Summary on: "Bandwidth Estimation in Broadband Access Networks by K. Lakshminarayana, V. Padmanabhan, J. Padhye"

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Motivations

- Token bucket rate regulation, non-FIFO packet scheduling and distinct rates in cable network and 802.11 network makes current measurement technique inaccurate
- Introduce ProbeGap

Two measurements of interest

- Link capacity – maximum IP-layer throughput that a flow can get, without any cross traffic
- Available bandwidth - maximum IP-layer throughput that a flow can get, given cross traffic

Existing Link capacity measurement tool

- Pathrate – use dispersion of packet-pairs and dispersion of packet-trains to calculate link capacity

Pathrate

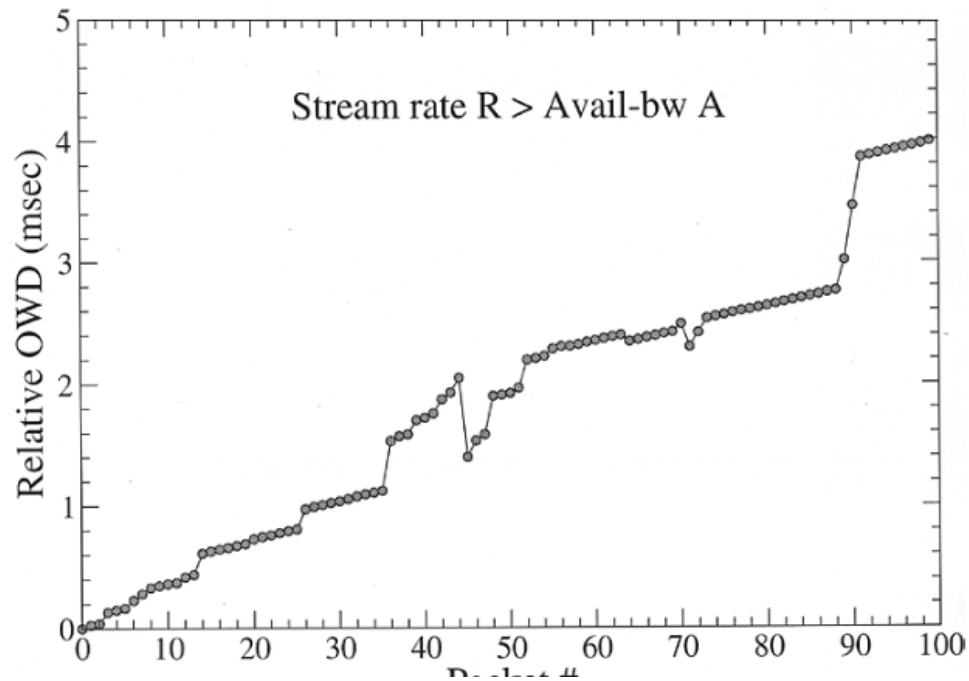- Use Asymptotic Dispersion Rate (ADR) to identify Common Mode
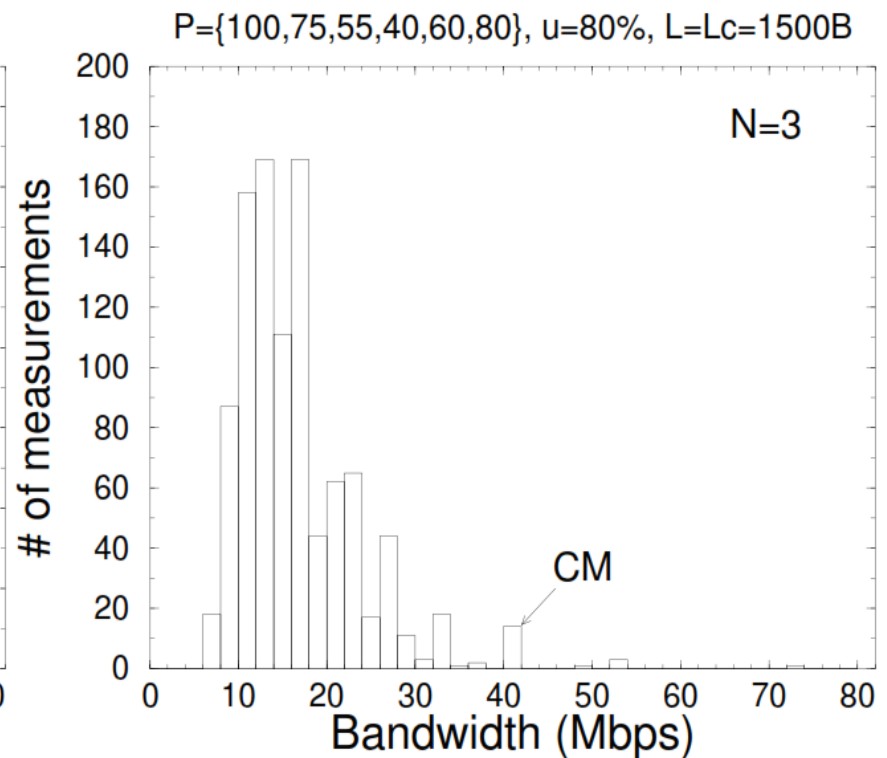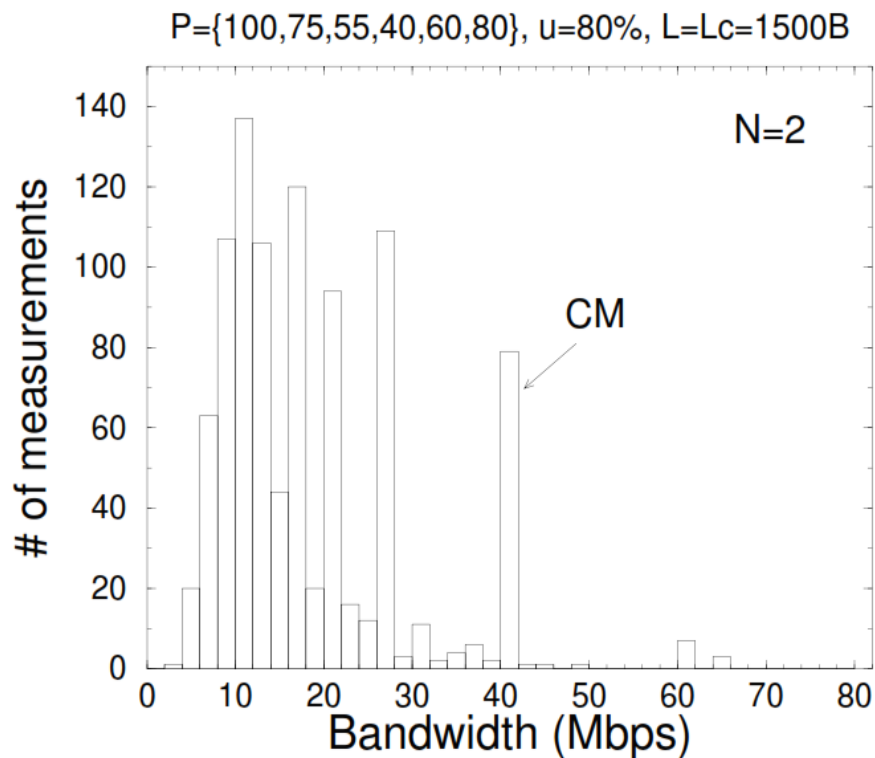
Existing Available Bandwidth measurement methods - PRM

- Packet Rate Method (PRM)
- Increase the sending rate until seeing an increasing one way delay (OWD) trend
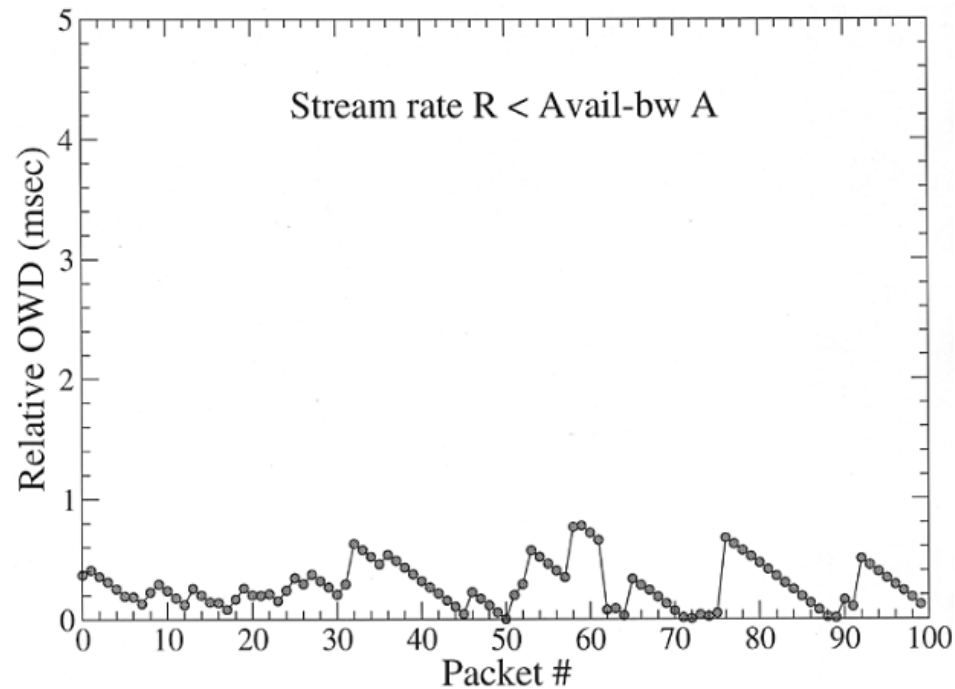- e.g. Pathload

Pathload

- Packet starts queuing up and OWD increase when sending rate > available bandwidth

Pathload

- OWD does not increase when sending rate < available bandwidth

Pathload
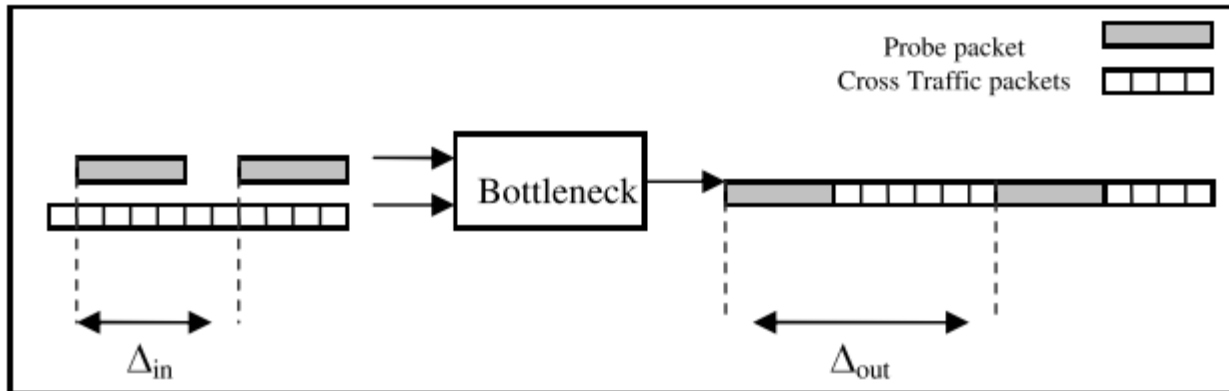
- The sending rate that is at the transition of two modes is the available bandwidth
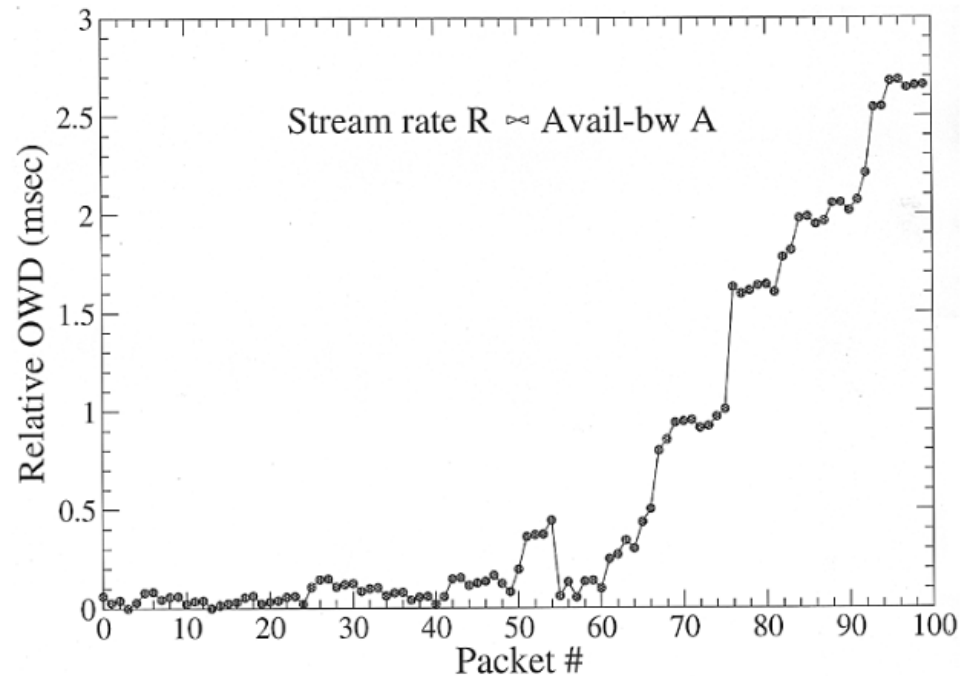
Existing Available Bandwidth measurement methods - PGM

- Packet Gap Mode (PGM)
- Look at the packet spacing between packet pairs to estimate cross traffic
- E.g. Spruce

Spruce

$$A = C \times \left(1 - \frac{\Delta_{out} - \Delta_{in}}{\Delta_{in}} \right).$$

- A – Available bandwidth
- C - Capacity

ProbeGap

- Send about 200 20-byte probe packets over 50-second interval
- Measure one-way delay (OWD) at the receiver

Packets　　Packets　　Packets　　Packets　　Packets　　Packets

Busy　　　　　　　　　　　　　　　　Busy
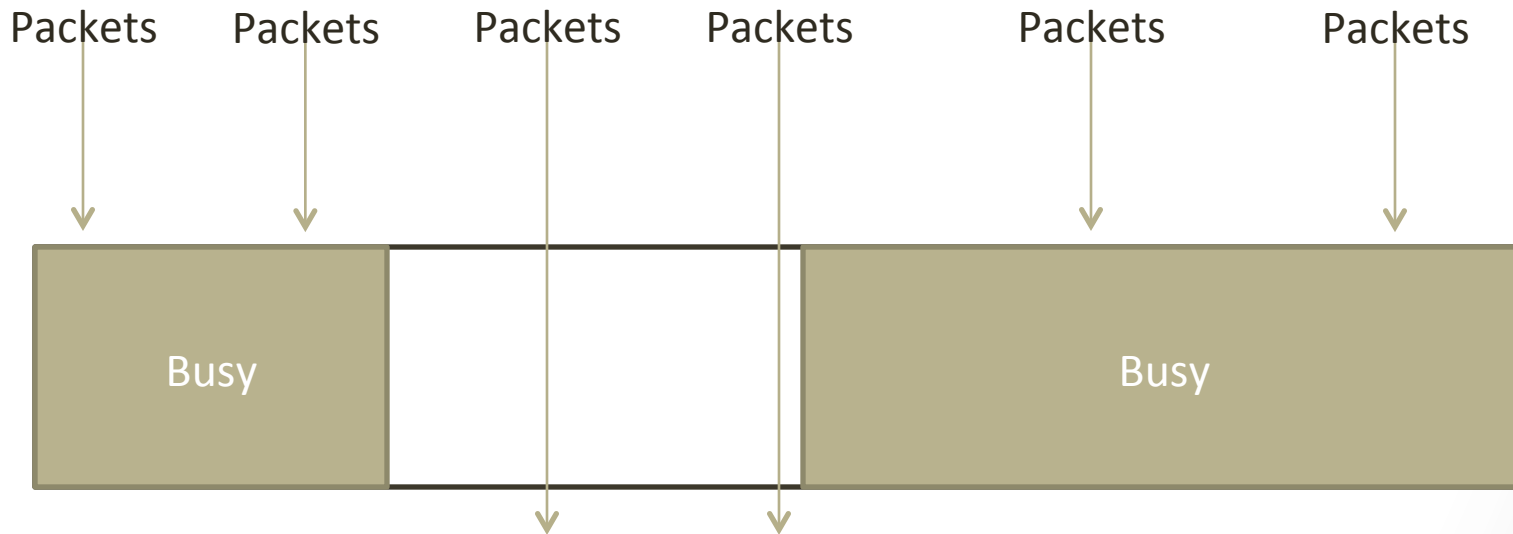
Concept behind ProbeGap (my understanding)
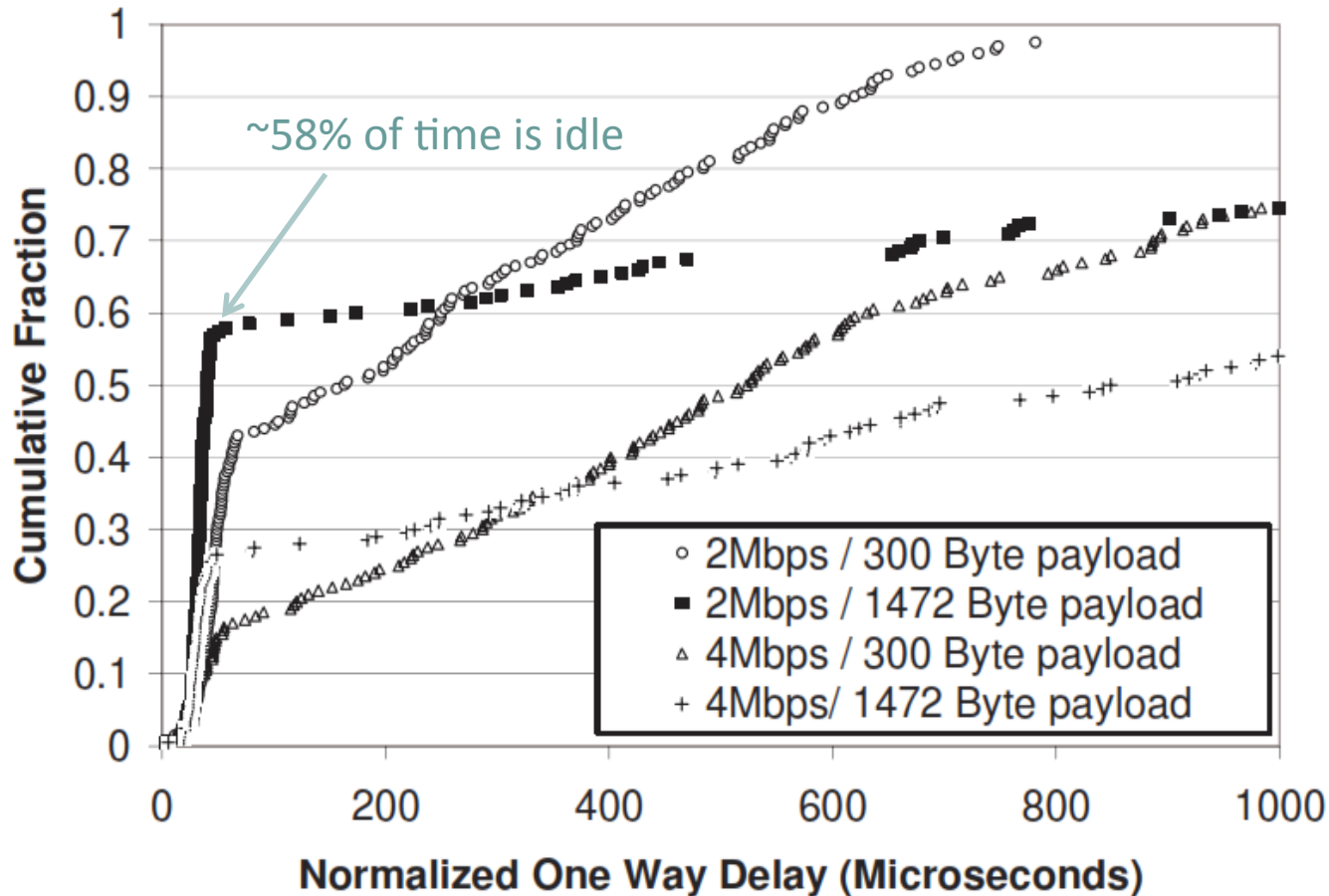
Validation - Cable modem testbed

- On-campus experimental cable network and two commercial connections

- With complete knowledge and control of the token bucket policy and cross traffic

- Confirm with UDPload afterward

Effect of Token Bucket policy

- **Pathrate**: overestimates the link capacity as the raw link capacity instead of the assigned capacity by the modem
- **Pathload:** overestimates when no cross traffic because of raw link capacity. Fairly accurate when cross traffic is introduced

Effect of Token Bucket policy

- **Spruce**: overestimates because of raw link capacity

Assumed capacity: 26 Mbps

Assumed capacity: 6 Mbps

Lost packet bias

Input gap difference
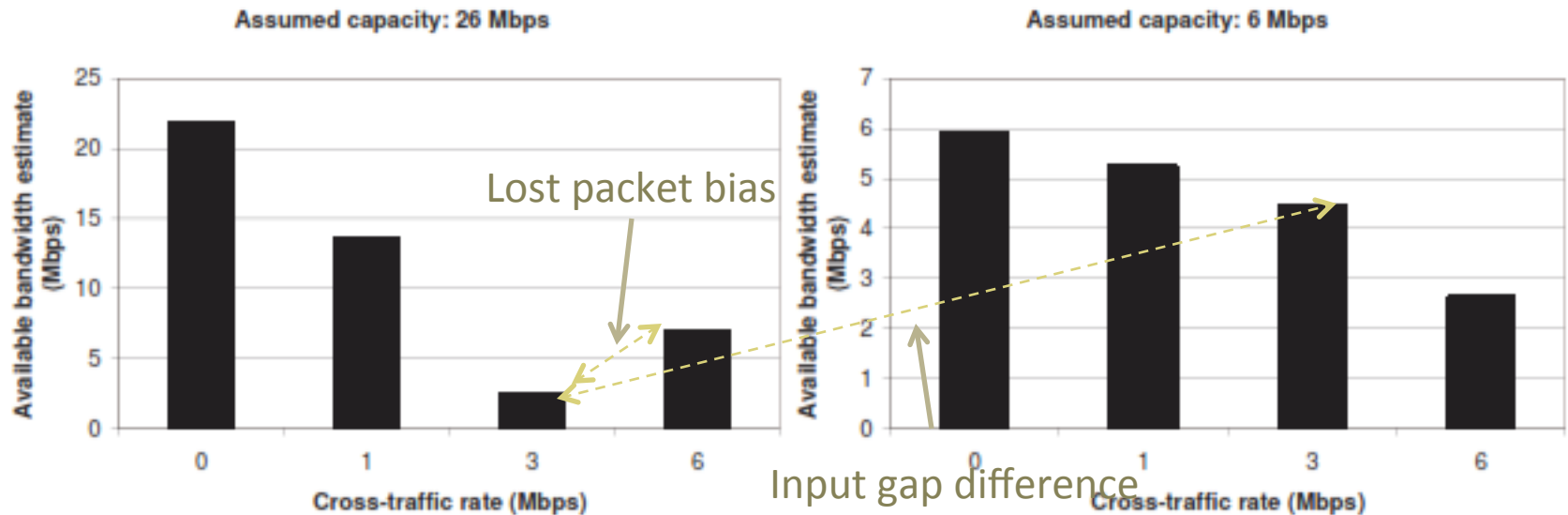
Validation – 802.11 testbed

- 6 machines in 802.11a ad hoc mode
- M1 and M2 connected as measurements machines, the rest for cross traffic

Effect of Contention based 802.11 MAC

- Pathrate is accurate in link capacity
- Pathload overestimate due to fairness in contention

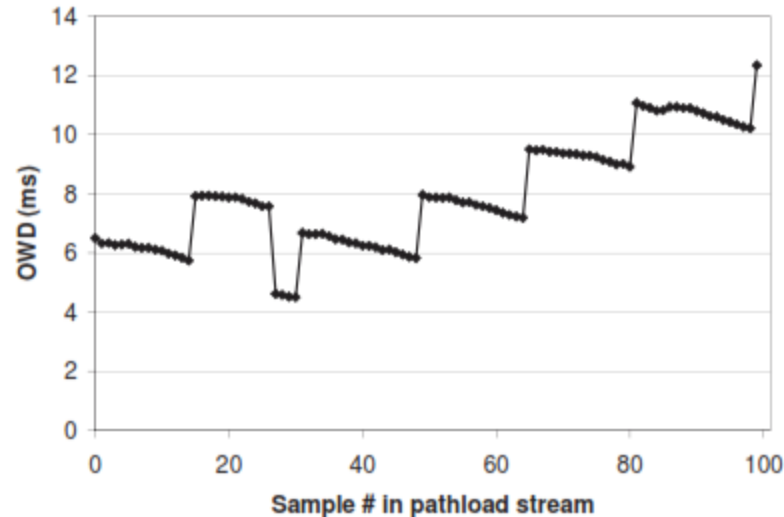| Cross-Traffic | | Estimate | | | | Measured | |
Rate	Payload (Bytes)	Pathload	Spruce	ProbeGap 300	1472	300	1472
1	300	2.9 − 2.9	3.7	2.4	3.4	2.5	3.7
	1472	3 − 3	4.2	2.7	3.9	2.7	4.2
2	300	2.2 − 2.3	3.2	1.6	2.3	1.7	2.3
	1472	2.2 − 2.3	3.5	2.0	2.9	2.0	3.3
3	300	2.3 − 2.3	3.8	0.8	1.1	0.4	0.6
	1472	1.6 − 1.6	1.5	1.4	2.1	1.4	2.4
4	300	2.3 − 2.3	3.7	0.4	0.6	0.1	0.1
	1472	0.9 − 0.9	1.2	0.7	1.1	0.7	1.1

Effect of Contention based 802.11 MAC

- Spruce inaccurate due to per-packet basis contention. Only small packets got inserted, thus less packet spacing.
- ProbeGap inaccurate due to non-FIFO probabilitic scheduling

Cross-Traffic		Estimate				Measured	
Rate	Payload (Bytes)	Pathload	Spruce	ProbeGap 300	1472	300	1472
1	300	2.9 − 2.9	3.7	2.4	3.4	2.5	3.7
	1472	3 − 3	4.2	2.7	3.9	2.7	4.2
2	300	2.2 − 2.3	3.2	1.6	2.3	1.7	2.3
	1472	2.2 − 2.3	3.5	2.0	2.9	2.0	3.3
3	300	2.3 − 2.3	3.8	0.8	1.1	0.4	0.6
	1472	1.6 − 1.6	1.5	1.4	2.1	1.4	2.4
4	300	2.3 − 2.3	3.7	0.4	0.6	0.1	0.1
	1472	0.9 − 0.9	1.2	0.7	1.1	0.7	1.1

Effect of 802.11 Multirate environment

- Pathrate is accurate in link capacity
- Pathload overestimate because large burst disrupt the steady OWD increasing trend. Only a few large step in OWD sequence

Effect of 802.11 Multirate environment

- Spruce underestimated the available bandwidth because the cross traffic packet is big, especially compared to the input gap; and overestimated when the packet gets too big, because it discarded those data points.

| Cross-Traffic | | Estimate | | | | Measured | |
Rate	Payload (Bytes)	Pathload	Spruce	ProbeGap 300	1472	300	1472
2	300	5.7 – 5.7	12	4.7	13.1	5.1	13.9
	1472	8.6 – 10.1	25.7	6.1	17.0	6.5	18
4	300	2.6 – 2.9	0	0.8	2.3	0.3	0.3
	1472	2.6 – 2.7	20.9	2.6	7.3	2.7	7.5