

# Long Distance 802.11b Links: Performance Measurement and Experience

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# 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



Src: <http://nepalwireless.net/>

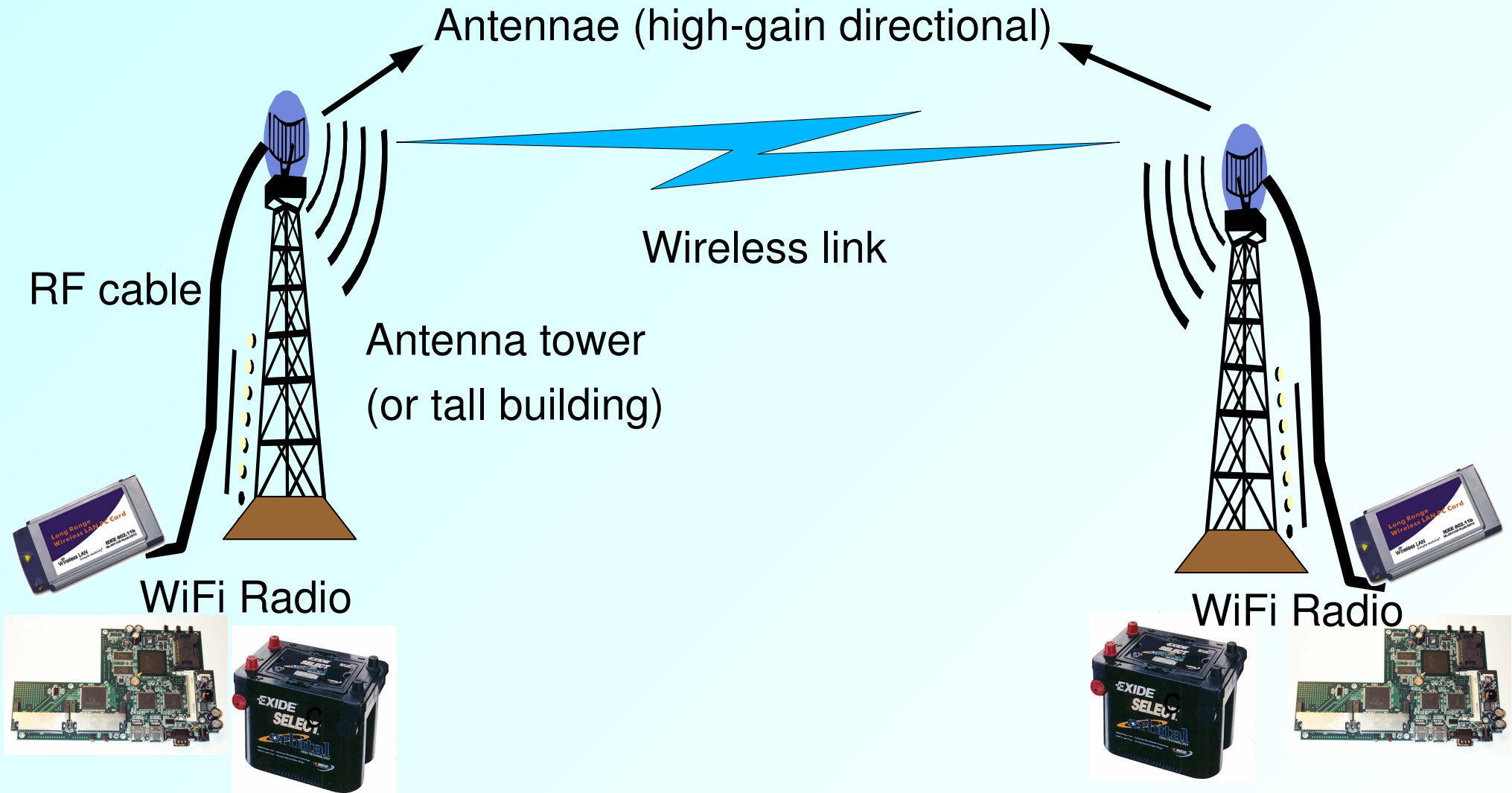
# The Ashwini Project

- 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

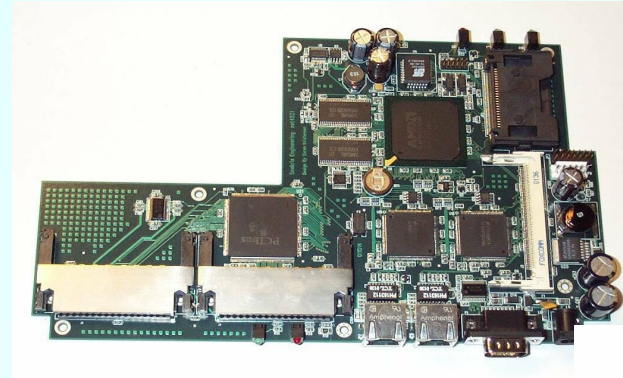
- Motivation & Background
- Methodology
- Packet error studies
- Throughput measurements
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- Some Lessons
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# Hardware Setup

- Senao 2511CD plus ext2 PCMCIA cards



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



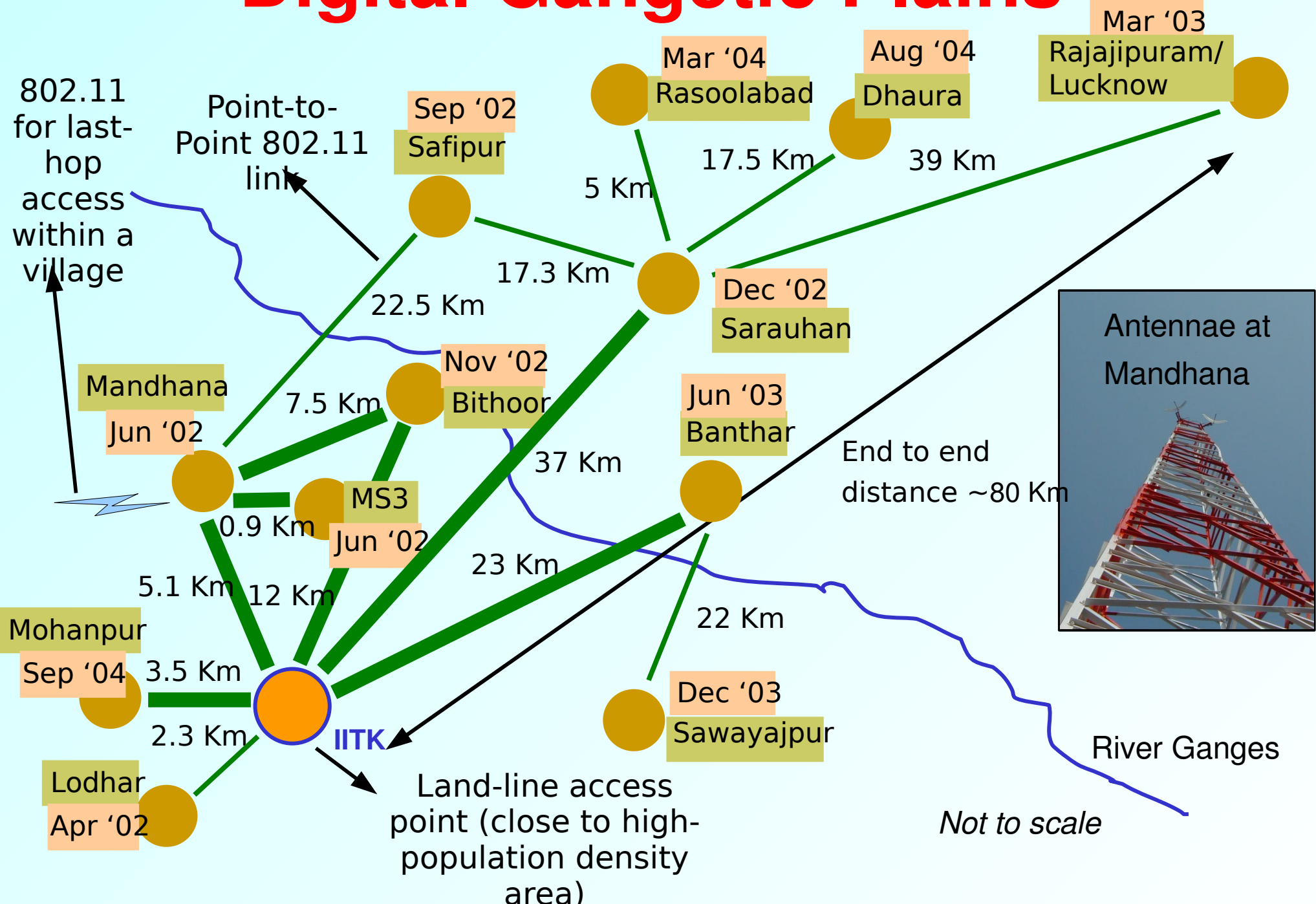
- 12V battery with a capacity of 32AH with a voltage stabilizer circuit



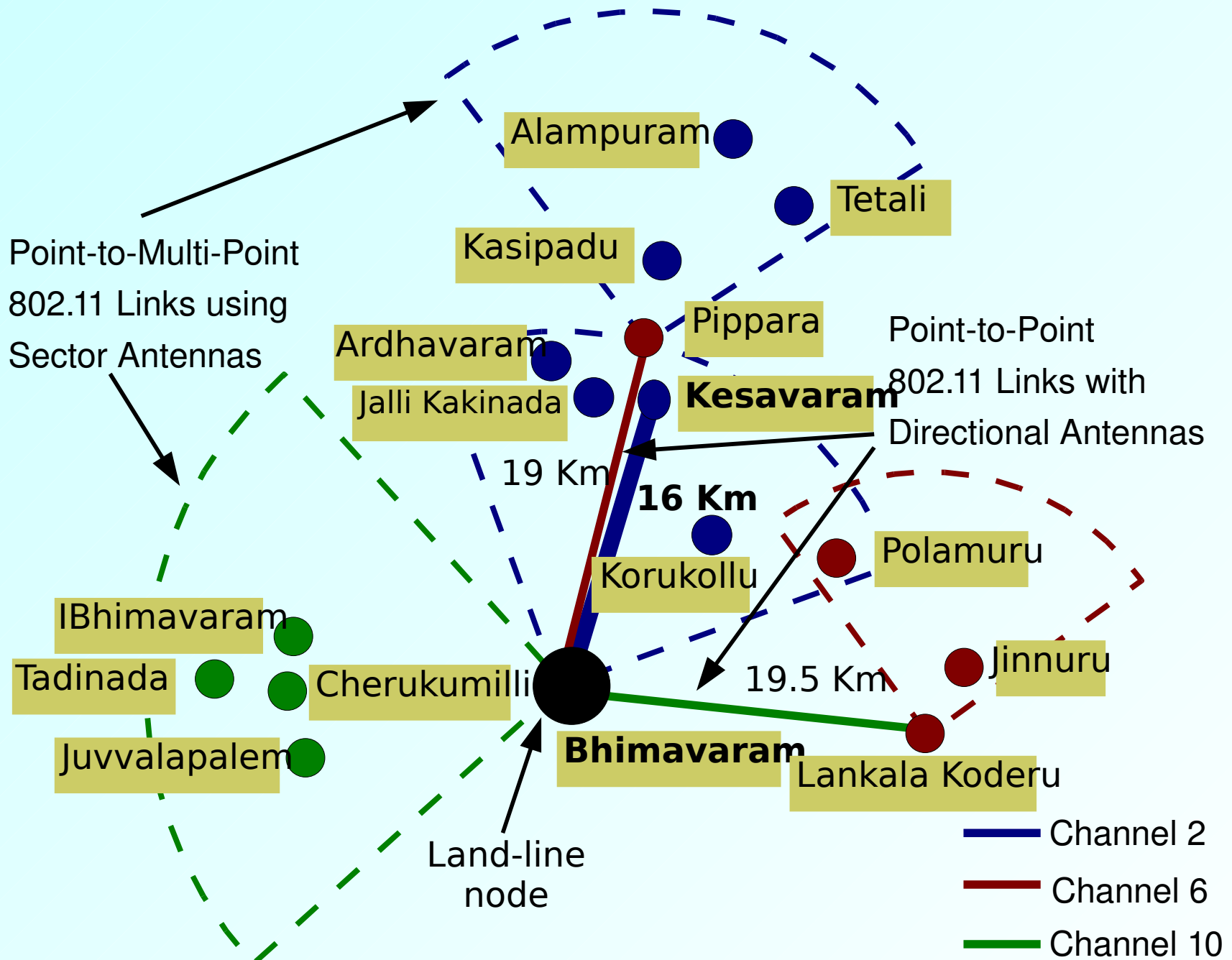
# Software Setup

- 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

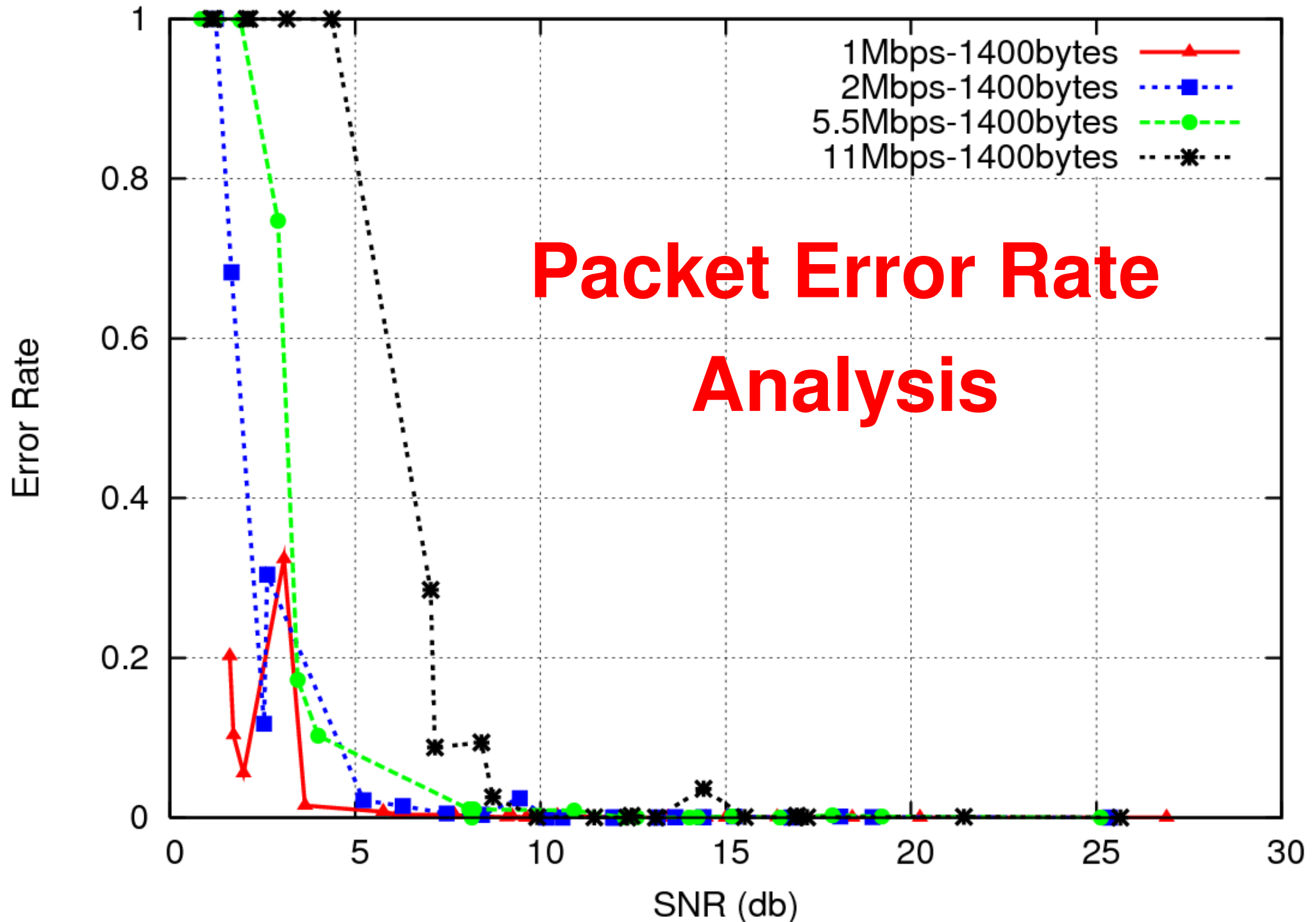
- UDP experiment
  - Specific values of transmit power, rate and pkt size
  - Inter arrival: Saturation, 2ms, 100ms, 500ms
  - MAC ACKs are off (broadcast)
  - Receiver in monitor mode
- TCP experiment
  - Choose a specific value of transmit power and rate
  - Data transfer for 25 sec
  - With and without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

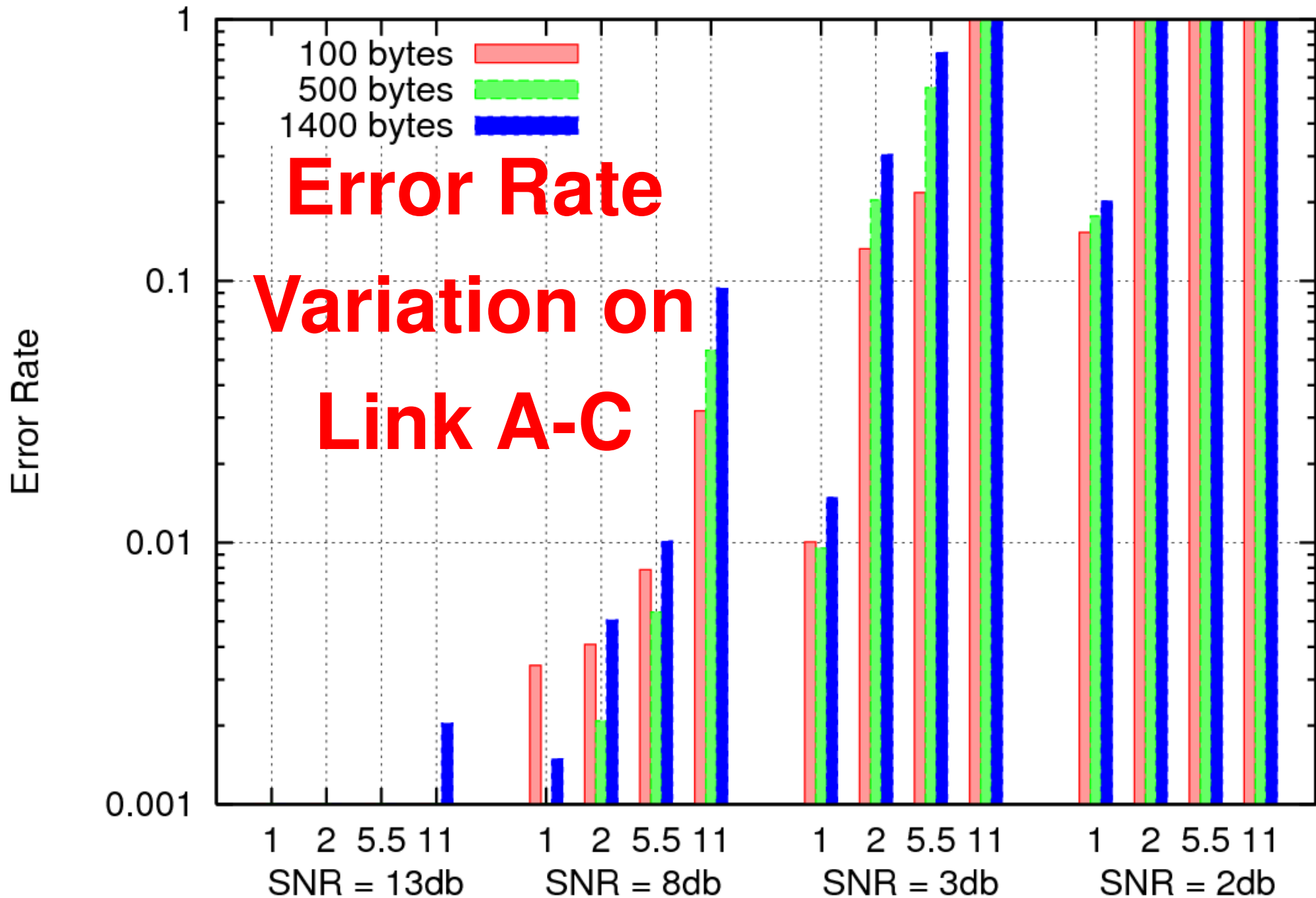
# Data Collection Procedure

- 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

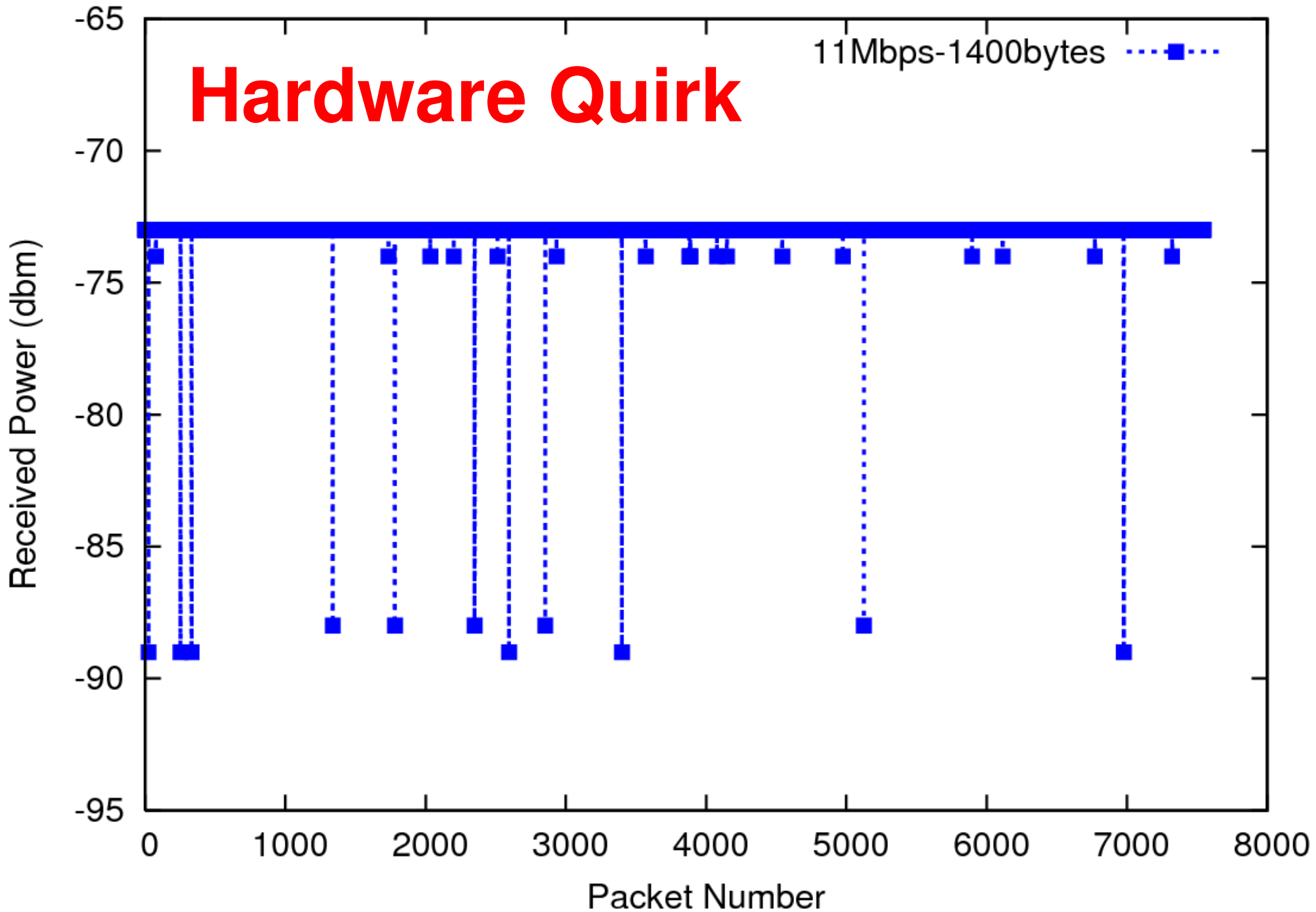
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# Hardware Quirk





# Time Correlation of Errors

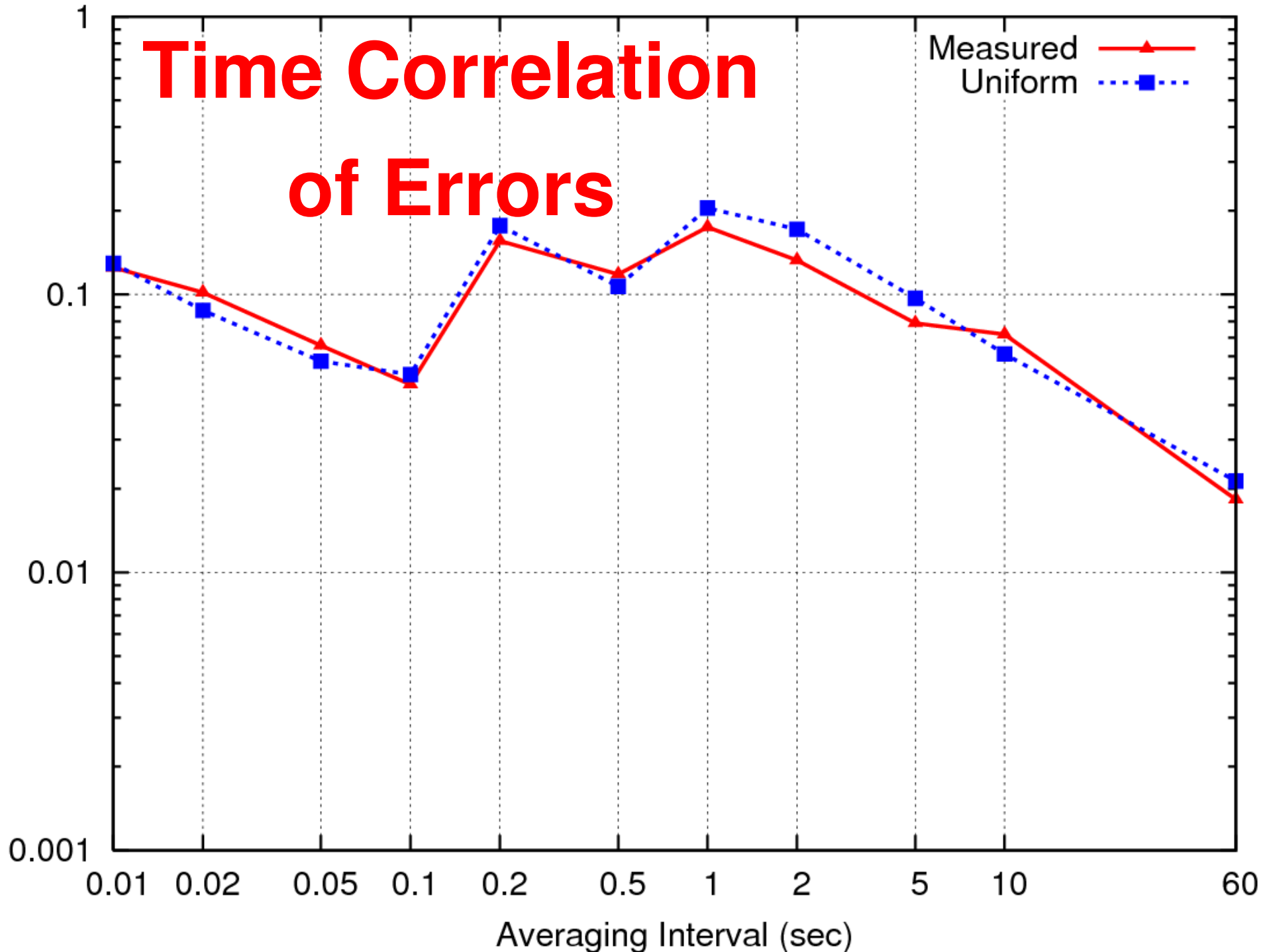
- Allan Deviation
  - Given a series of values

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

# Time Correlation of Errors

Allan Deviation

Measured   
Uniform 

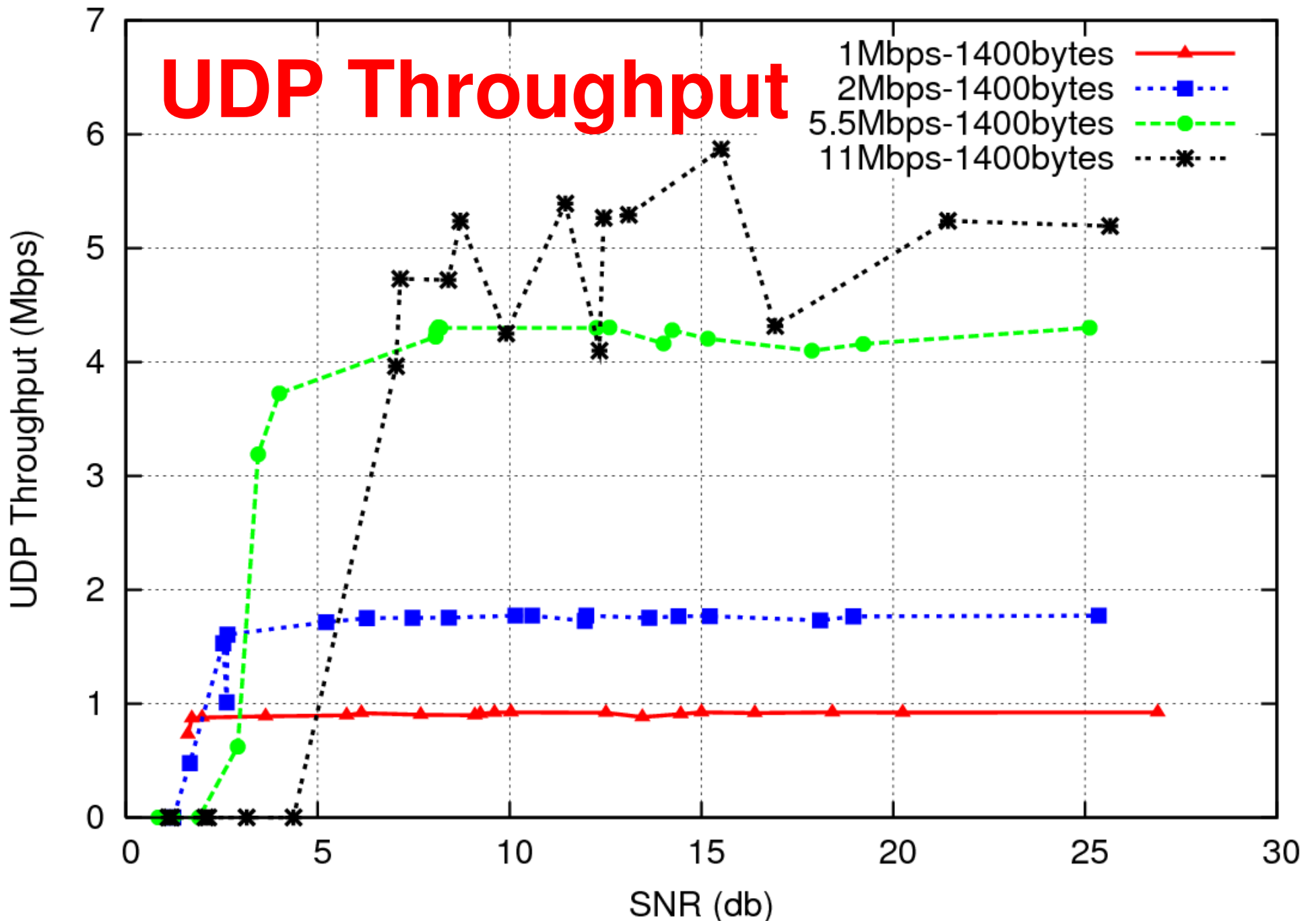


# A Few Other Results

- 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

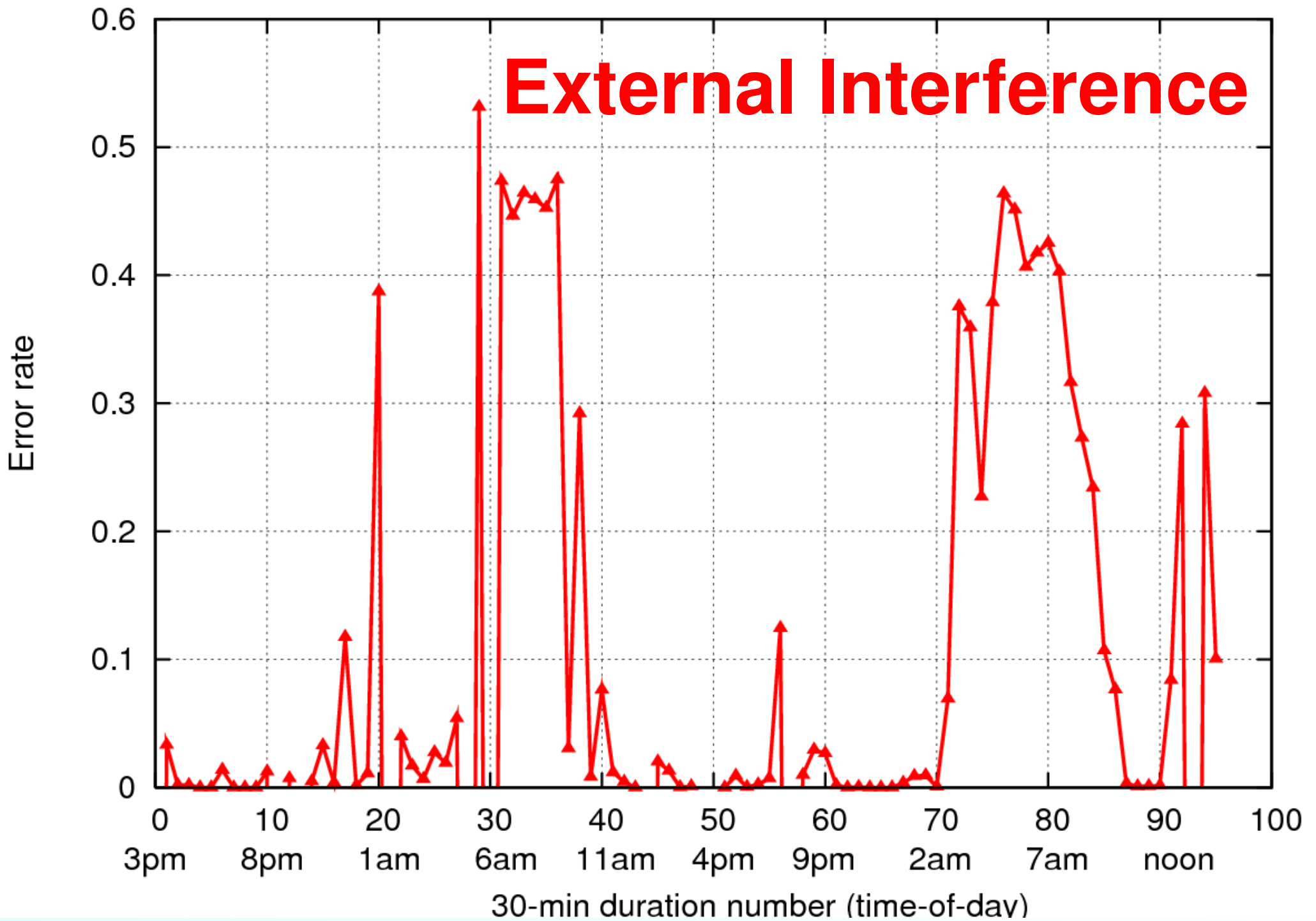
- Neither HostAP driver nor PCMCIA card support DMA
- Net4521 has a 133MHz processor
- 11Mbps, 100 byte packets
  - Achieved: 0.77Mbps, Theoretical: 1.53Mbps
  - Rate of interrupt to clear buffer is small
- There are **system bottlenecks** other than wireless interface
  - VOIP calculations

# 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
- Implication: need selective ACK mechanism

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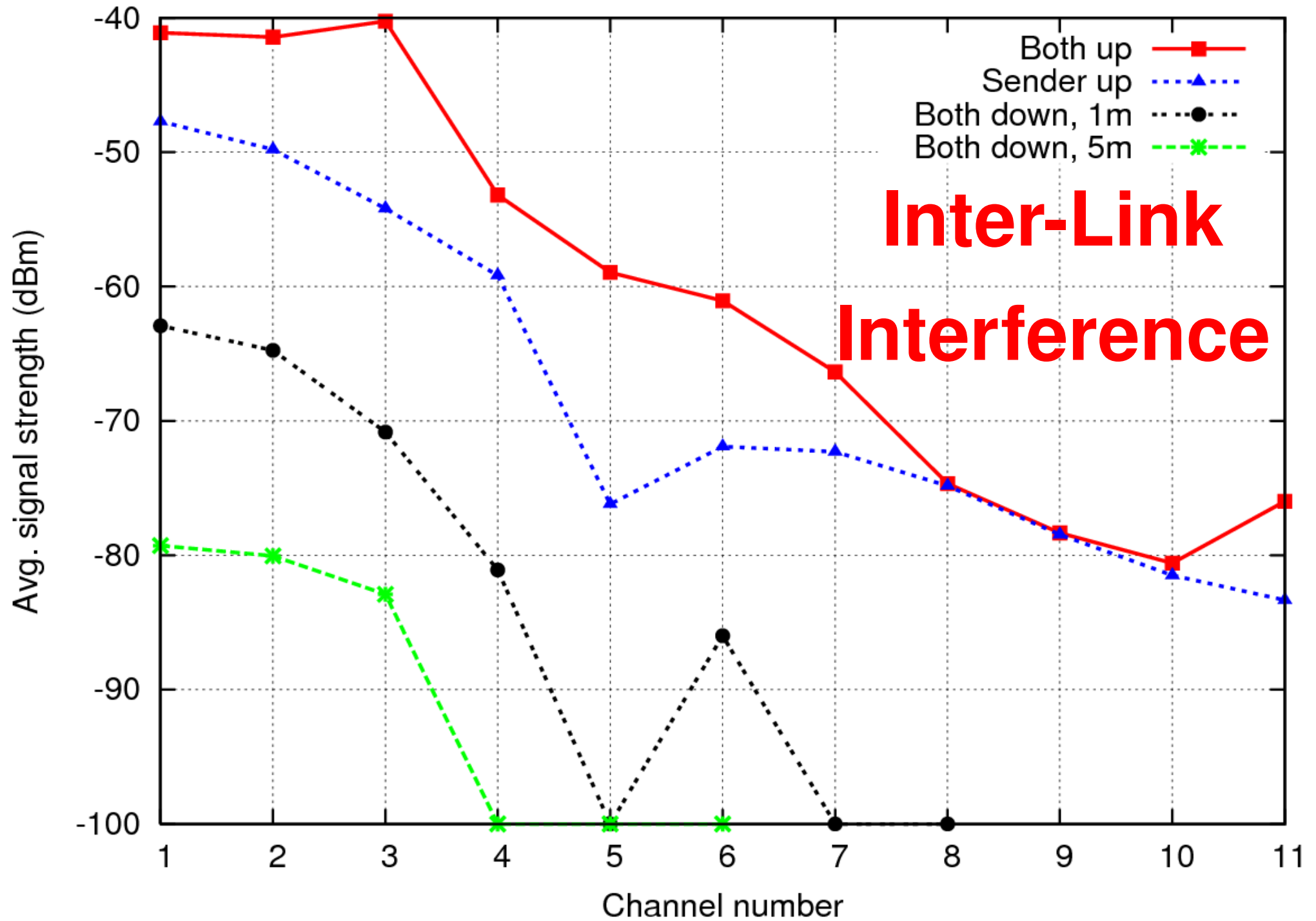


# Inter Link Interference: Setup



Parabolic Grid  
Antennae

- Transmitter **Setup Details**
  - 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



# 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

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# 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

# Link Abstr.: DGP, Roofnet, FRACTEL

	Typical link distances	Network architecture	Environment	Multipath effects	SNR or RSSI	External interference	Link abstraction
<b>Long-distance mesh networks (e.g. DGP)</b>	Up to few tens of kms	High gain directional & sector antennas on tall towers or masts	Rural setting studied in depth	Effect not apparent	Has strong correlation with link quality	Affects links performance	Valid
<b>Rooftop mesh networks (e.g. Roofnet)</b>	Mostly < 500 m	Mostly omnidirectional antennas on rooftops	Dense urban setting studied in-depth	Reported as a significant component	Not useful in predicting link quality	Reported as not significant	Not valid
<b>LACNs</b>	Mostly < 500 m	Would like to avoid tall towers	Rural, campus, residential	<i>To be determined</i>	<i>To be determined</i>	<i>To be determined</i>	<i>To be determined</i>

**Thanks You!**

**Questions?**

