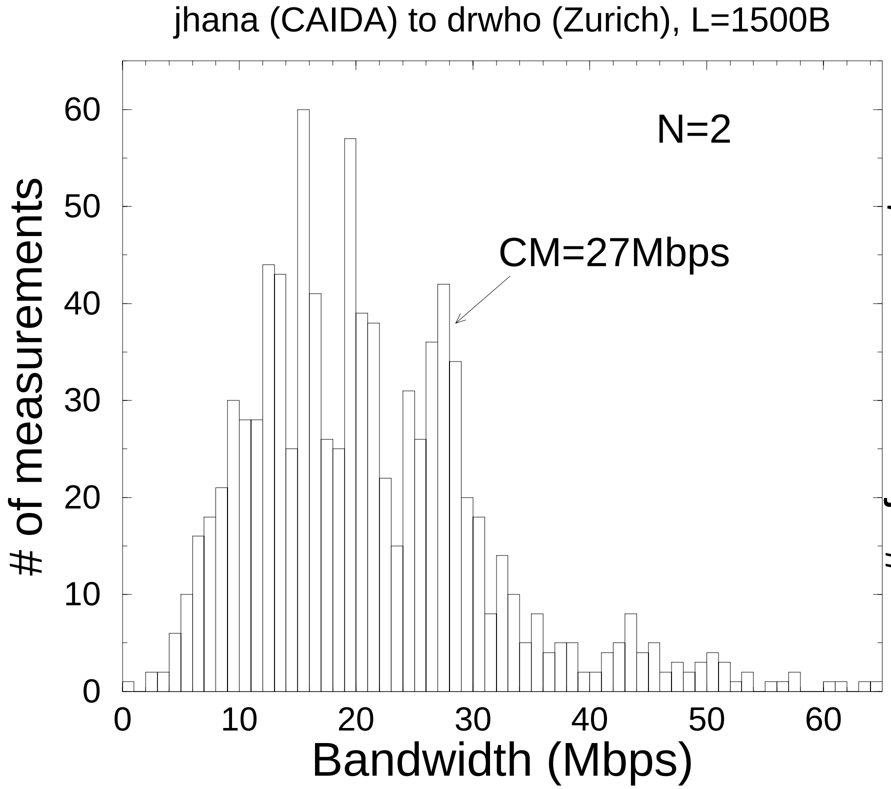
- Packet-pair modes $\mathcal{M}=\{9,14,17,23,26,29,33,40,44,56,75,90\}$

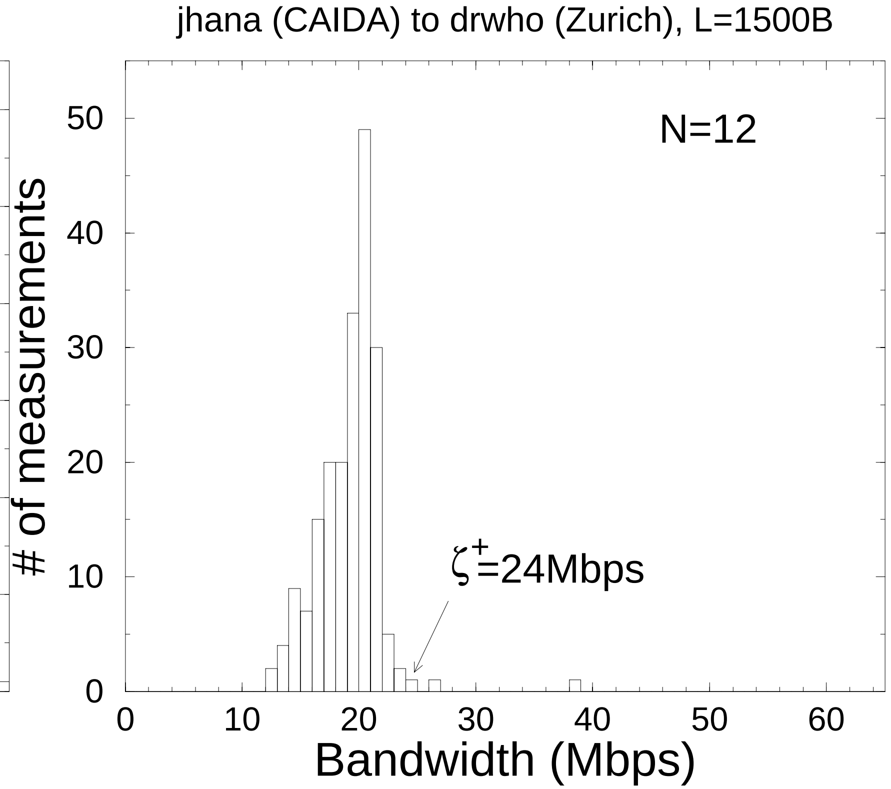




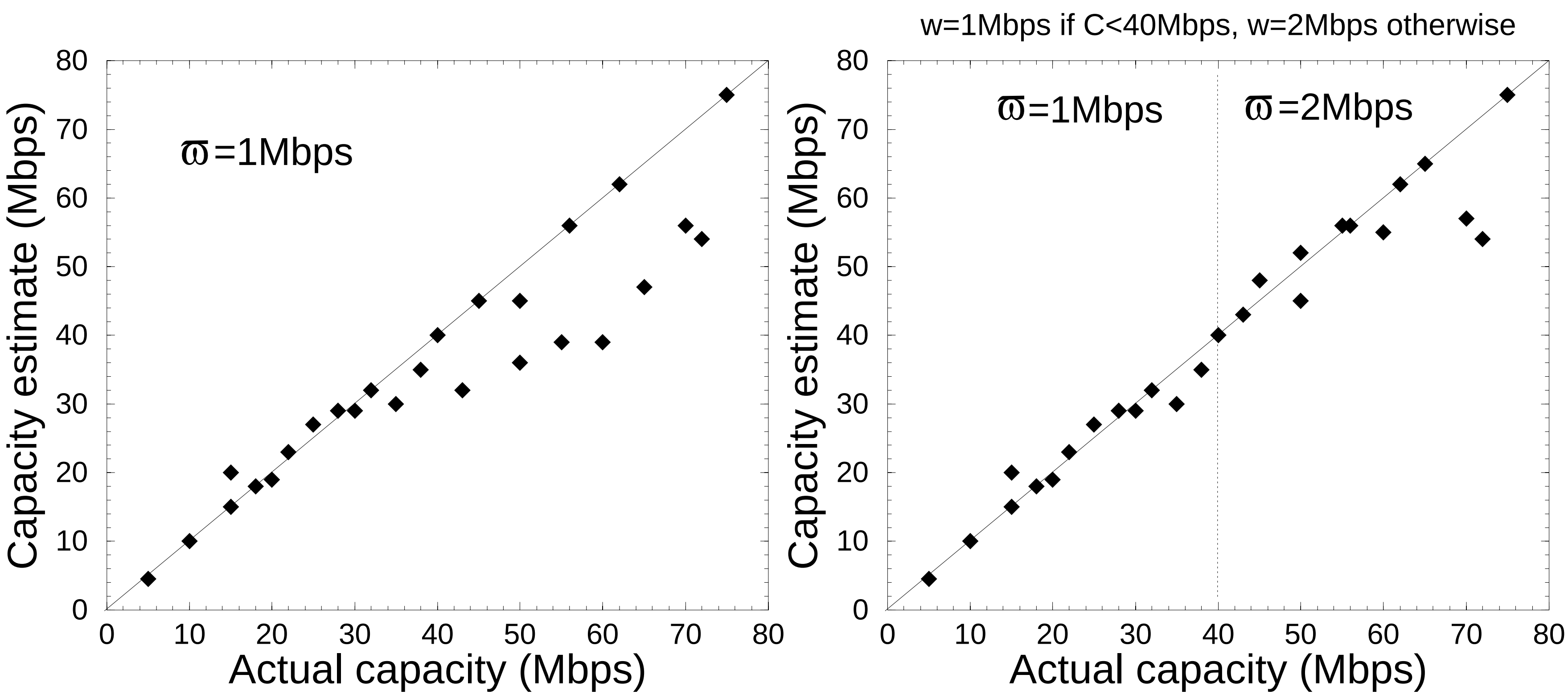
From CAIDA (San Diego) to ETH (Zurich)

- Packet-pair modes $\mathcal{M}$=$\{$9,11,13,15.5, 19.5, 27, 32, 43$\}$





Pathrate verification



- Higher capacity values require larger bandwidth resolution ω
- Adaptive selection of bandwidth resolution?

Summary and contributions

- Capacity estimation in heavily-loaded paths is *hard!*
- Statistical filtering of packet-pair measurements does not work
- Use of maximum-sized packets is not optimal
- Packet-train dispersion does not estimate available bandwidth
- Available bandwidth can be computed from ADR in single-hop paths
- Pathrate takes into account effect of cross traffic on packet-trains