Long Distance 802.11b Links: Performance Measurement and Experience

Kameswari Chebrolu
Bhaskaran Raman
Sayandeep Sen
Indian Institute of Technology, Kanpur

802.11 to Bridge the Digital Divide

- Example Deployments
  - Akshaya, Kerala
  - Digital Gangetic Plains, Uttar Pradesh
  - Djurslands.Net, Denmark
  - Nepal Wireless
- Several commercial products exist
- Important Issue
  - Understand link performance

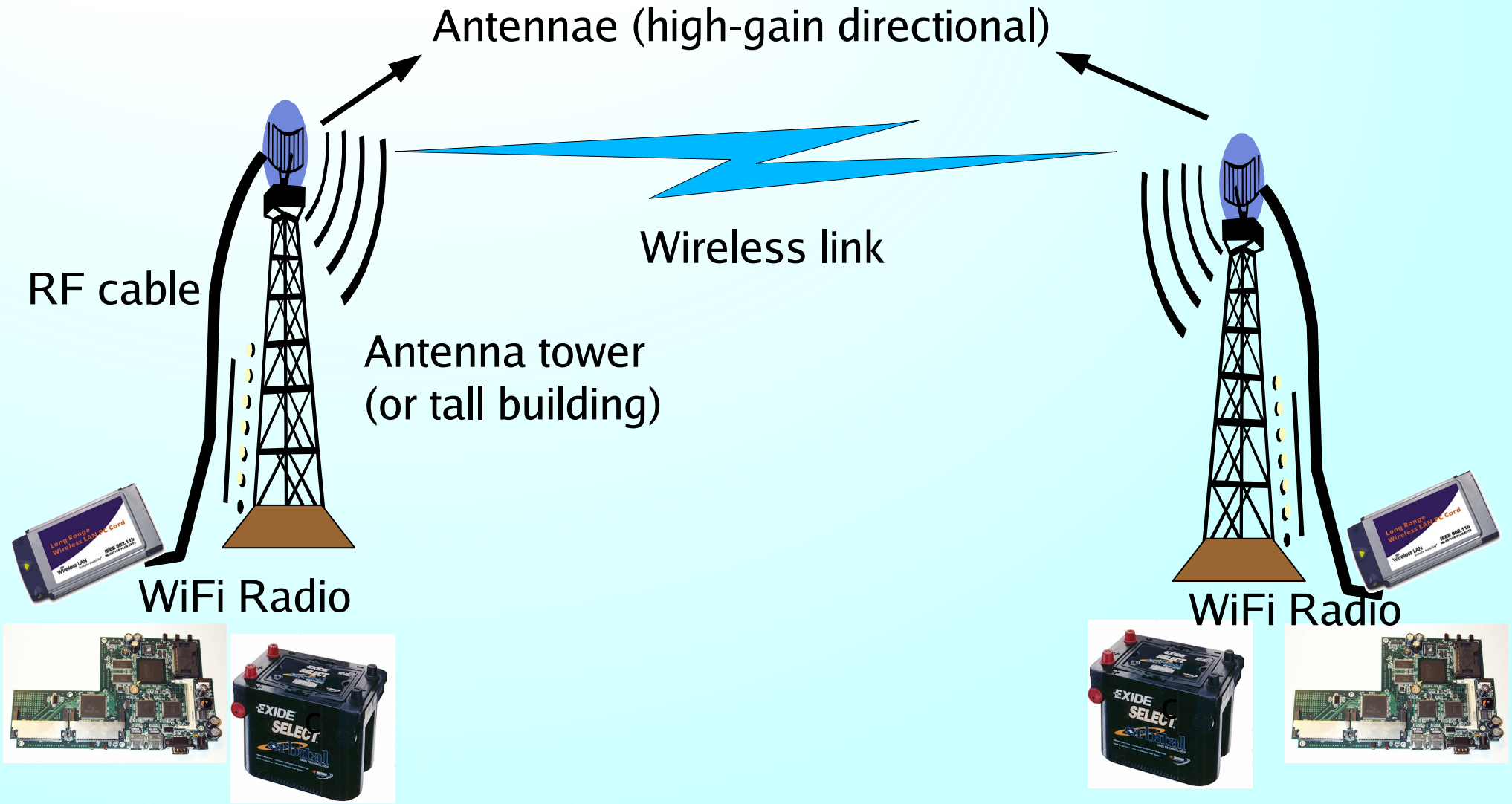
Src: http://nepalwireless.net/

The Ashwini Project

- West & East Godavari, Andhra Pradesh, India
- Deployment by Byrraju Foundation
- One link used in our tests

The antenna tower at Kasipadu

Long Distance Link Setup



Questions

- What is the effect of received signal strength on packet error rate?
- What is the effect of packet size and transmit rate on packet error rate?
- Is there time correlation of packet errors? If so, at what granularity?

Questions

- What is the maximum achievable application throughput?
- What is the effect of interference?
- What is the effect of weather on link performance?
- What is the effect of MAC ACK timeouts on application throughput?

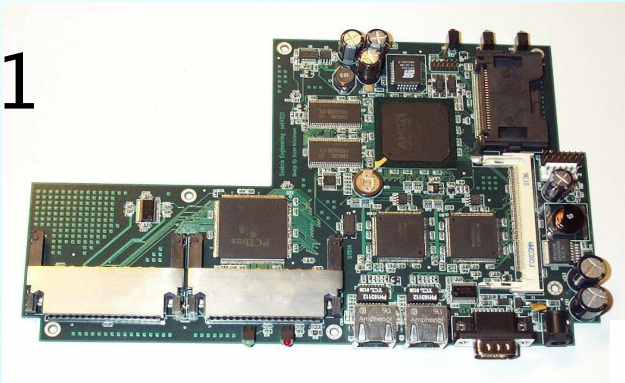
Outline

- Motivation & Background
- Methodology
- Packet error studies
- Throughput measurements
- Interference Analysis
- Some Lessons
- Conclusion
- Questions

Hardware Setup

- Senao 2511CD plus ext2 PCMCIA cards

- Soekris platform with pebble Linux
  - Net 4521 and Net 4501

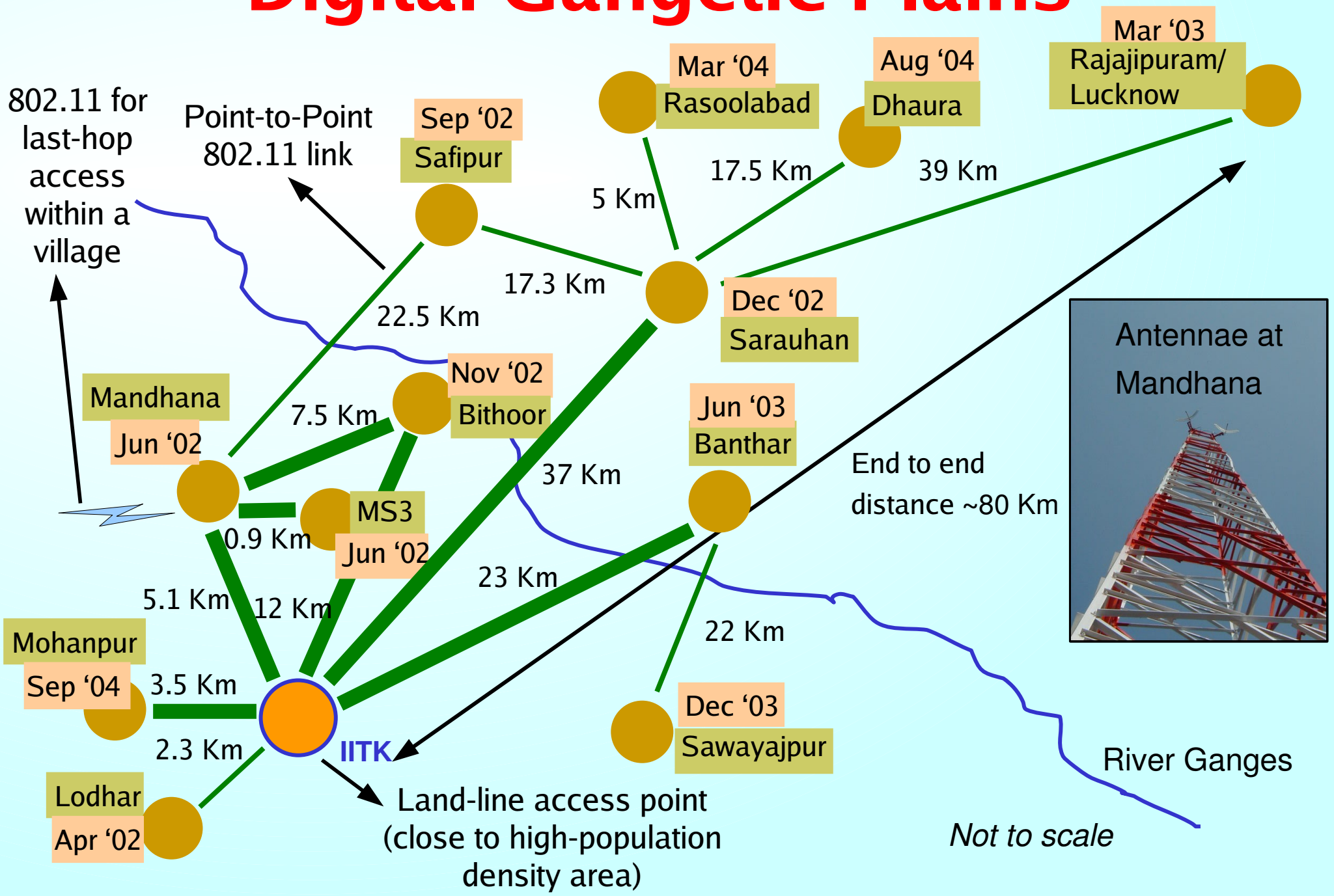


- 12V battery with a capacity of 32AH with a voltage stabilizer circuit

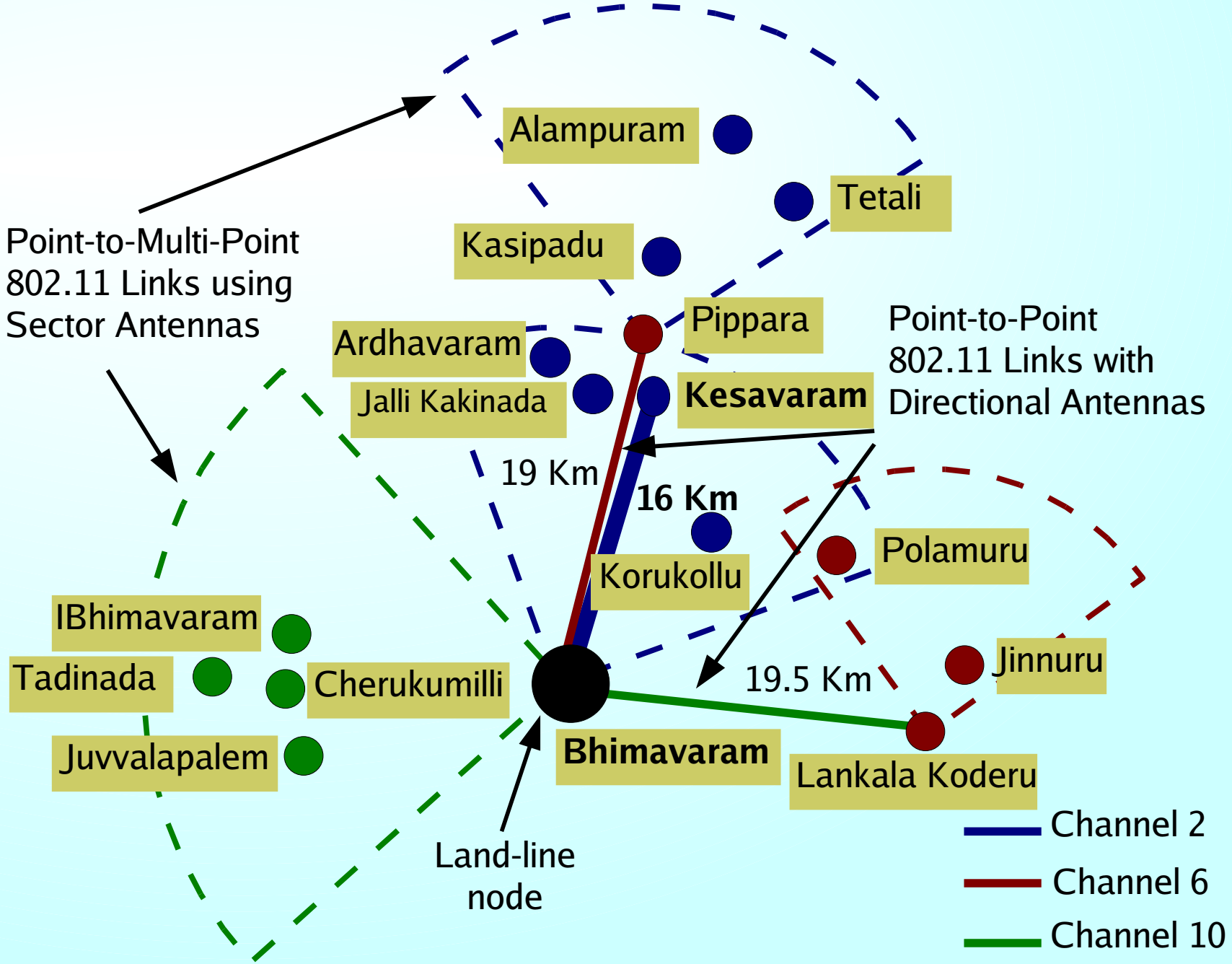
Software Setup

- Open source HostAP driver
- Export per packet information via /proc system
  - PHY: Signal strength, noise level, data rate
  - MAC: CRC check status, MAC sequence, etc.
- Enable/disable MAC level Ack
  - Driver exports an interface for this

Digital Gangetic Plains



The Ashwini Network



Sites Used

Site Name	Notation	Tower arrangement	Mains power supply	Alternate power supply
IITK	A	40m building	Available mostly	--
Mohanpur	B	17m tower	Not available	12V battery + stabilizer circuit
Mandhana	C	40m tower	Available at times	12V battery + stabilizer circuit
MS3	D	30m tower	Unreliable, huge voltage fluctuations	12V battery + stabilizer circuit
Bithoor	E	25m tower on roof of 15m building	Available at times	12V battery + stabilizer circuit
Banthar	F	25m tower	Available at times	12V battery + stabilizer circuit
Sarauhan	G	40m tower	Not available	12V battery + stabilizer circuit, solar panel
Bhimavaram	P	45m tower	Available mostly	--
Kesavaram	Q	30m tower	Available at times	Battery + inverter

Long Distance Links Used

Link	Length (km)	Antennae	RF cables	Remarks
A-B	3.5	ParG-ParG	50ft, 100ft	--
A-C	5	Sec-ParG	50ft, 150ft	--
C-D	1	ParG-Can	125ft, 50ft	Ant at 30m at C, 15m at D
E-D	7.5	ParG-ParG	125ft, 50ft	--
A-F	23	ParG-ParG	50ft, 100ft	--
A-G	37	ParG-ParG	50ft, 150ft	--
A-E	12	ParG-ParG	50ft, 150ft	--
P-Q	16	Sec-ParG	1ft, 1ft	Power-over-Ethernet for radio atop the tower

Measurement Methodology

- Metrics
  - Packet error rate
  - Signal Strength
  - Application throughput (UDP and TCP)
- Parameter space
  - Transmit power (4 settings)
  - Transmit rate (4 settings)
  - Packet size (3 settings) and inter-arrival (4 settings)
  - Broadcast vs unicast
  - Channel of operation: fixed for each link

Experiment Setup

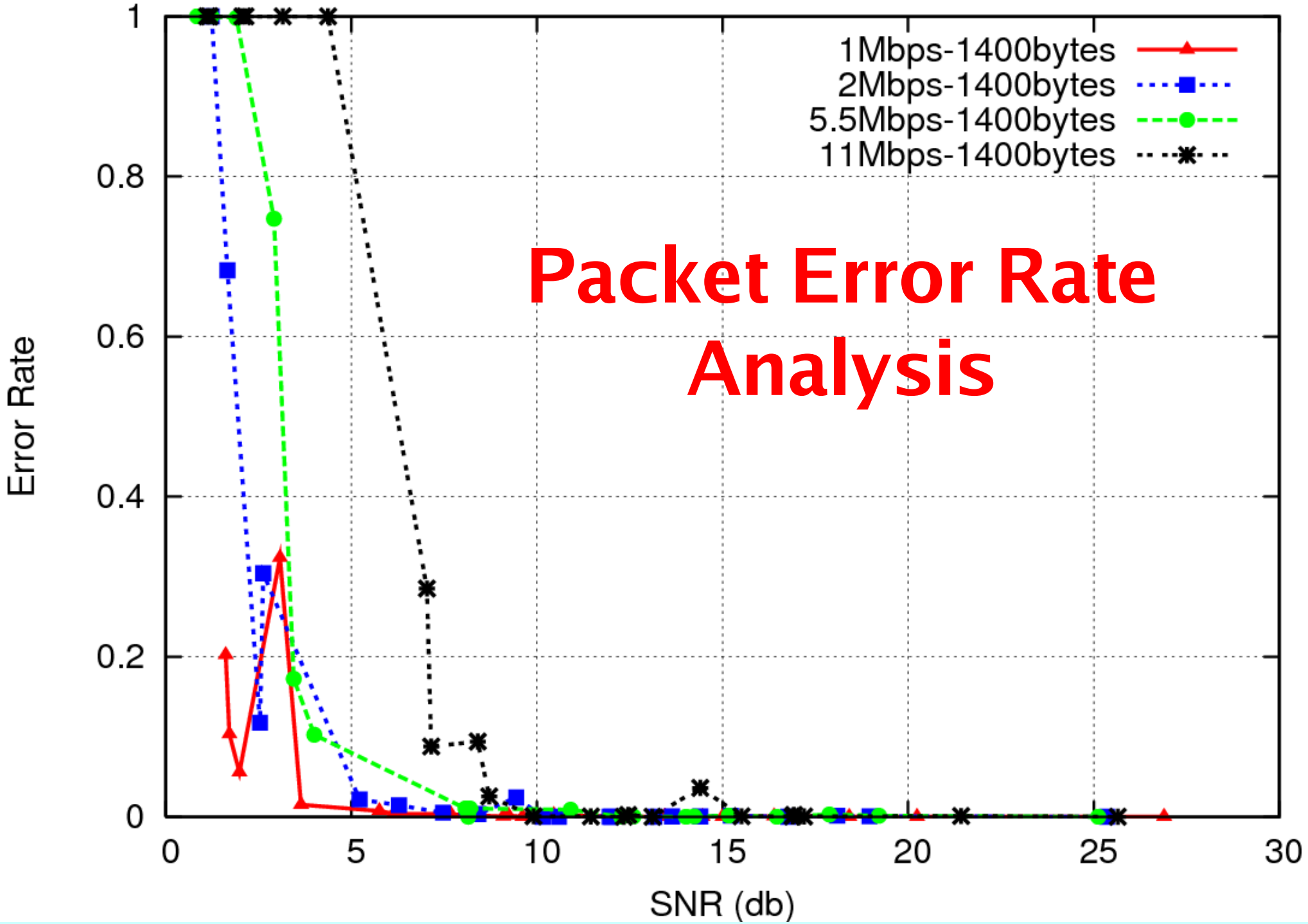
- UDP experiment
  - Choose a specific value of transmit power, rate and packet size
  - Inter arrival: Saturation, 2ms, 100ms, 500ms
  - MAC ACKs are off (broadcast)
  - Receiver in monitor mode
- TCP experiment
  - Choose a specific value of transmit power and rate
  - Data transfer for 25 sec
  - With and without MAC ACKs

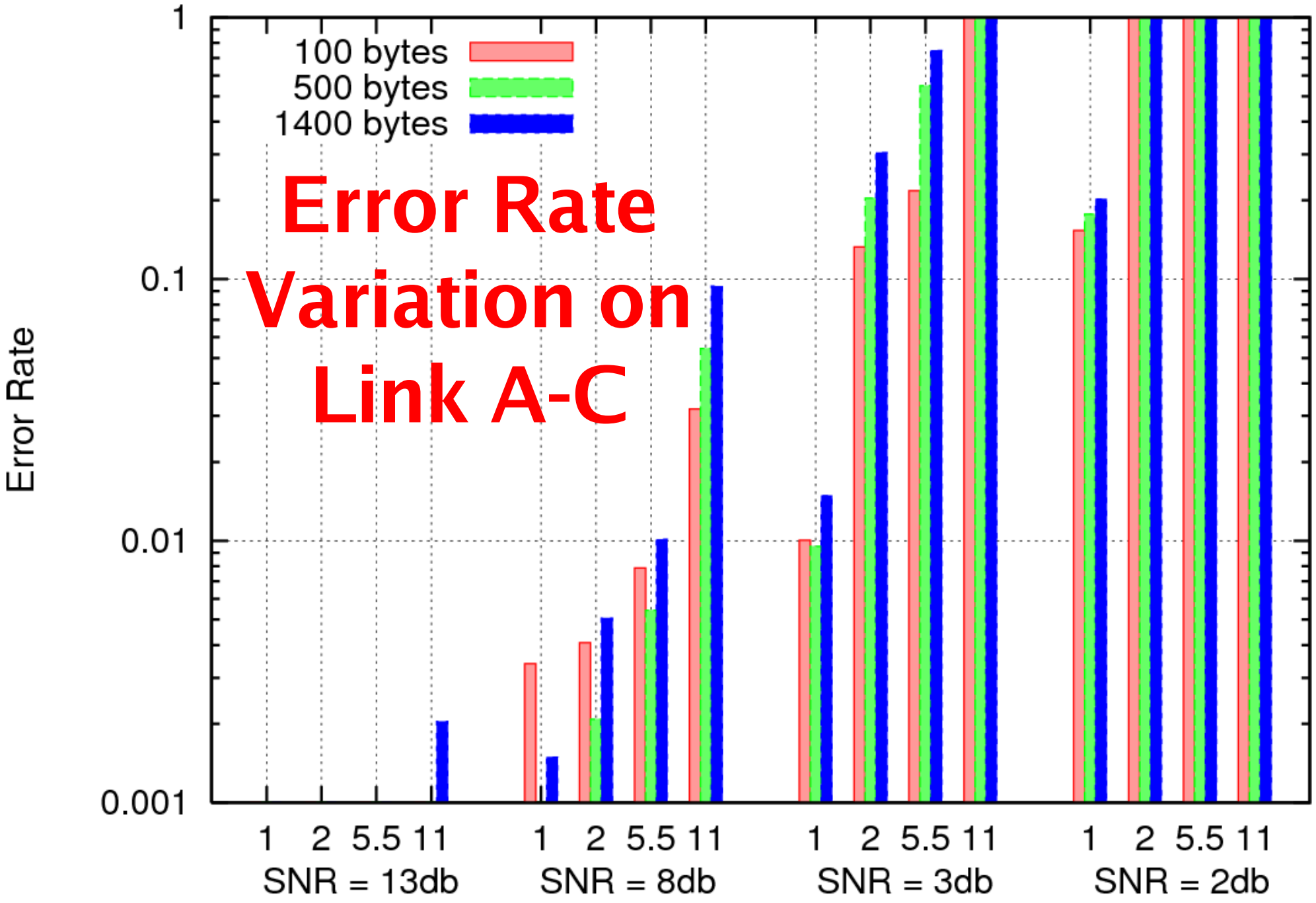
Data Collection Procedure

- Two ends of link form link with default settings
- One end determines which experiment to run and communicates the same to other end
- Two ends change settings, perform the experiment and record results
- Two ends store data collected during experiment via LAN or flash memory

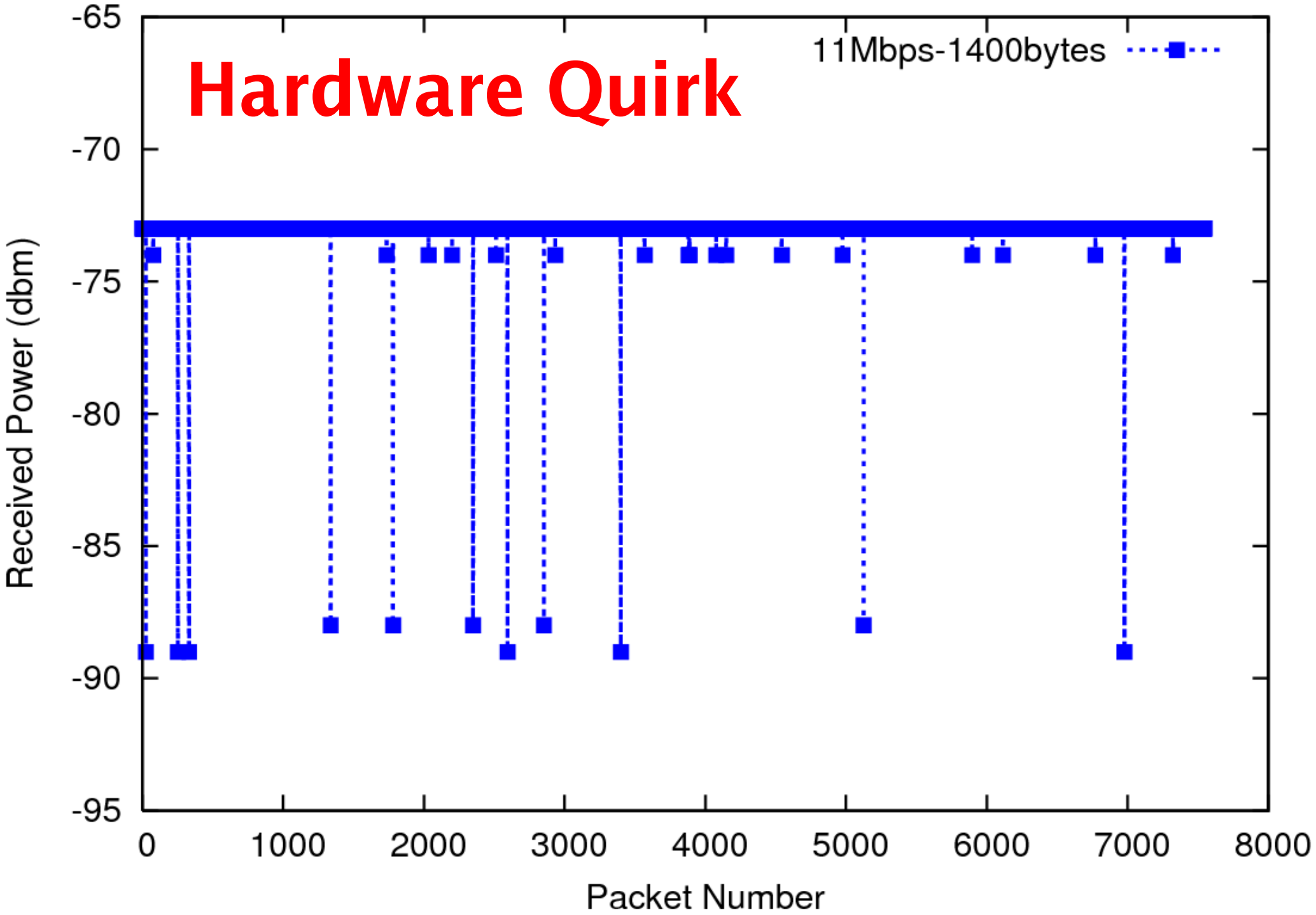
Outline

- Motivation & Background
- Methodology
- Packet error studies
- Throughput measurements
- Interference Analysis
- Some Lessons
- Conclusion
- Questions


Packet Error Rate Analysis
1Mbps-1400bytes
2Mbps-1400bytes
5.5Mbps-1400bytes
11Mbps-1400bytes
Error Rate
SNR (db)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30


Error Rate Variation on Link A-C
100 bytes
500 bytes
1400 bytes
Error Rate
1
0.1
0.01
0.001
1 2 5.5 11
SNR = 13db
1 2 5.5 11
SNR = 8db
1 2 5.5 11
SNR = 3db
1 2 5.5 11
SNR = 2db

Hardware Quirk

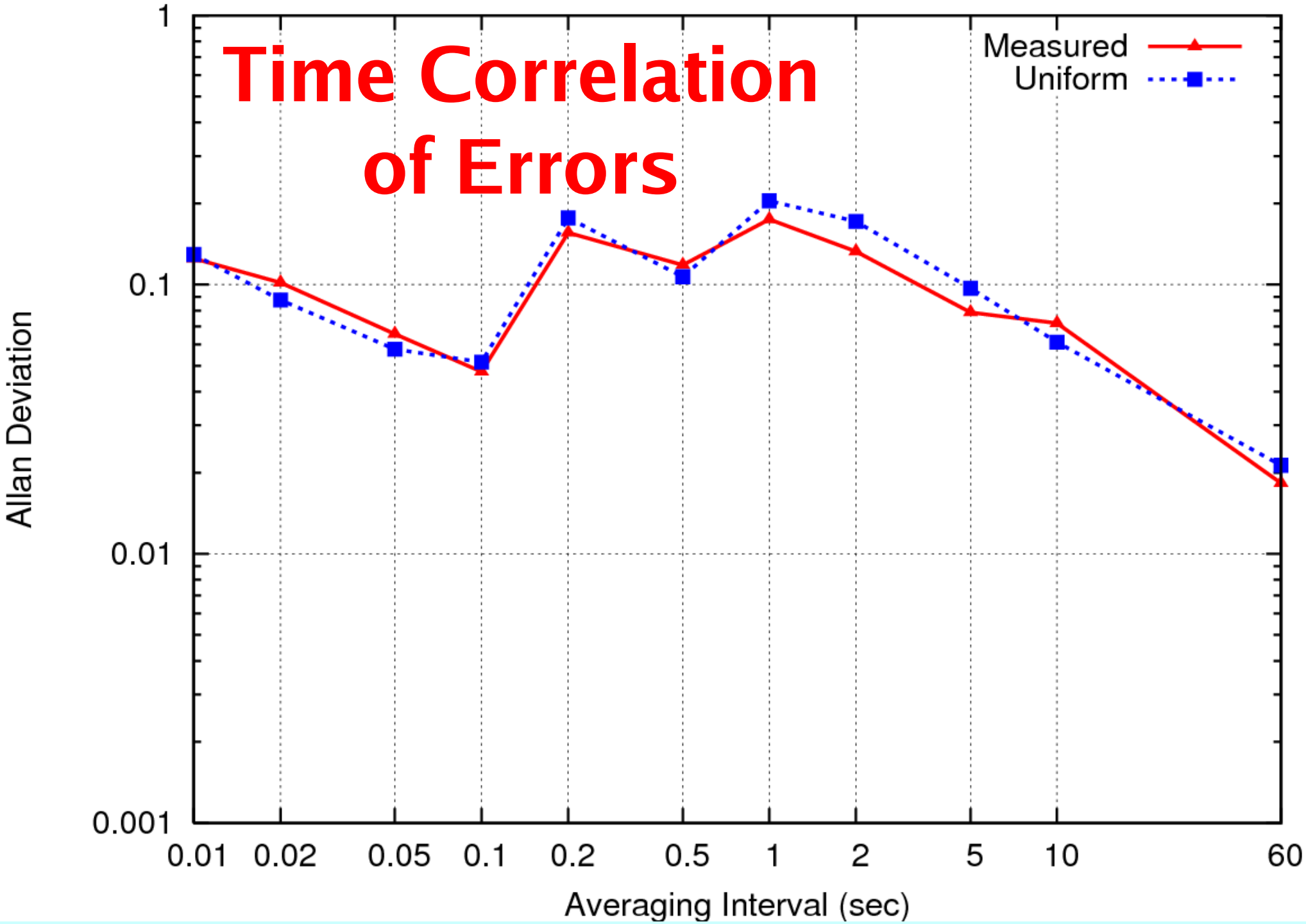


Time Correlation of Errors

- Allan Deviation
  - Given a series of values

$$\sqrt{\frac{\sum_{i=2}^{N} (x_i - x_{i-1})^2}{2N}}$$

Time Correlation of Errors

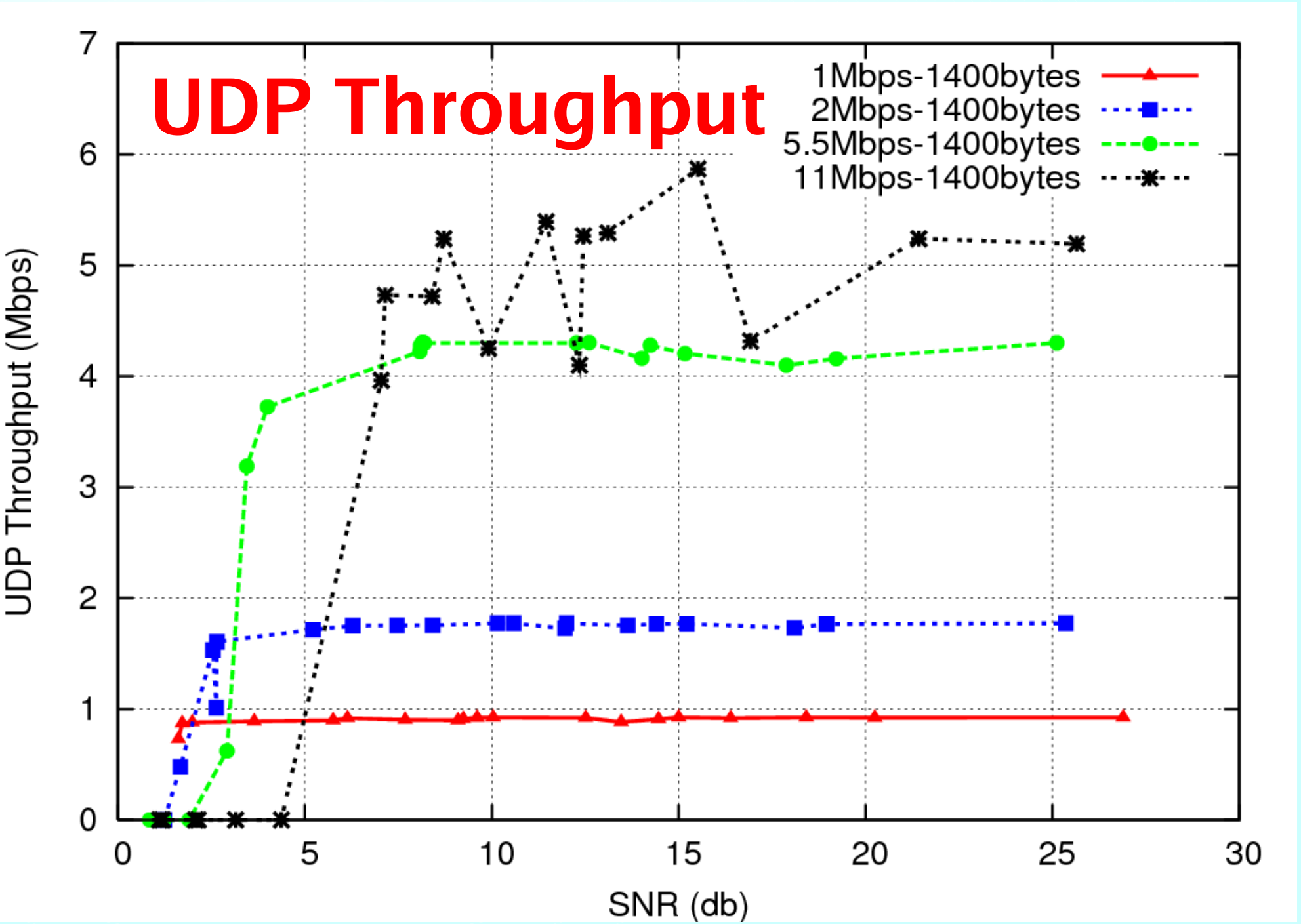


A Few Other Results

- Error rate is independent of time
- At high SNR, error rate variation is very small and under 0.1%
- At low SNR, error rate variation is high:
  - Steep region of Error-Rate vs. SNR curve
  - 1.5% to 45%
- Weather does not seem to effect link performance!

Implications

- Link abstraction holds
  - Links can be planned such that error rates are low
- No sophisticated routing is required
- Transmit rate adaptation based on SNR



Theoretical Limit: 0.92(1Mbps), 1.79(2Mbps), 4.42(5.5Mbps), 7.63(11Mbps)

Bottlenecks & Implications

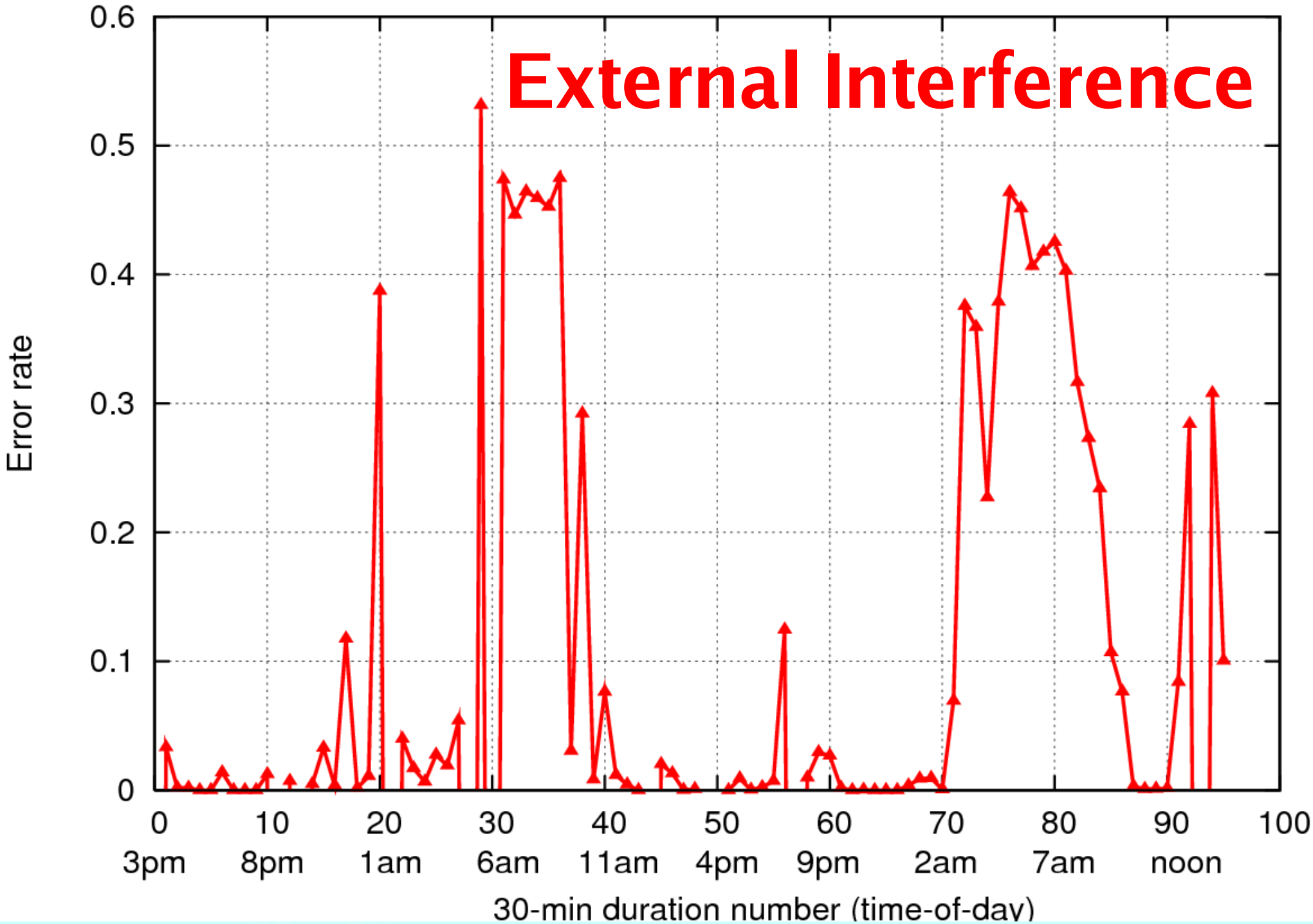
- Neither HostAP driver nor PCMCIA card support DMA
- Net4521 has a 133MHz processor
- 11Mbps, 100 byte packets
  - Achieved: 0.77Mbps, Theoretical: 1.53Mbps
  - Rate of interrupt to clear buffer is small
- There are system bottlenecks other than wireless interface
  - VOIP calculations

TCP Throughput

- Effect of ACK timeout on 37 km link
  - MAC unicast: 0.5Mbps, MAC broadcast: 1.9Mbps
- TCP evaluation
  - Inter-packet gap was 10-20ms
    - Exponential rise in contention window
    - Collision between TCP Data and ACK
- Hardware quirk:
  - MAC receiving same sequence number packets
- Implications
  - Need selective acknowledgment mechanism

Outline

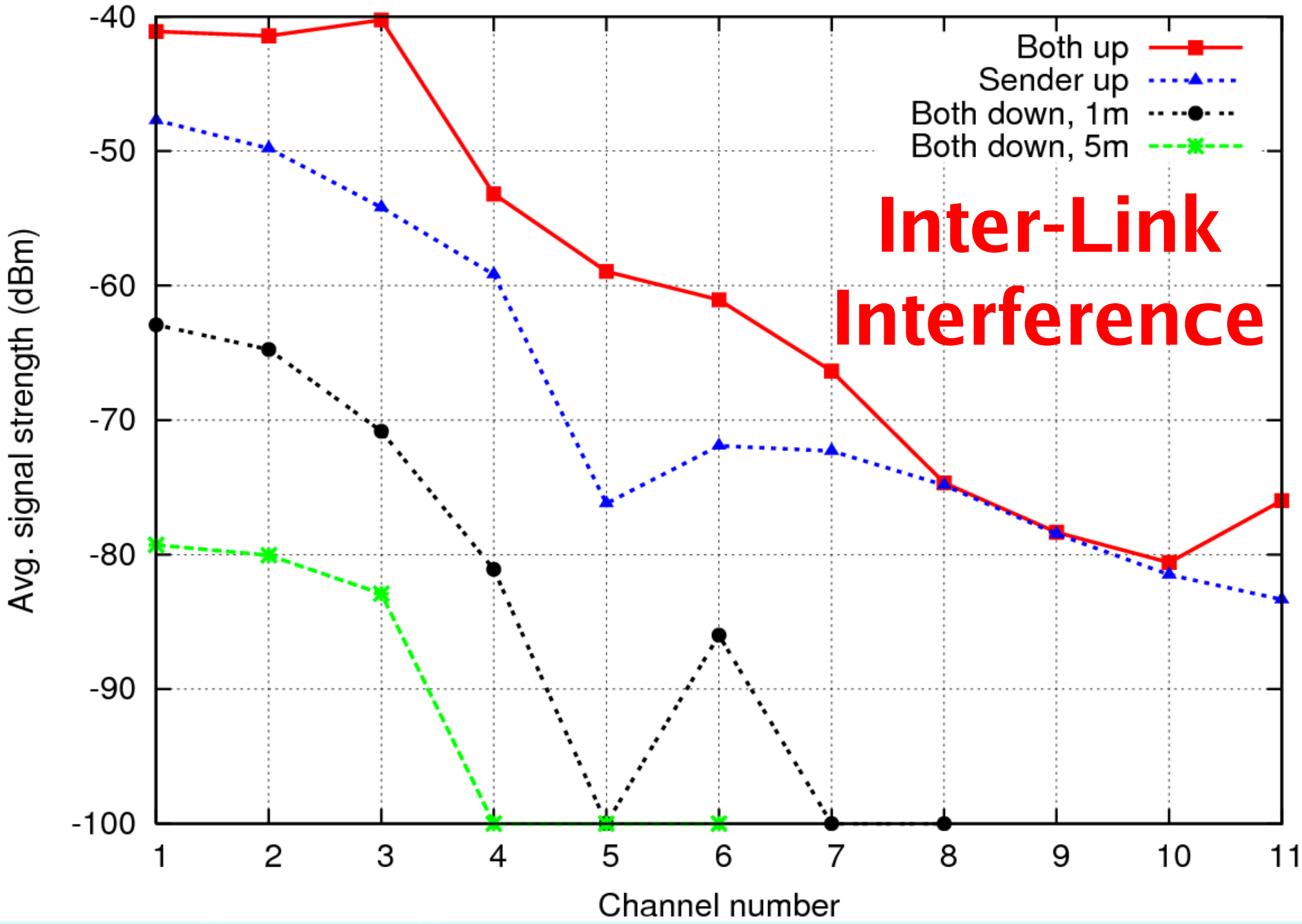
- Motivation & Background
- Methodology
- Packet error studies
- Throughput measurements
- Interference Analysis
- Some Lessons
- Conclusion
- Questions


External Interference
Error rate
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
3pm
8pm
1am
6am
11am
4pm
9pm
2am
7am
noon
30-min duration number (time-of-day)

Inter Link Interference: Setup

Setup Details

- Transmitter
  - Sends beacons every 100ms, txpower = 20dbm
  - Operates in Channel 1
- Sniffer
  - Listens in monitor mode, scans channel 1-11
- Four configurations
  - Both transmitter and sniffer are up the tower (20m)
  - Transmitter is up, Sniffer is down
  - Both transmitter and sniffer are down, 1m apart
  - Both transmitter and sniffer are down, 5m apart


Both up
Sender up
Both down, 1m
Both down, 5m
Inter-Link Interference
Avg. signal strength (dBm)
-40
-50
-60
-70
-80
-90
-100
1
2
3
4
5
6
7
8
9
10
11
Channel number

Implications

- External interference can significantly degrade application performance
- Issue of RF pollution needs immediate attention
  - Technical: Mechanisms to detect and diagnose causes of interference
  - Non-Technical: Some legal or semi-legal mechanism to control interference across deployments
- Need to be aware of inter-link interference
  - Use of RF cables recommended

Outline

- Motivation & Background
- Methodology
- Packet error studies
- Throughput measurements
- Interference Analysis
- Some Lessons
- Conclusion
- Questions

Some Lessons Learnt the Hard Way

- Tricky txpower/channel settings
  - Must be set *after* setting the mode
- Use hardware register directly for txpower
- Cannot force association!
- Check for possible interference at remote site
  - Can affect log size
- Beware of kernel UDP buffer
- Account for RF leakage during calibration

Conclusion

- Long distance links can be planned well for predictable performance
- Interference can cause drastic reduction in performance: planning necessary
- Beware of bottlenecks other than wireless interface
- Future directions:
  - Network planning
  - Detecting interference sources, network mgmt.
  - Link perf. in 200-3000m distances in village settings

Thanks You!

Questions?