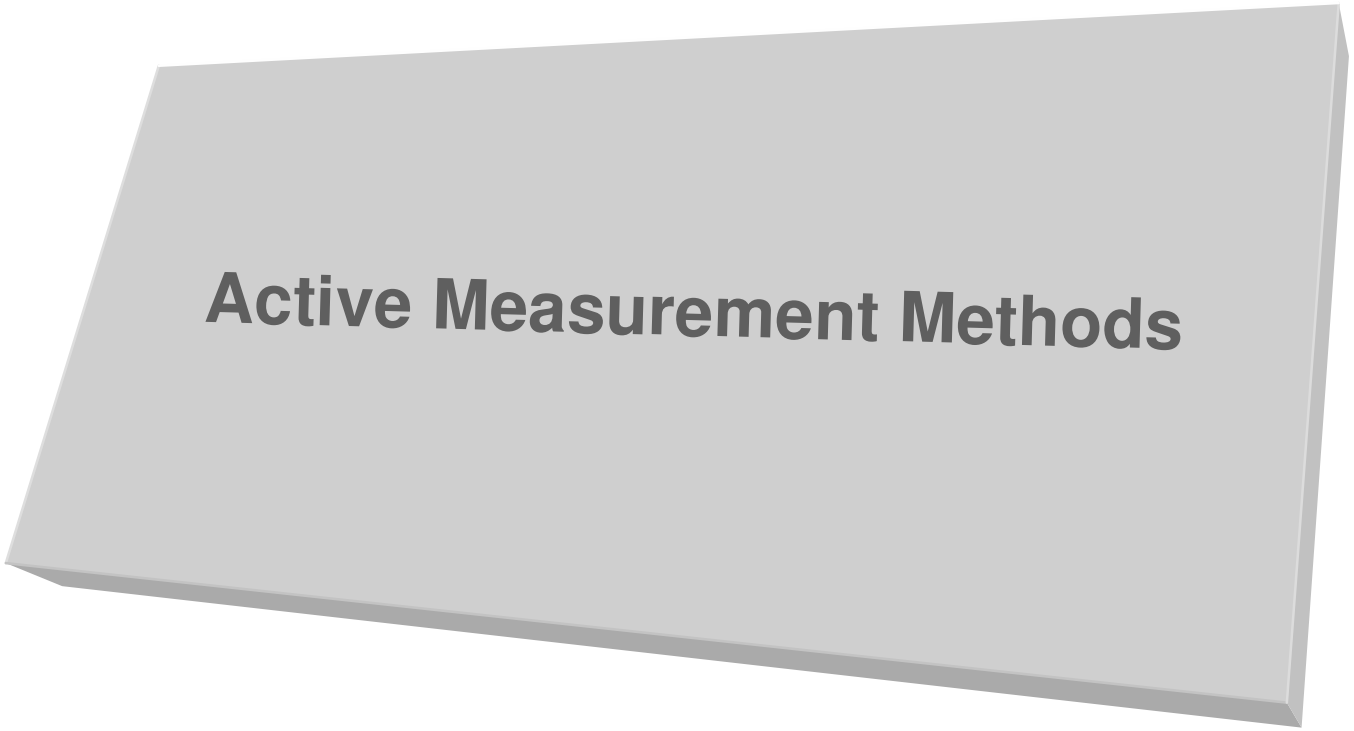
ERICSSON

Active Probing Using Packet Quartets

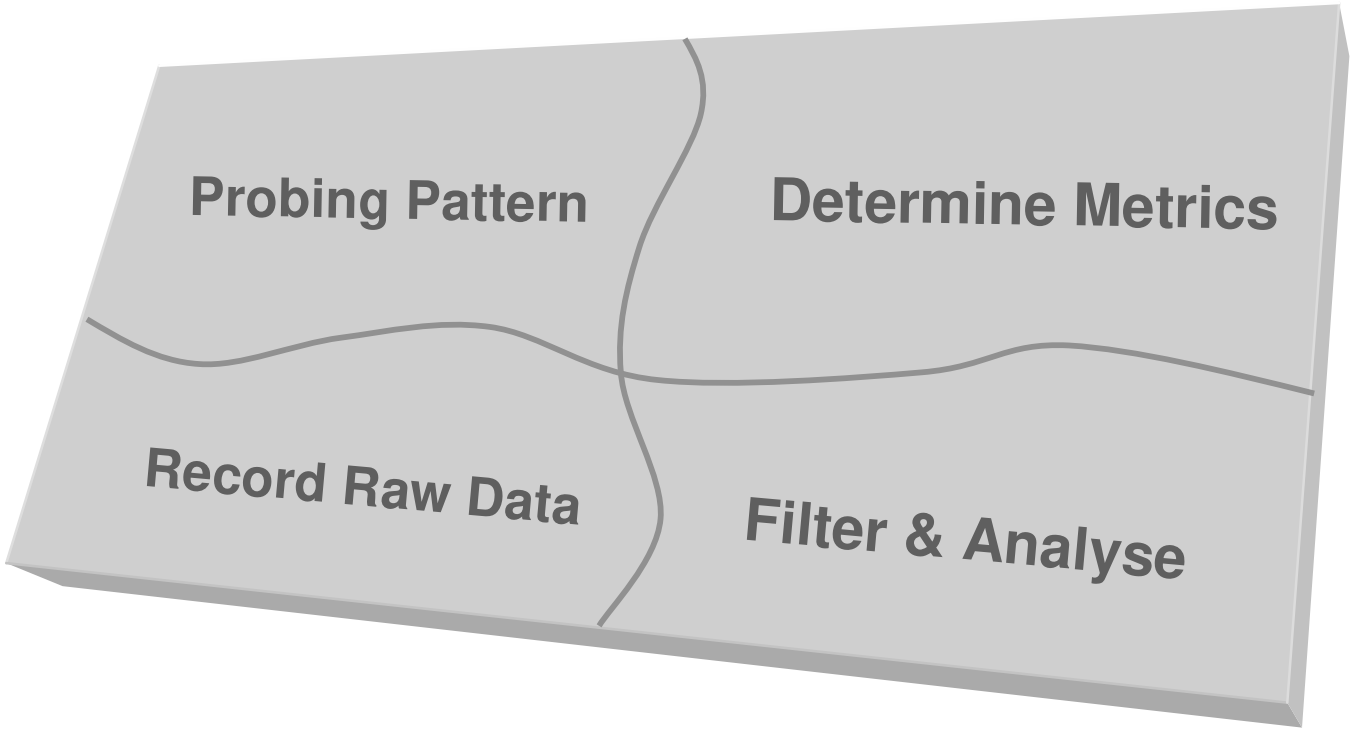
Attila Pásztor[1,2] **Darryl Veitch[1]**

1 - CUBIN at the Department of Electrical & Electronic Engineering The University of Melbourne
2 - Ericsson Hungary R&D

In focus: Link bandwidth estimation

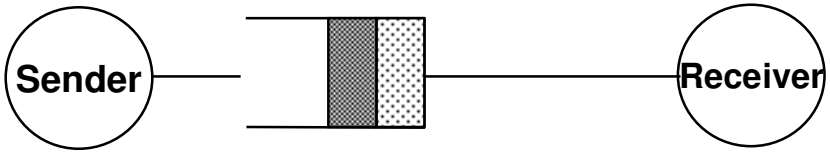


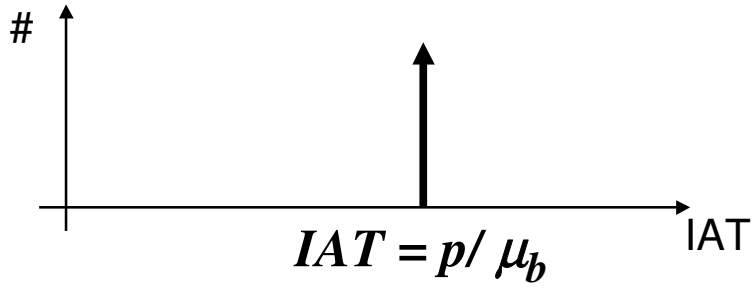
Active Measurement Methods



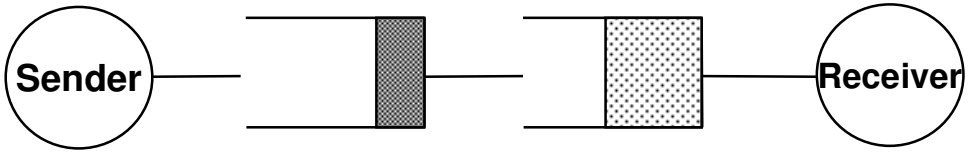
Fundamental Network Effects

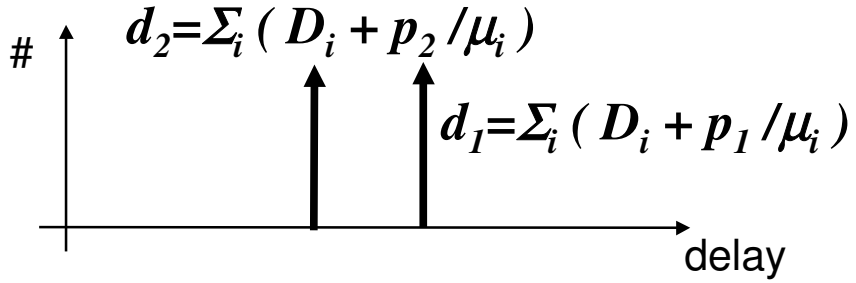
- **Spacing Effect**





- **Packet Size Dependence of Service Time**



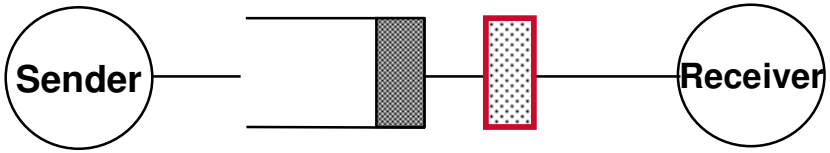


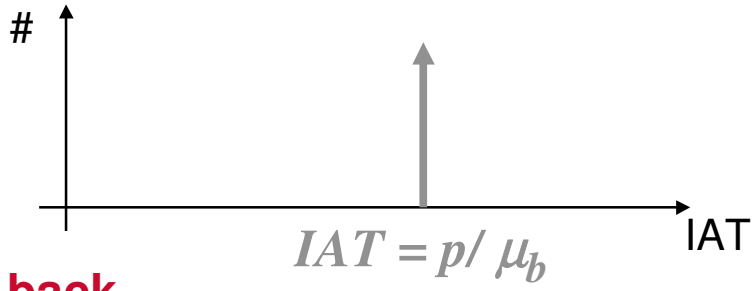
Difference in estimates due to lower layer headers

$$d_1 - d_2 = (p_1 - p_2)\Sigma_i (1 /\mu_i)$$

Fundamental Network Effects
SENDER EFFECTS

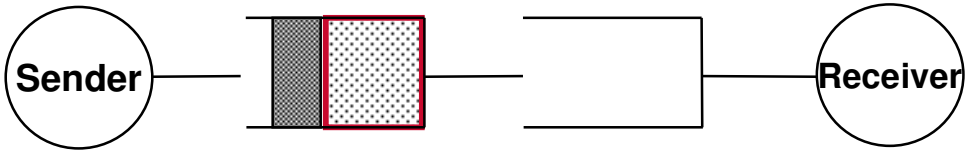
- Spacing Effect

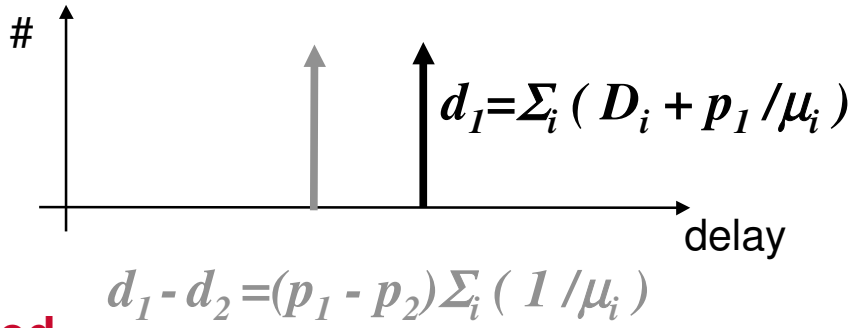




Inter departure time too large to remain back-to-back

- Packet Size Dependence of Service Time

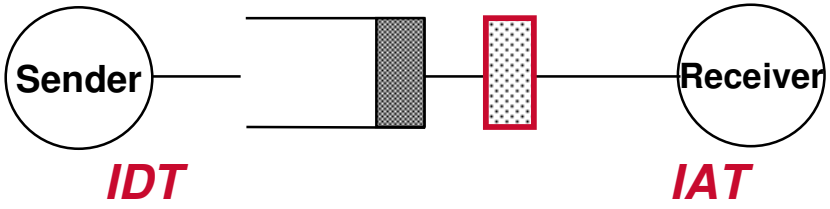


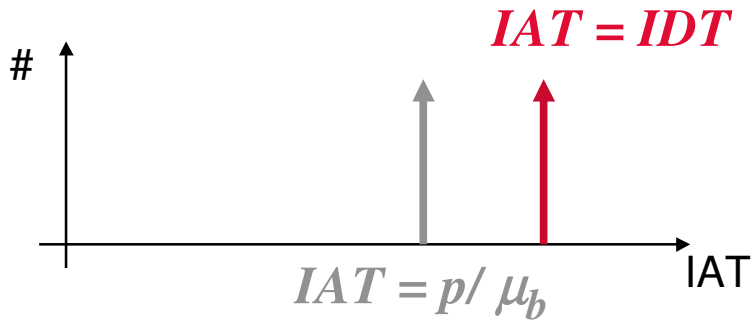


Inter departure time too small to remain separated

Fundamental Network Effects
SENDER EFFECTS

- Spacing Effect





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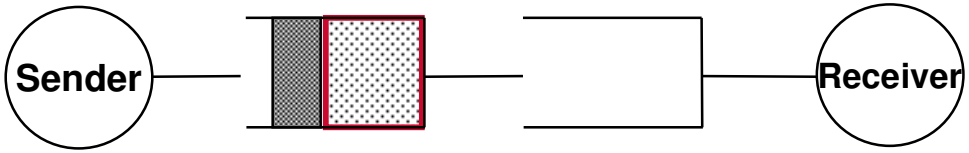
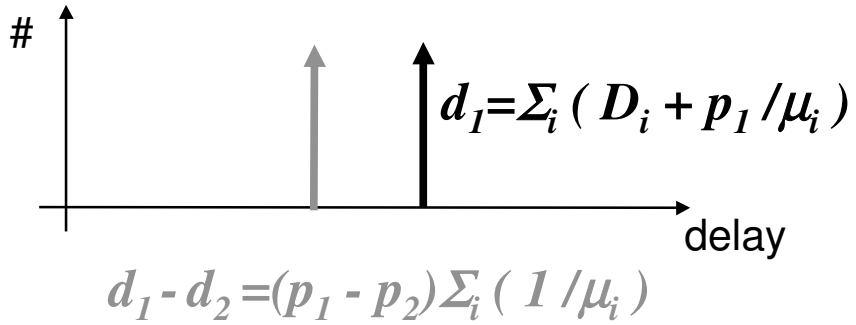
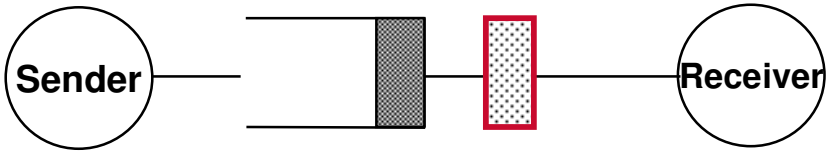
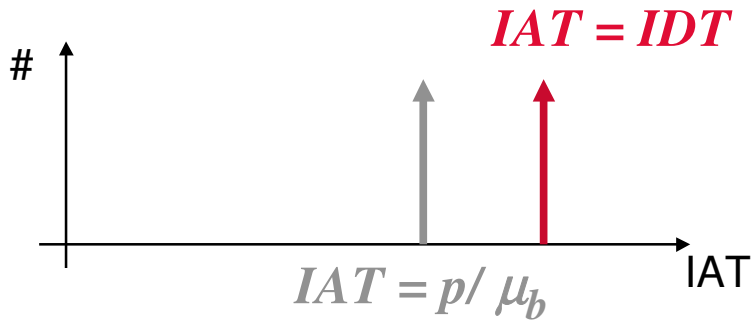




Fundamental Network Effects
SENDER EFFECTS

- **Spacing Effect**





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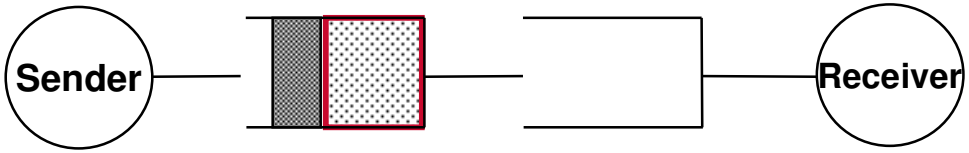
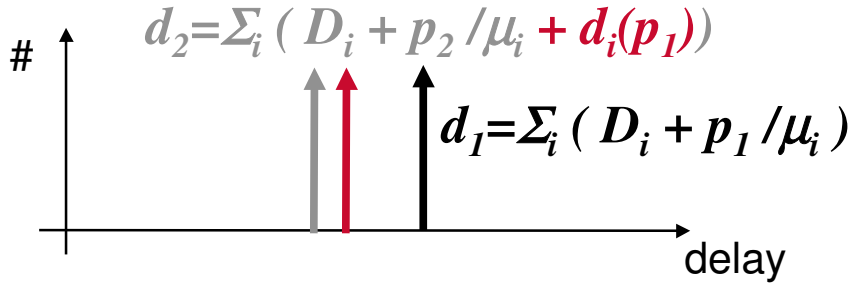


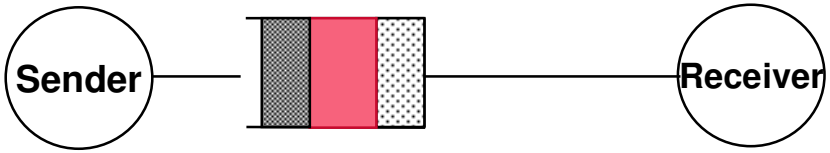


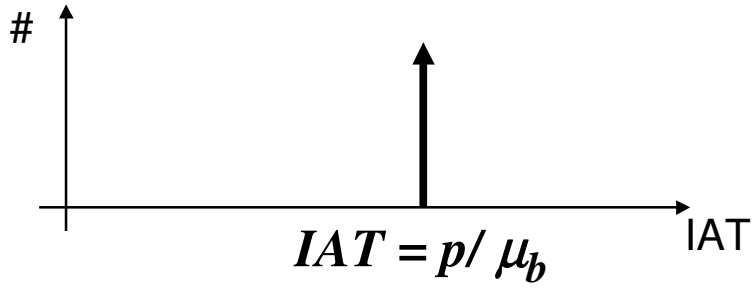
$d_1 - d_2 = (p_1 - p_2) \Sigma_i (1 / \mu_i)$

$d_1 - d_2 = \Sigma_i ((p_1 - p_2) / \mu_i - d_i(p_1))$

Fundamental Network Effects
NOISE - CROSS TRAFFIC

- **Spacing Effect**





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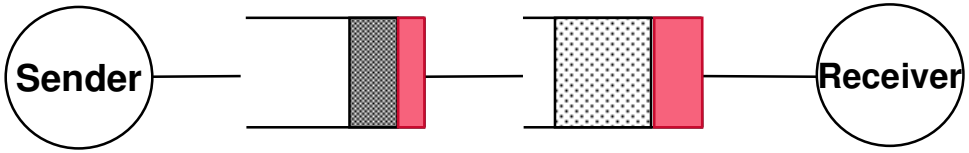

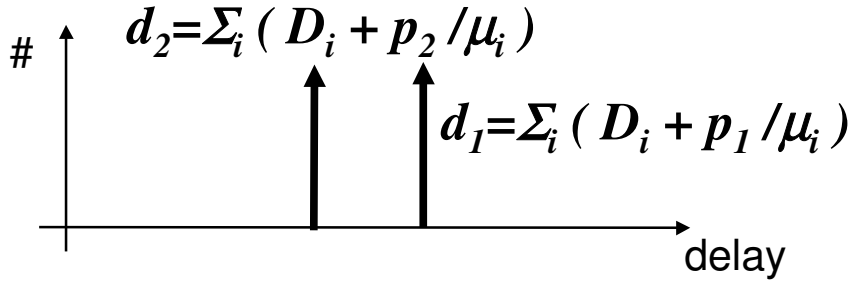

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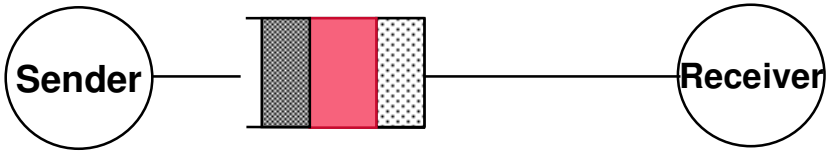
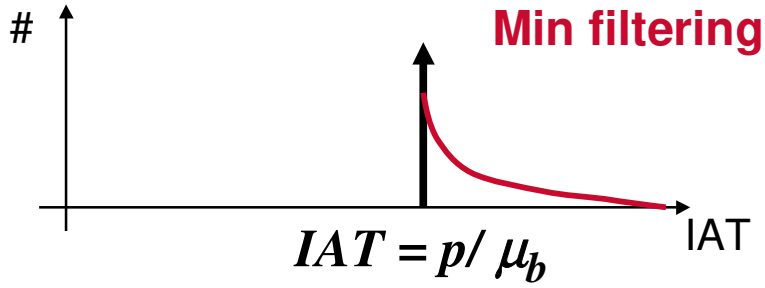
Fundamental Network Effects
NOISE - CROSS TRAFFIC

- **Spacing Effect**





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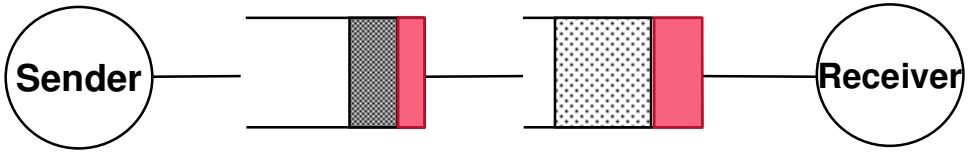

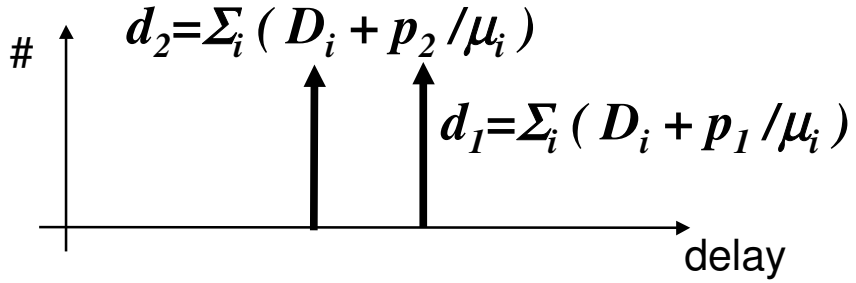

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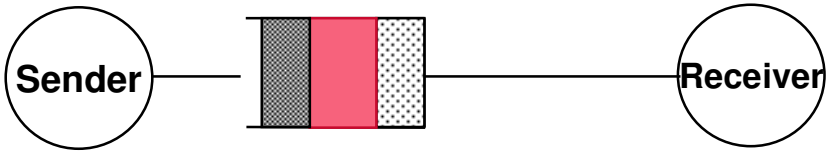
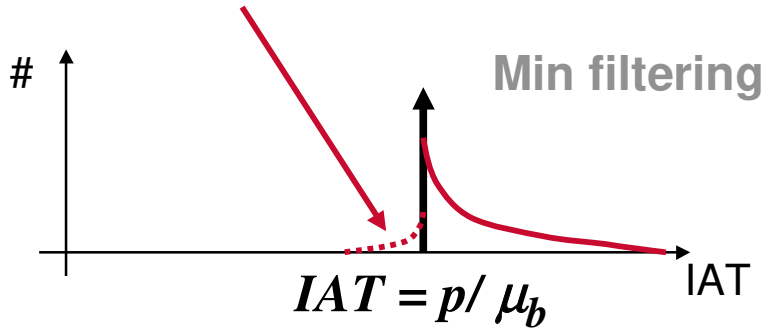
Fundamental Network Effects
NOISE - CROSS TRAFFIC

- **Spacing Effect**



Multiple hops -> Mode detection



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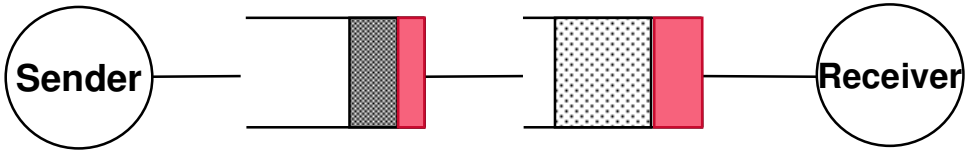

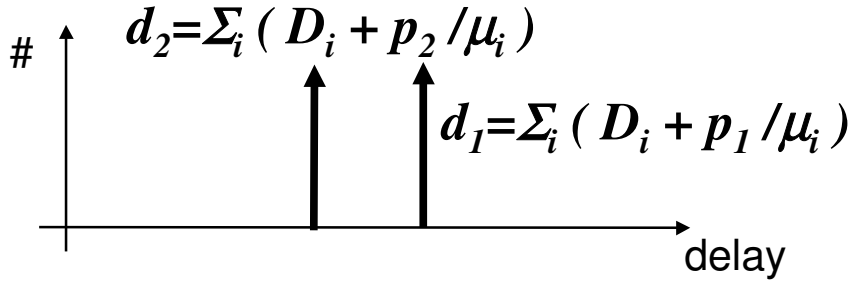

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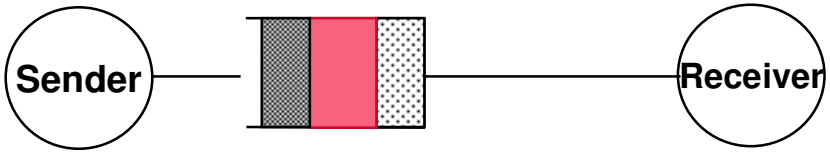
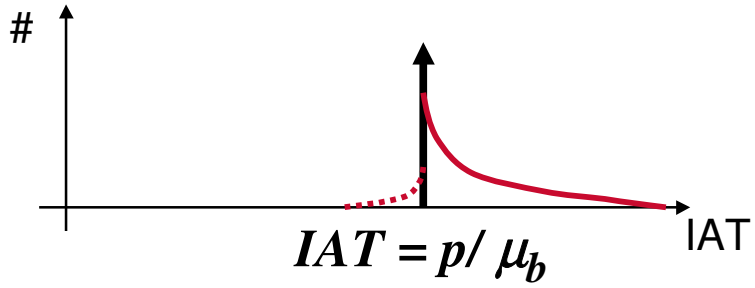
Fundamental Network Effects
NOISE - CROSS TRAFFIC

- **Spacing Effect**





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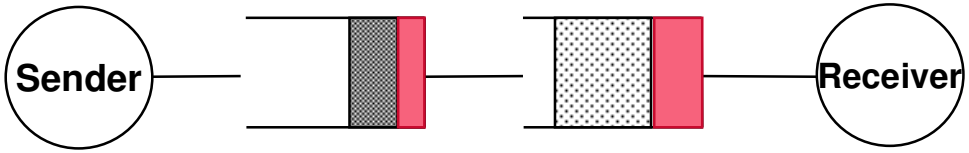
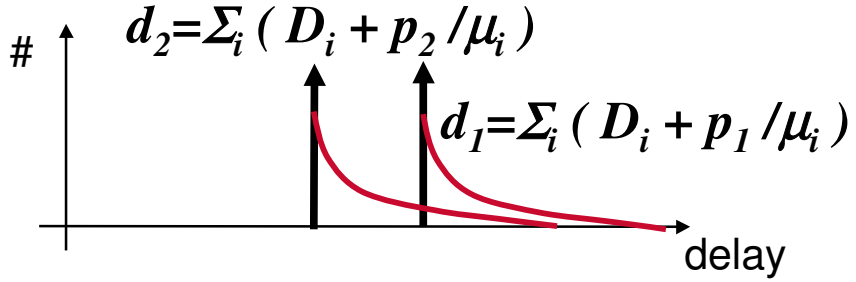


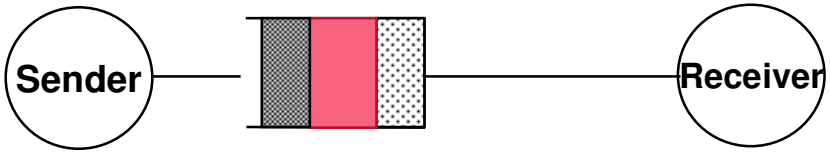
Min filtering

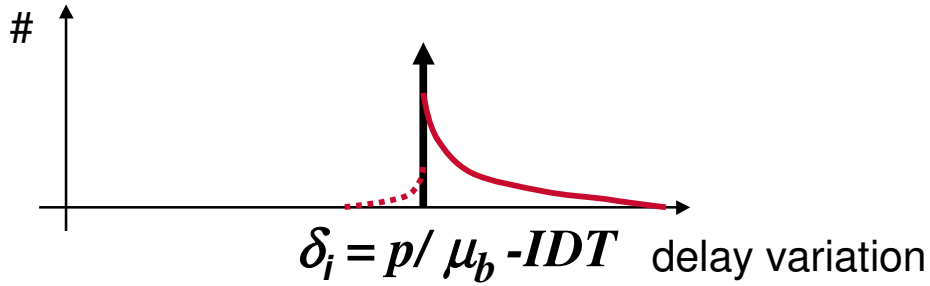


$$d_1 - d_2 = (p_1 - p_2)\Sigma_i (1 /\mu_i)$$

Fundamental Network Effects
DELAY VARIATION

- **Spacing Effect**





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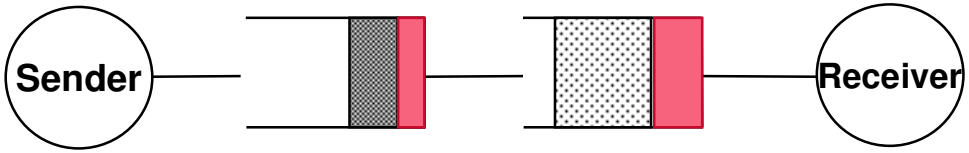
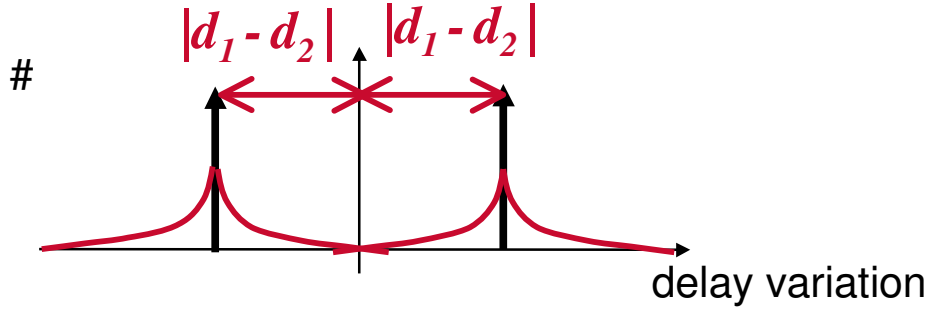


Potential for new filtering methods
eg. Medians of sub histograms

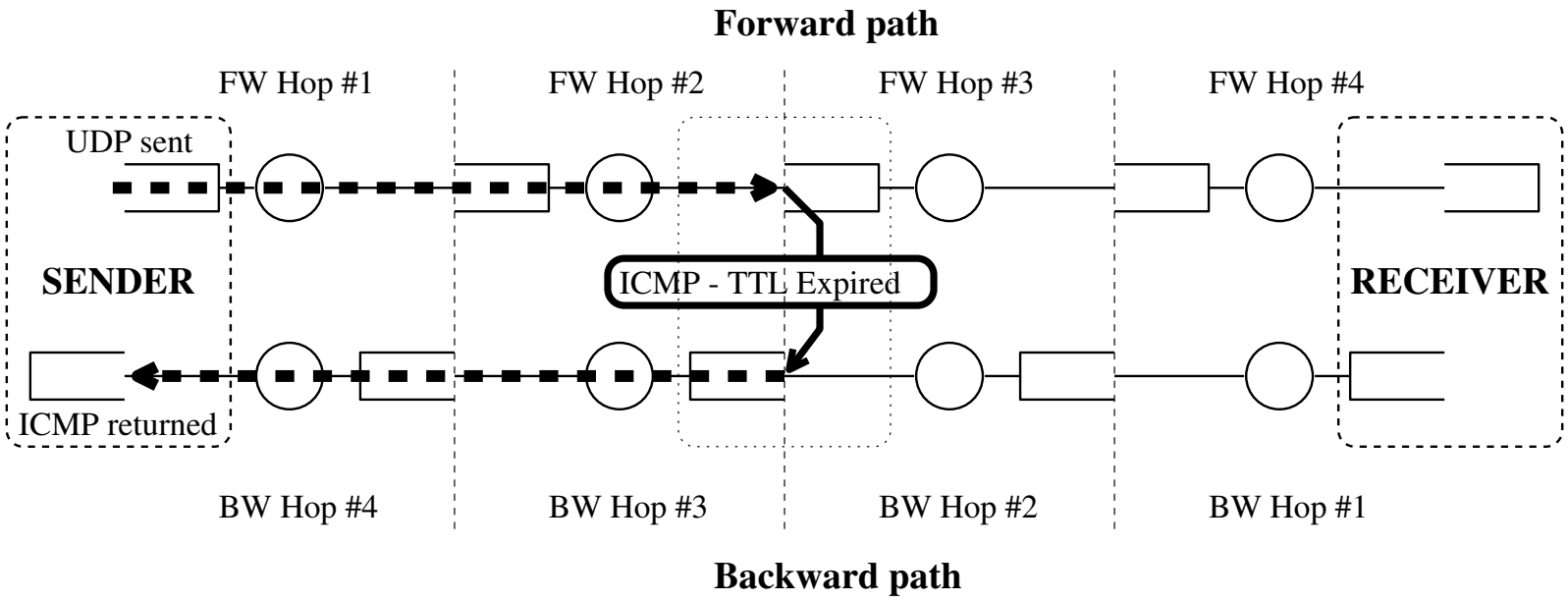


$$d_1 - d_2 = (p_1 - p_2)\Sigma_i (1/\mu_i)$$

The role of TTL - Time To Live

- **From the packet size dependence we can estimate $\Sigma_i (1 / \mu_i)$.**
  How do we get the individual μ_i ?

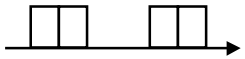
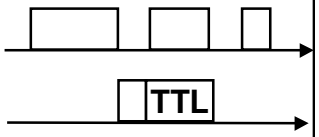
$$1 / \mu_j = \sum_{i=1}^{j} (1 / \mu_i) - \sum_{i=1}^{j-1} (1 / \mu_i)$$



Fundamental Network Effects - SUMMARY

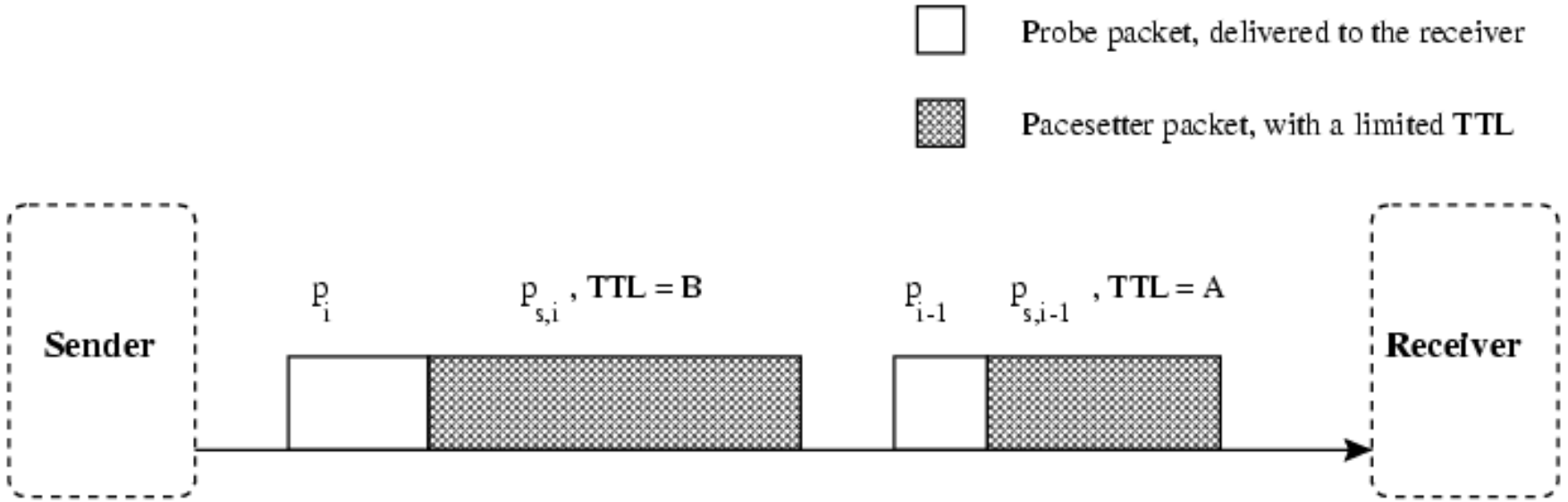
- **Two fundamental effects**
  - SPACING EFFECT - PROBES IN THE SAME BUSY PERIOD
    - **provides information about the bottleneck and secondary bottlenecks**
  - ACCUMULATION - PROBES IN DIFFERENT BUSY PERIODS
    - **information about *almost all* hops**
  - Estimates differ in the presence of lower layer headers (packet size dependence of packet pair based estimates)
- **Filtering needed due to cross traffic effects**
- **Associated metrics**
  - IAT - spacing effect
  - DELAY - accumulation
  - DELAY VARIATION - for both effects, allows new filtering and analysis methods to be introduced

Methods

	Method	Probe Pattern	Raw data Received	Metric	Filtering, Analysis
Spacing effect	Packet Pair		**Arrival time (AT)**	**IAT**	**Mode det.**
Accumu-lation effect	Pathchar Clink		**UDP DT, ICMP AT** **UDP DT, ICMP AT**	**RTT** **RTT**	**Min, slope det.** **Min, slope det.**
Hybrid	Tailgater		**UDP DT & AT**	**OWD (RTT)**	**Min, slope det.**

Packet Quartets

- **Six parameters to define a pattern**



Delay variation of PQ probes

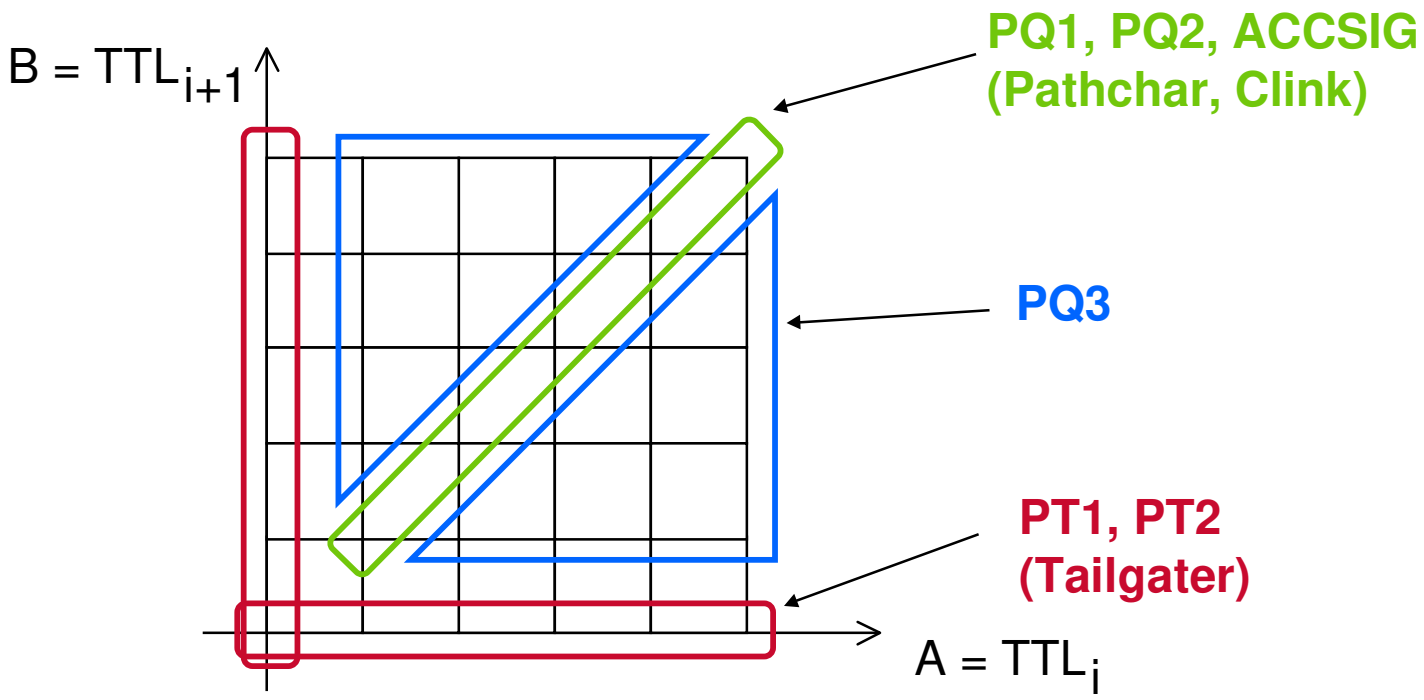
$$\delta_i = t^1_{s,i} - t^1_i + \sum_{h=1}^{A} (x^h_{s,i} - x^h_{s,i-1}) + \sum_{h=A+1}^{B} x^h_{s,i} -$$

$$\sum_{h=A}^{B-1} x^h_{i-1} + \sum_{h=B}^{H} (x^h_i - x^h_{i-1}) + c^B_{s,i} - c^A_{s,i-1} +$$

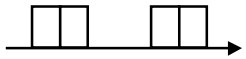
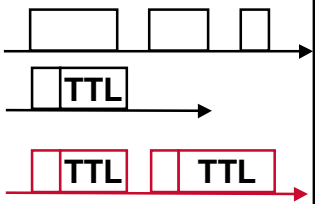
$$\sum_{h=1}^{A} (w^h_{s,i} - w^h_{s,i-1}) + \sum_{h=A+1}^{B} (w^h_{s,i} - w^h_{i-1}) +$$

$$\sum_{h=B+1}^{H} (w^h_i - w^h_{i-1})$$

New methods


B = TTL$_{i+1}$
A = TTL$_i$
PQ1, PQ2, ACCSIG
(Pathchar, Clink)
PQ3
PT1, PT2
(Tailgater)

New Methods

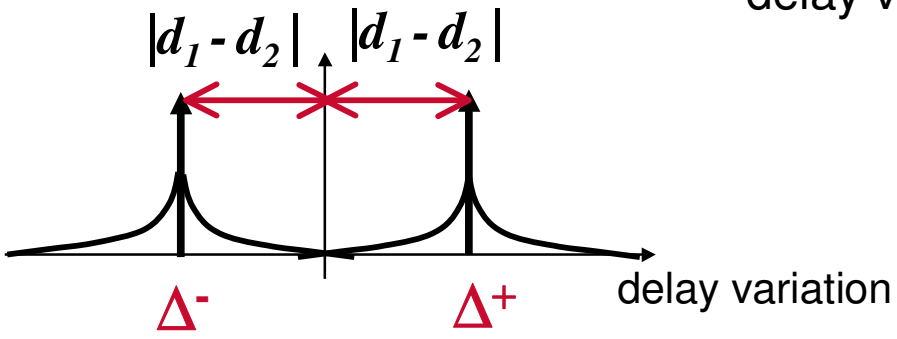
	Method	Probe Pattern	Raw data Received	Metric	Filtering, Analysis
Spacing effect	Packet Pair		Arrival time (AT)	IAT	Mode det.
Accumu-lation effect	Pathchar Clink ACCSIG		UDP DT, ICMP AT UDP DT, ICMP AT UDP DT, ICMP AT	RTT RTT DV	Min, slope det. Min, slope det. Med. Peak det.
Hybrid	Tailgater PQ 1,2 PQ 3 PT 1,2		UDP DT & AT UDP DT & AT UDP DT & AT UDP DT & AT	OWD (RTT) DV DV DV	Min, slope det. Med. Peak det. Med. Peak det. Med. Peak det.

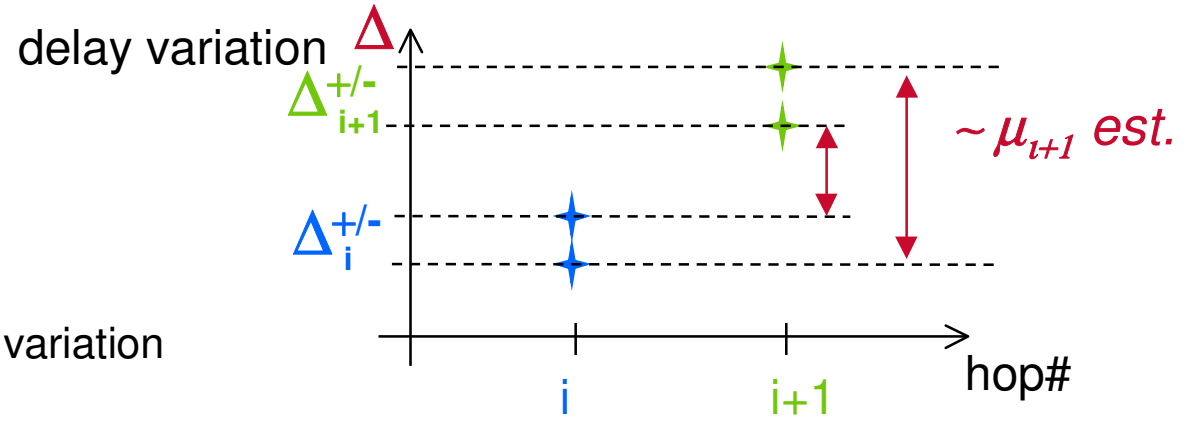
Still to come...

- Method definitions
- Simulation results
- Measurement results from real networks

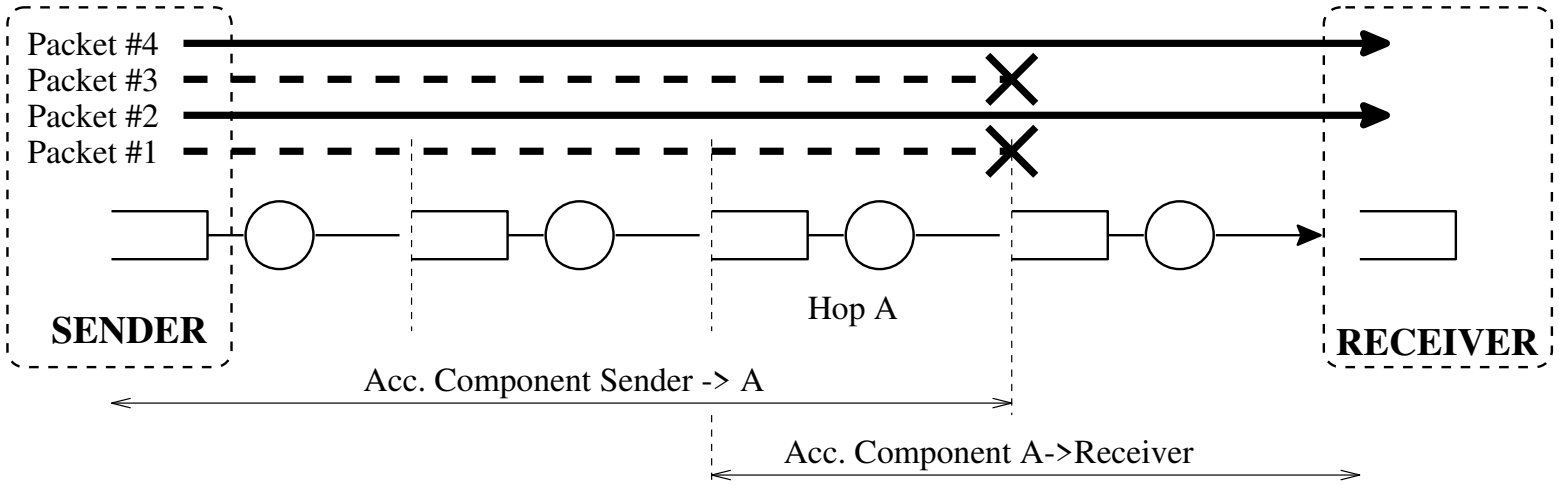
ACCSIG

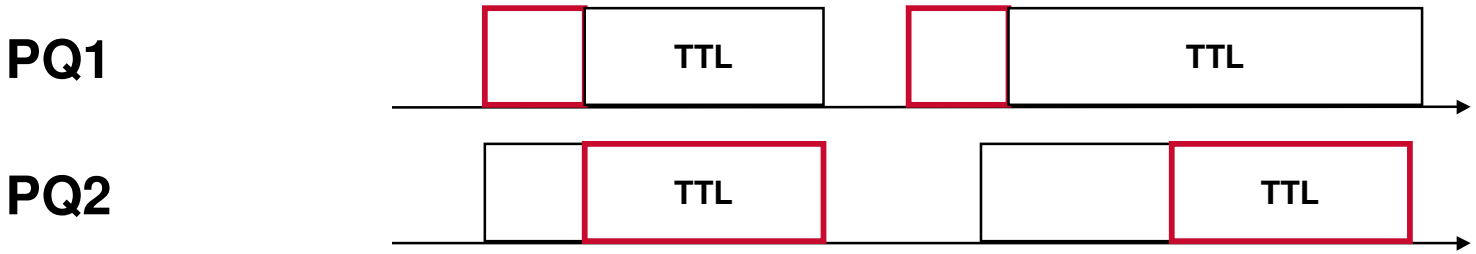
- **A close relative of Pathchar and Clink**
- **Differences:**
  - probe stream - alternating packet sizes, well spaced probes
  - metric - delay variation
  - filtering and analysis - median based peak detection, utilising the information in ALL probes





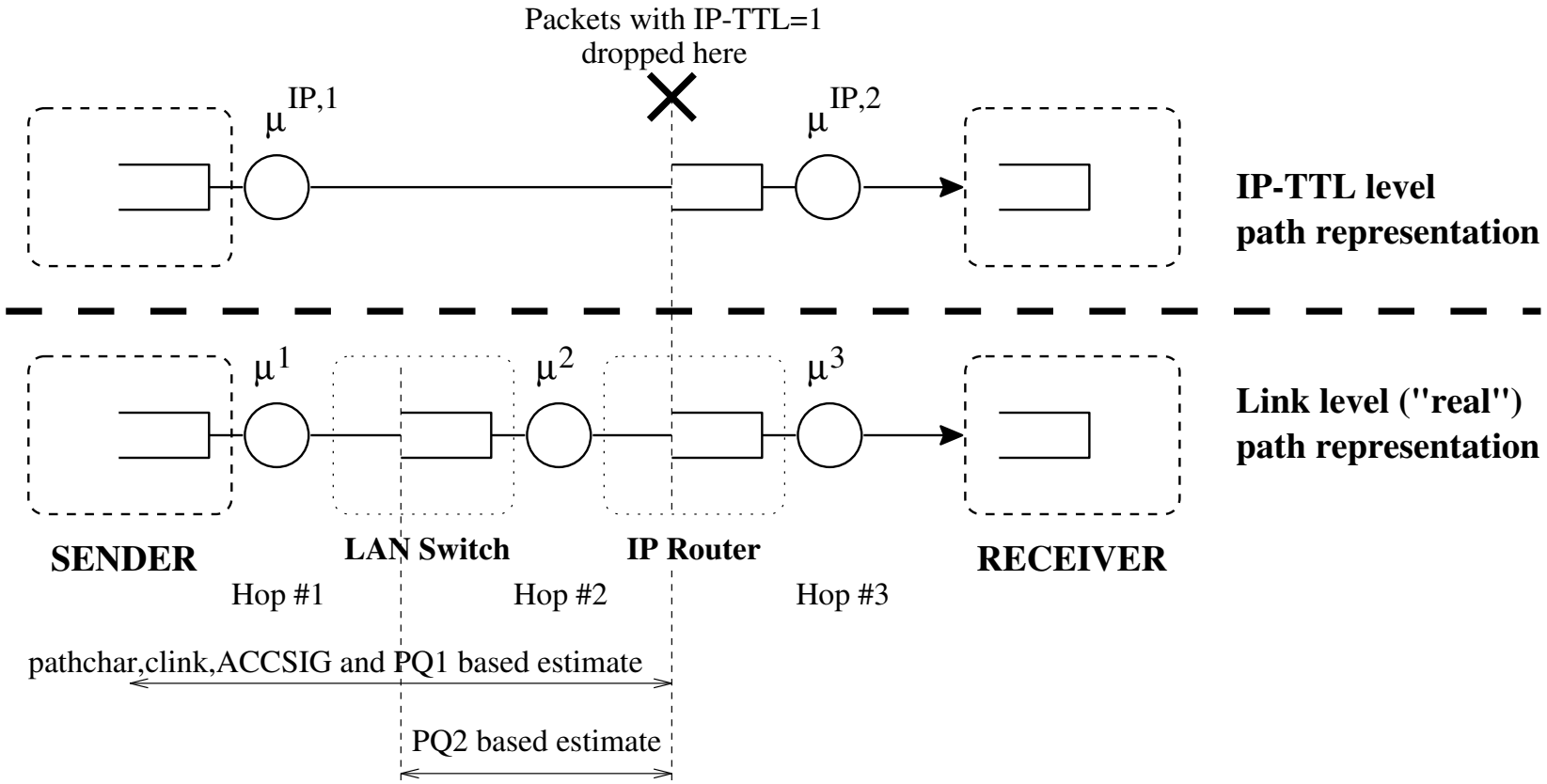
PQ 1 & 2



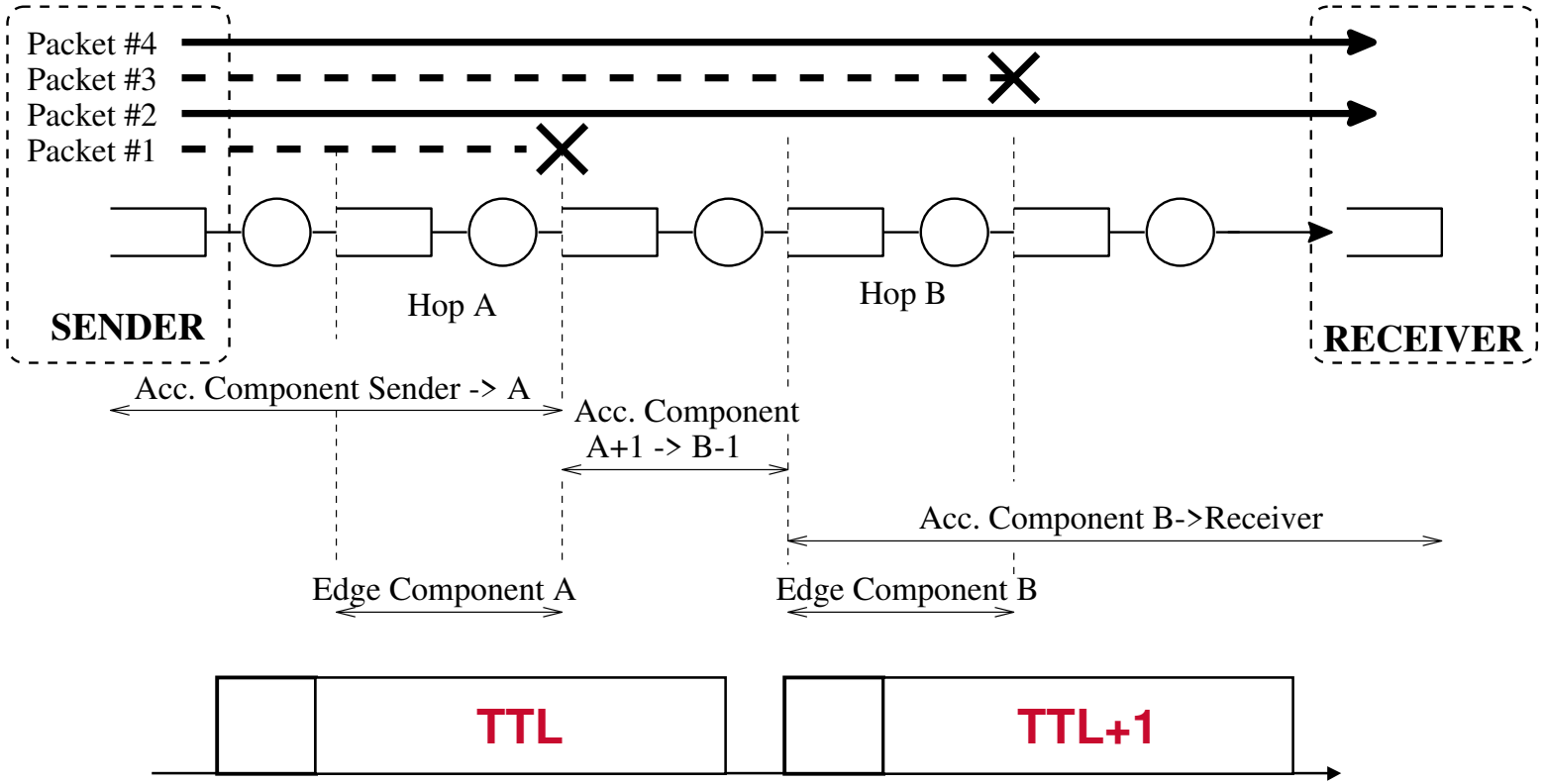


Difference - in accuracy and something more...

PQ 1 & 2 - Invisible hops

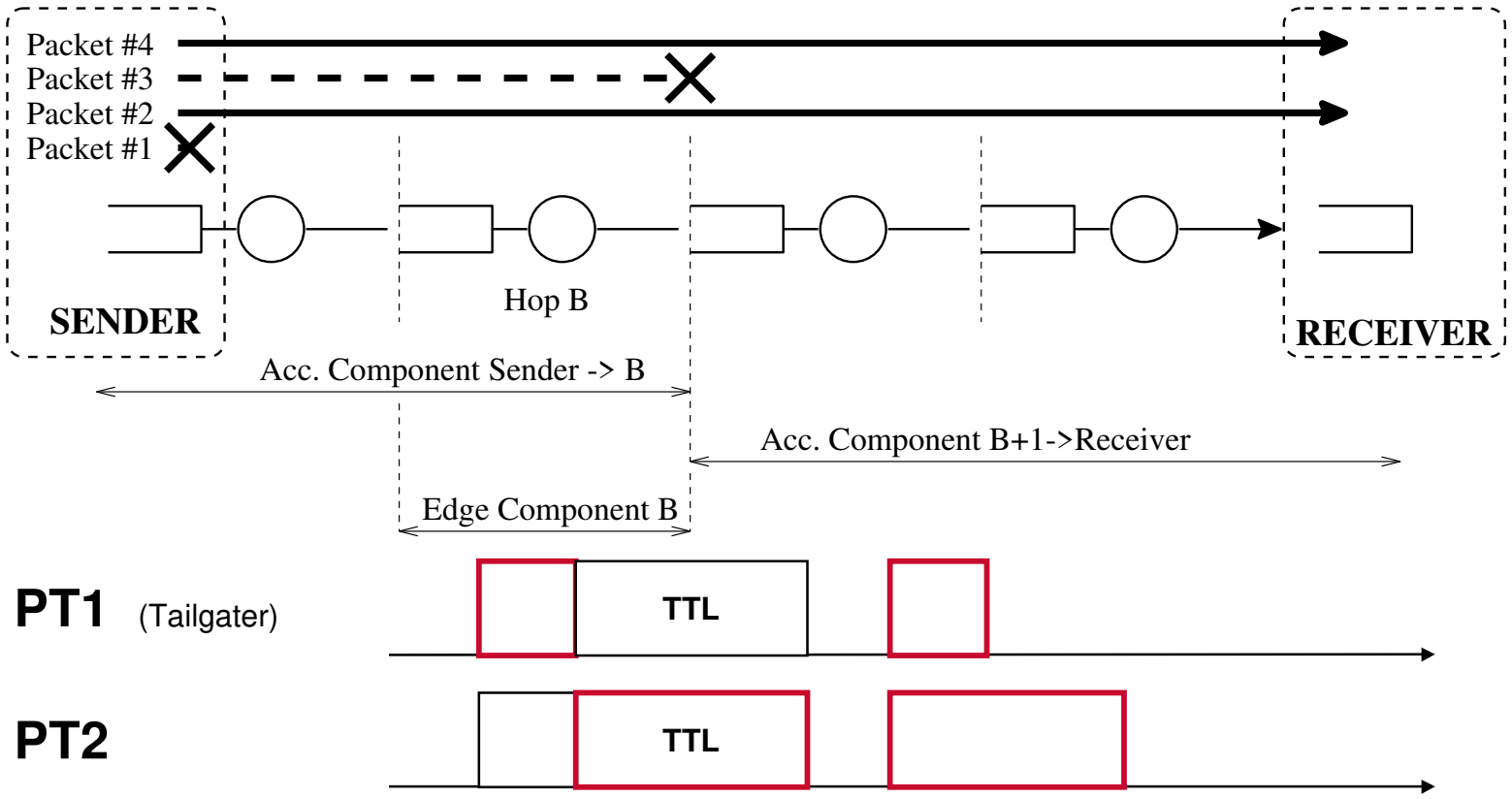


PQ 3



Problem - error propagation and estimation errors due to lower layer headers
Interesting feature - zooming in on a single hop (CT estimation?)

PT 1 & 2



Problem - error propagation (stronger for PT2) and estimation errors due to lower layer headers

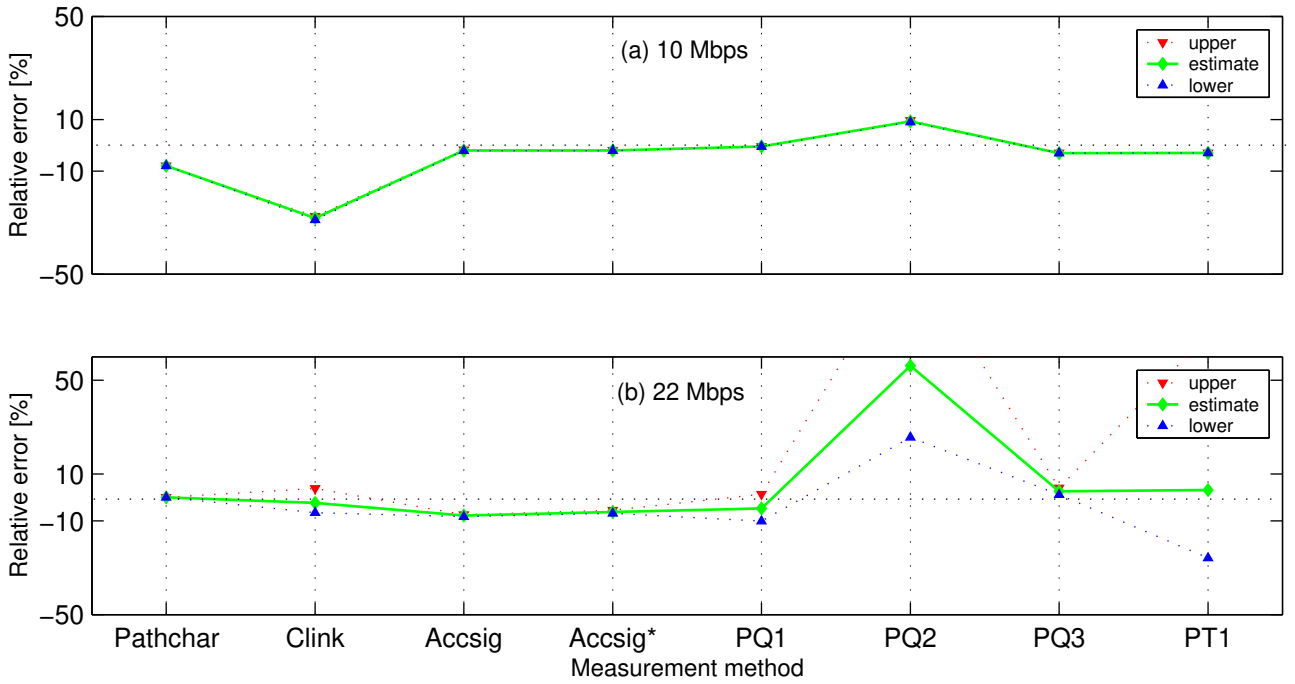
Simulation results

Nominal link bandwidth	PQ1		PQ2		PQ3		PT1		PT2	
	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]
1. 100Mbps	100 100 99.99	100 100 99.99	100 99.99 99.99	20.7 15.8 12.7	100 100 100	143 120 103	100 100 100	143 120 103	inf 0.4 0.08	0 0 0
2. 10Mbps	10 10 10	10.3 10.3 10.3	10 10 10	59 54 19	10 10 10	10.3 10.2 10.1	10 10 10	10.4 10.1 9.9	inf 6.01 2.2	0 0 0
3. 10Mbps	10 10 10	9.67 9.44 9.22	10 10 10	51.6 16.3 9.7	10 10 10	9.69 9.67 9.65	10 10 10	9.9 9.4 9.0	10.6 9.83 9.1	$3e^{-4}$ $2e^{-4}$ $2e^{-4}$
4. 2Mbps	2 2 2	2.01 1.99 1.98	2 2 2	2.14 2.03 1.94	2 2 2	1.99 1.99 1.99	2 2 2	2.04 2.01 1.98	2.00 1.99 1.99	$9e^{-3}$ $7e^{-3}$ $6e^{-3}$
5. 2Mbps	2 2 2	2.03 2.02 2.00	2 2 2	3.34 3.08 2.85	2 2 2	2.00 2.00 1.99	2 2 2	2.05 1.98 1.91	2 2 2	0.3 0.24 0.2
6. 10Mbps	10 10 10	11.13 10.6 10.11	10 10 10	3.00 2.88 2.77	10 10 10	10.02 9.99 9.96	10 10 10	15 10 7.4	10 10 10	5.6 5.06 4.5

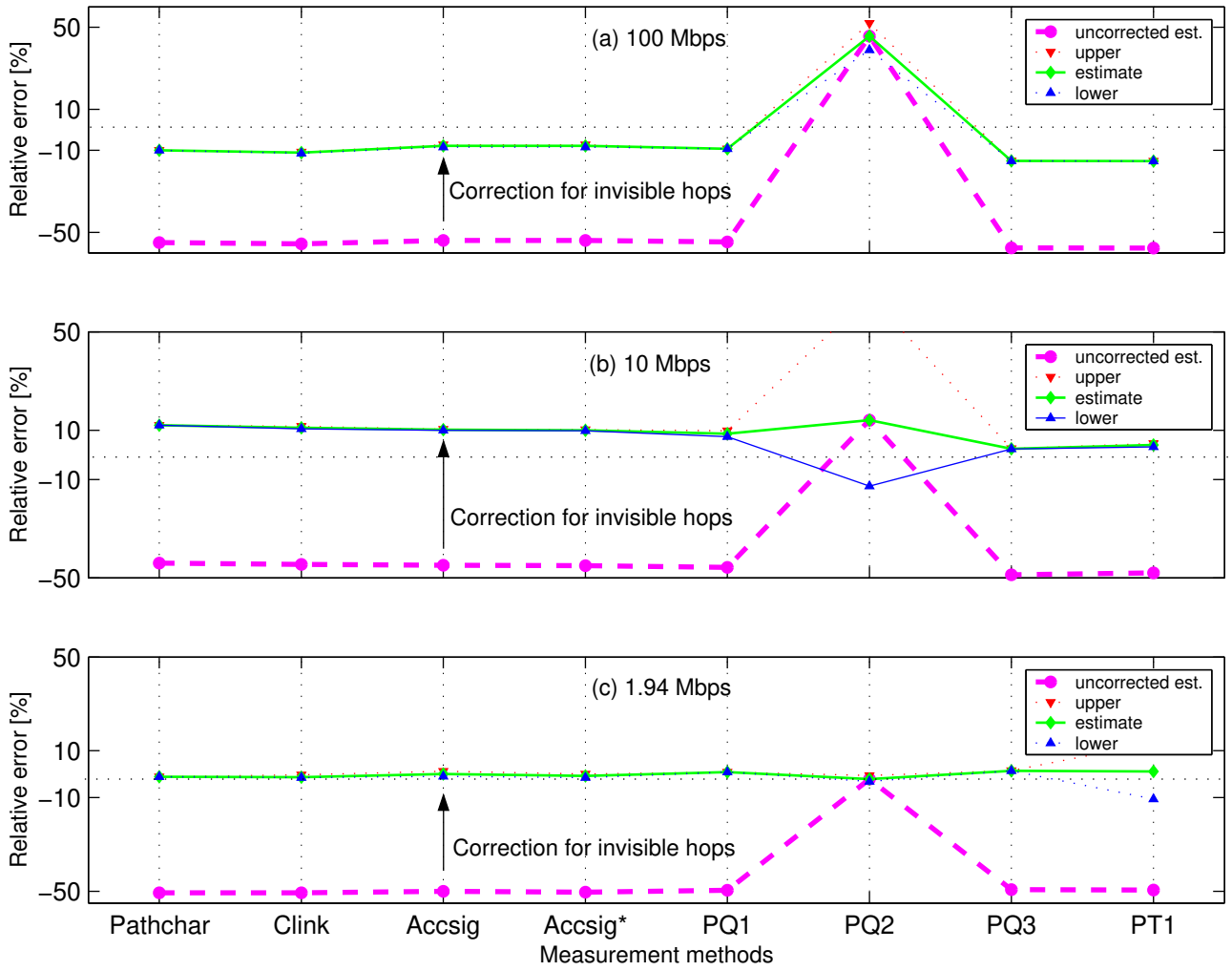
Simulation results - Invisible hops

Nominal link bandwidth (Segment details)	PQ1		PQ2		PQ3		PT1	
	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]	no CT [Mbps]	with CT [Mbps]
1. 100Mbps	100 100 100	100 100 100	9.09 9.09 9.09	15.8 10.5 7.8	100 100 100	143 120 103	100 100 100	143 120 103
2. 10Mbps (2x10Mbps)	5 5 5	5.06 5.04 5.01	1.67 1.67 1.67	1.83 1.74 1.65	5.07 5.07 5.07	5.18 5.15 5.11	5.07 5.07 5.07	5.09 5.04 5
3. 2Mbps (2x2Mbps)	1 1 1	1 0.99 0.99	2 2 2	4.24 3.71 3.3	1.01 1.01 1.01	1.01 1.01 1.01	1.01 1.01 1.01	1.1 1 1
4. 10Mbps	10 10 10	10.65 10.45 10.25	10 10 10	2.93 2.71 2.52	8.85 8.85 8.85	8.83 8.81 8.79	8.85 8.85 8.85	9.6 9.1 8.6

Measurement results - No invisible hops



Measurement results - segments with invisible hops



Conclusions

- **Delay variation based model**
- **Noise understood and exploited**
- **Packet Quartets**
- **6 new methods introduced**
  - new probe patterns
  - different metrics
  - new filtering and analysis methods
- **Basic properties discussed and compared**
- **Effect of lower layer headers demonstrated**
- **Effects of invisible hops demonstrated, a method for their detection demonstrated**

Future work

- Thorough comparison of ACCSIG with Pathchar and Clink on significantly loaded paths
- Develop refined filtering methods (consider other methods then median based filtering for peak detection)
- PQ 3 - ‘zooming’ - investigate the possibilities of cross traffic estimation