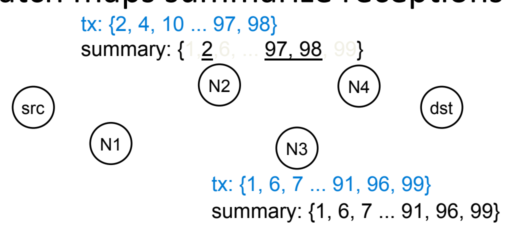
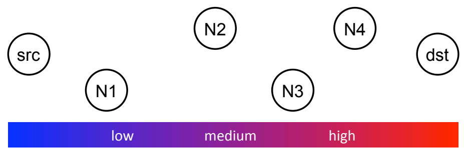
28th Jan	SampleRate: bit rate adaptation in 802.11 wireless networks
30th Jan	MRD: exploiting radio link diversity with multiple access points
Monday	(Lectures cancelled due to weather)
Tuesday	**ExOR: wireless mesh routing**
Today	**SampleWidth: channel width adaptation**
Friday	Interference cancellation for wireless LANs

Batch maps summarize receptions



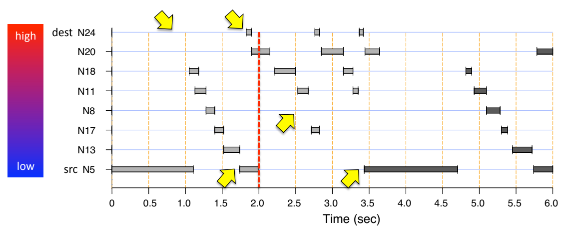
- Repeat summaries in every data packet
- Cumulative: what all previous nodes rx'd
- How src receives acknowledgement

Priority ordering



- Goal: nodes "closest" to the destination send first
- Sort by ETX metric to dst
  - Nodes periodically flood ETX "link state" measurements
  - Path ETX is weighted shortest path (Dijkstra's algorithm)
- Source sorts, includes list in ExOR header

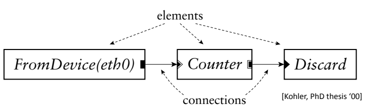
Transmission timeline



Implementation

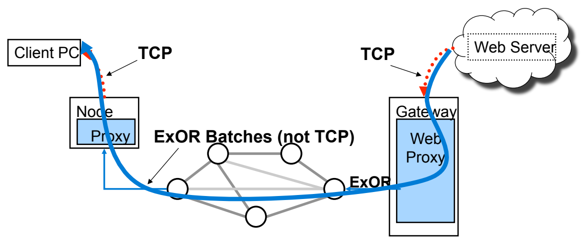
- Click userlevel, libpcap

http://read.cs.ucla.edu/click/



- ExOR: unreliable delivery
- TCP/ExOR window size issue
- Prism 2.5 802.11b, Atheros AR5212

Using ExOR with TCP



- Batching requires more packets than typical TCP window

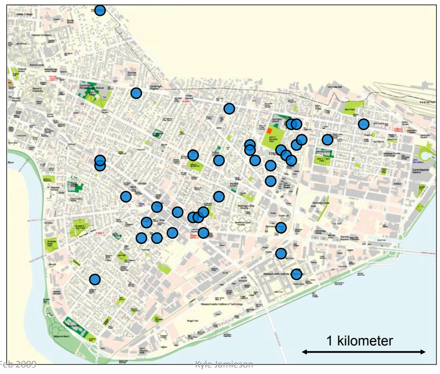
Outline

- Introduction
- Why ExOR might increase throughput
- ExOR protocol
- Measurements
- Related Work

ExOR Evaluation

- Does ExOR increase throughput?
- When/why does it work well?

65 Roofnet node pairs

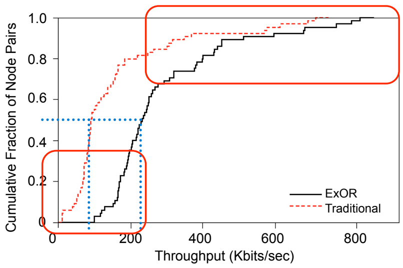


Evaluation Details

- 65 Node pairs
- 1.0 Mbyte file transfer
- 1 Mbit/s 802.11 bit rate fixed
- 1 Kbyte packets

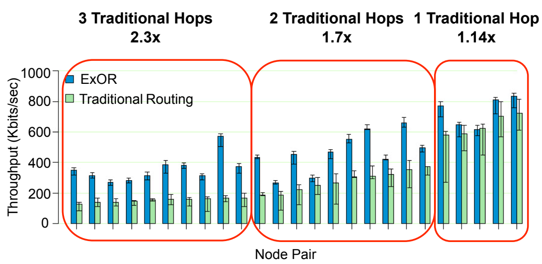
Traditional Routing	ExOR
802.11 unicast with link-level retransmissions,	802.11 broadcasts,
Hop-by-hop batching, UDP sending as MAC allows	100-packet batch size

ExOR: 2x overall improvement

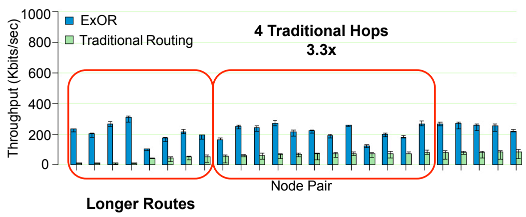


- Median throughputs: 240 Kbits/sec for ExOR, 121 Kbits/sec for Traditional

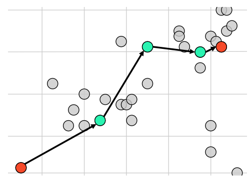
25 Highest throughput pairs



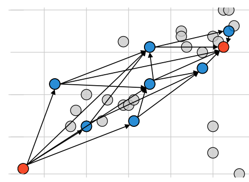
25 Lowest throughput pairs



ExOR uses links in parallel

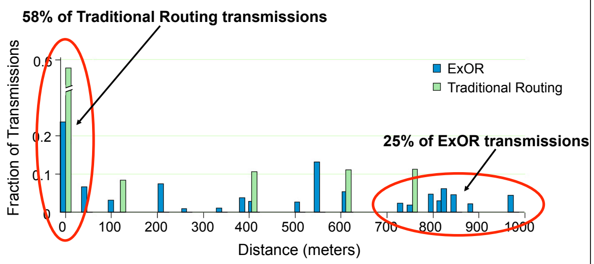


Traditional Routing
3 forwarders
4 links



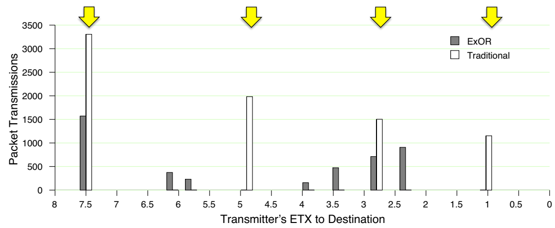
ExOR
7 forwarders
18 links

ExOR moves packets farther



- ExOR average: 422 meters/transmission
- Traditional Routing average: 205 meters/tx

Traditional approach constrains *who* routes



Future Work

- Choosing the best 802.11 bit-rate
- Cooperation between simultaneous flows
- Coding/combining

Summary

- ExOR achieves 2x throughput improvement
- ExOR implemented on Roofnet
- Exploits radio properties, instead of hiding them

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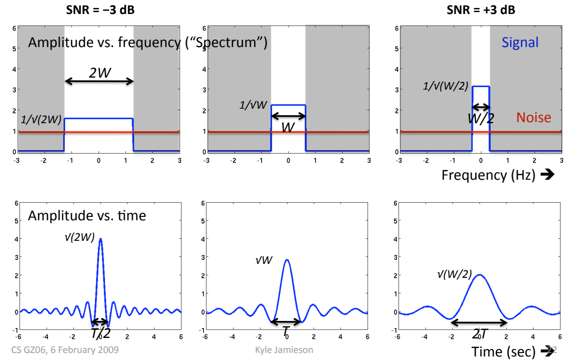
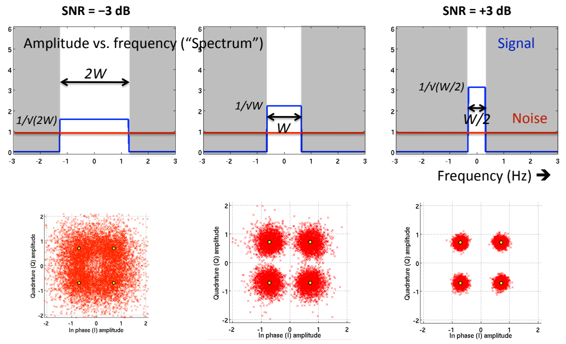
Narrower band, slower in time



Narrower band: higher SNR

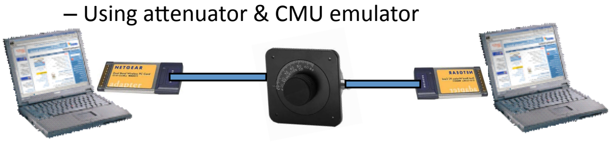


A case for adapting channel width

- Take measurements of narrow band channels
- Identify benefits of adapting channel width
- SampleWidth adaptation algorithm

Experimental Setup

- Conducted (clean) experiment
  - Using attenuator & CMU emulator



- Indoor experiments at MSR & UCSB
- Outdoor experiments in large park

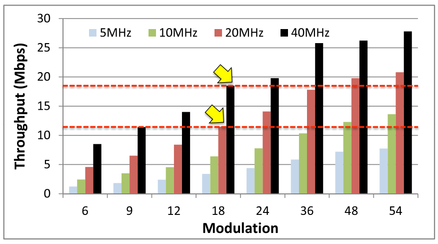
Experimental method

- B = 5, 10, 20, 40 MHz channel widths

	5 MHz	10 MHz	20 MHz	40 MHz
Symbol Duration	16 μs	8 μs	4 μs	2 μs
SIFS	40 μs	20 μs	10 μs	5 μs
Slot Duration	20 μs	20 μs	20 μs	20 μs
Guard Interval	3.2 μs	1.6 μs	0.8 μs	0.4 μs

- Wireless channel emulator (CMU)
- Indoor office environment

Peak throughput proportional to channel width?



Shannon capacity tells us $C = B \cdot \log\left(1 + \frac{S}{N}\right)$

Modeling throughput

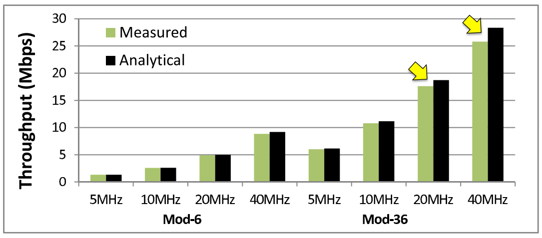
	5 MHz	10 MHz	20 MHz	40 MHz
Symbol Duration	16 μs	8 μs	4 μs	2 μs
SIFS	40 μs	20 μs	10 μs	5 μs
Slot Duration	20 μs	20 μs	20 μs	20 μs
Guard Interval	3.2 μs	1.6 μs	0.8 μs	0.4 μs

$$\mathcal{B} = \frac{20\text{ MHz}}{B}$$

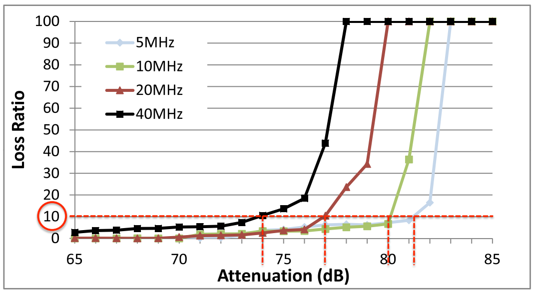
$$\begin{aligned} t &= t_{\text{CW}} + t_{\text{DIFS}} + t_{\text{data}} + t_{\text{SIFS}} + t_{\text{ACK}} \\ &= 8t_{\text{slot}} + \left(2t_{\text{slot}} + \mathcal{B}t_{\text{SIFS}}\right) + \mathcal{B}(\cdots) + \mathcal{B}t_{\text{SIFS}} + \mathcal{B}(\cdots) \\ &= 10t_{\text{slot}} + \mathcal{B}(\cdots) \end{aligned}$$

Analytical model throughput = $1/t$ Mbits/s

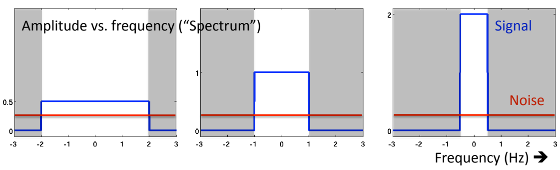
Throughput model matches experiments



Lower channel width, lower loss rate



Theoretical predictions to halving bandwidth

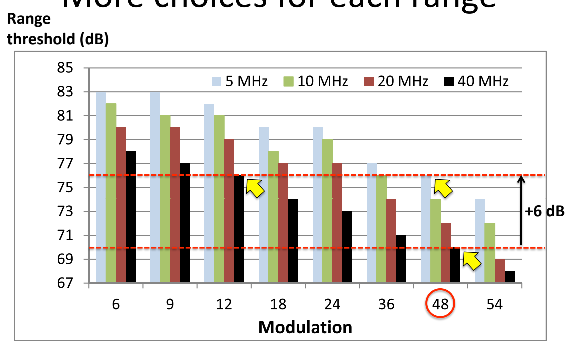


SNR
Symbol time $T/2$

SNR +3 dB
Symbol time T

SNR= +6 dB
Symbol time $2T$

More choices for each range



Translating SNR gain to real distance

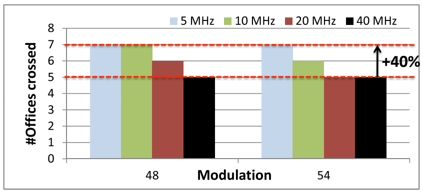
Assume signal power decays as $1/d^{\alpha}$

$$A = 10\log\left(\frac{P_{\text{send}}}{P_{\text{recv}}}\right) = 10\alpha \log d$$

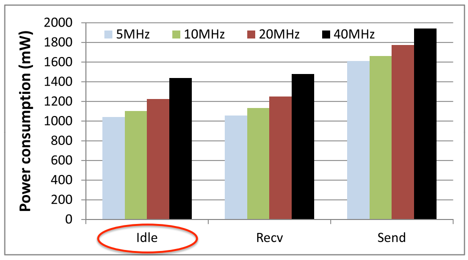
$$d = 10^{A/10\alpha}$$

$$\frac{d_2}{d_1} = \frac{10^{A_2/10\alpha}}{10^{A_1/10\alpha}} = 10^{\Delta A/10\alpha}$$

6 dB gain, α=4 → $d_2/d_1 = 1.41$

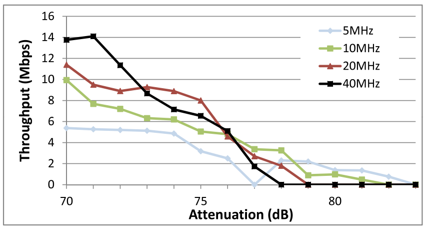


Narrower channels reduce power



Reduce power because of slower clock speed.

Channel width adaptation: potential for improvement

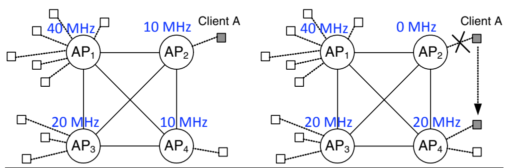


Similar motivation to SampleRate: can adapt to stay at best throughput.

Benefits of adapting channel width

1. Reduce power and increase range
2. Improve flow throughput
3. Improve fairness
4. Improve capacity

Improving fairness and load balancing



Scenario	AP_1	AP_2	AP_3	AP_4	T	FI
Case 1: (fixed)	1/6	1	1/3	1	4	0.58
Case 1: (adaptive)	2/6	1/2	1/3	1/2	4	**0.97**
Case 2: (fixed)	1/6	X	1/3	1/2	3	0.82
Case 2: (adaptive)	2/6	X	1/3	1/2	**4**	**0.97**

Capacity improvement