Thesis Defence

The Feasibility and Usefulness of Link Abstraction in Wireless Networks

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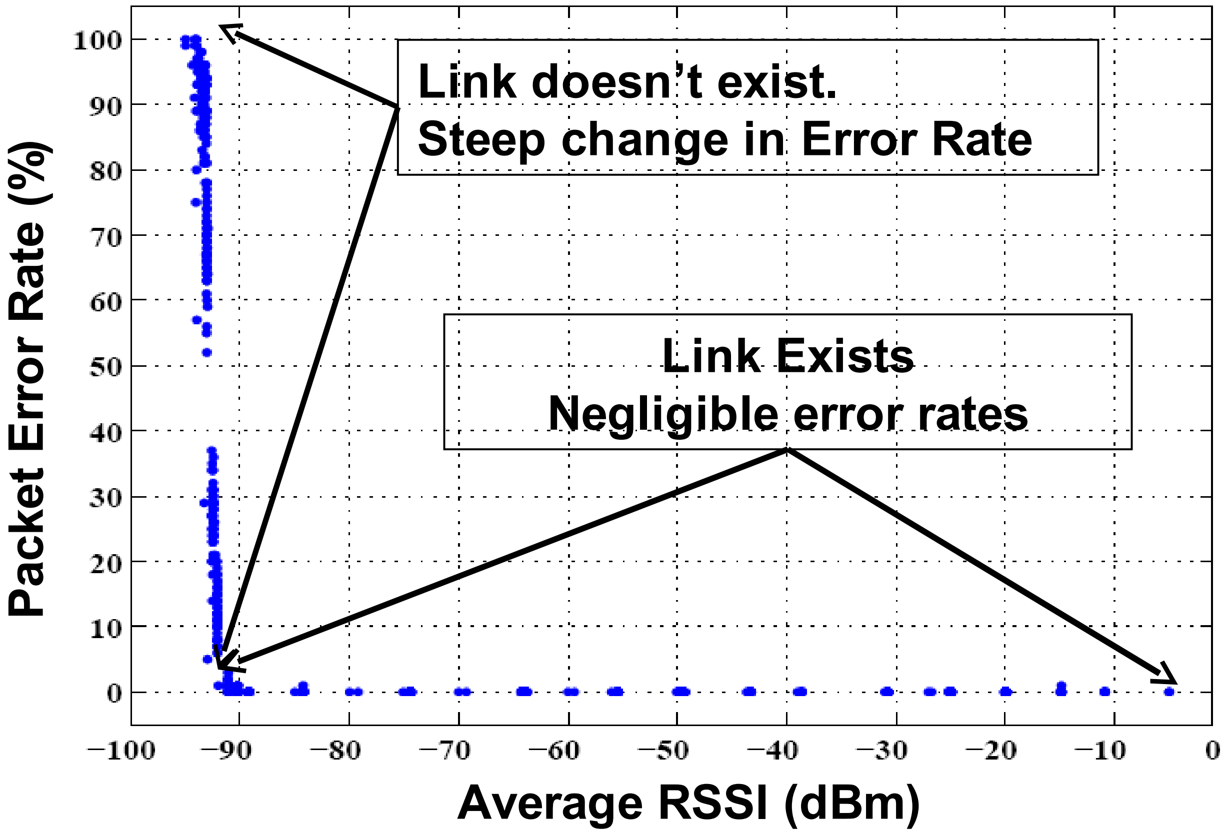
Contents

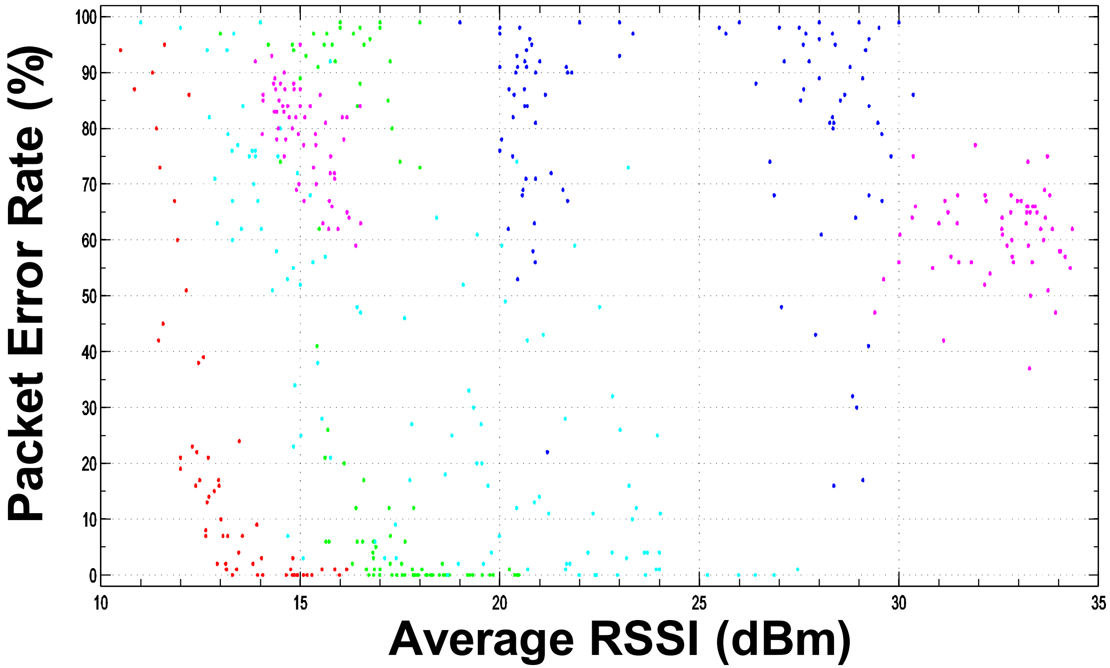
Introduction

- What is 'link abstraction'?
  - Concept derived from 'wired networks'
  - If link abstraction exists –



Introduction – Link Abstraction

- If link abstraction is absent –



- It's Existence simplifies
  - Complex routing metrics
  - Network protocols
  - Improves network performance

Introduction – Link Abstraction

- If link abstraction exists -

Link	Exists	Doesn't exist
Error rate	Negligible (0%)	All packets lost (100%)
SNR and BER	Rapid change	Gradual change

- It's Existence simplifies
  - Complex routing metrics
  - Network protocols
  - Improves network performance

Introduction – Our Work

- **We look for answers to:**
  - Is link abstraction feasible? Especially in
    - Wireless Sensor Networks (WSNs)
    - Wireless Mesh Networks based on 802.11b (WMNs) – link distances < 500m
  - Is there a method to engineer links with *'link abstraction'*?
  - Is there a possibility of classifying existing links?
  - Is there a factor / factors that invalidate 'link abstraction'?

Related Work
and
Motivation

Related Work and Motivation: WMNs

Motivation

- Measurement study of WMNs motivated by FRACTEL (wi-**F**i based **R**egional/Rural data **Ac**cess and **TEL**ephony)

- FRACTEL : AIM

  "*Extend the connectivity available at a single location in a village, to multiple locations while aiming to provide data, voice and video services over the links….*"

Related Work and Motivation: WMNs

- **Important wireless measurement studies –**
  - ***Roofnet*** – Community Mesh Network
  - ***DGP*** – Long Distance Network
- **Setting:**

	Community WMNs E.g.: Roofnet	Long Distance WMNs E.g.: DGP	FRACTEL (Presently)
External Connectivity	Multiple points	Single point	**Single**
Link Distance	Mostly <500m	Up to few 10s of kms	**Mostly < 500m**
Network Architecture	Unplanned, Omni antennas on rooftops	High gain directional antennas on tall towers	**Avoid use of tall towers**
Environment	Dense urban	Rural	**Rural**

Related Work and Motivation: WMNs

❖Contrasting Results

	Community WMNs E.g.: Roofnet	Long Distance WMNs E.g.: DGP	FRACTEL (Presently)
Link Abstraction	INVALID	VALID	To be determined
Effect of Multi-path	Strong Component observed	Less Susceptible	To be determined
SNR / RSSI & Link Quality	Not useful to predict link quality	Has strong correlation with link quality	To be determined

❖ FRACTEL link characteristics ???

Related Work and Motivation: WMNs

- **Roofnet Results –**
  - Intermediate delivery probabilities (*neither 0% or 100%*) on majority links
  - Multi-path is major cause of losses

- **Proposed routing metrics to work around –**
  - ETX –
    - Minimises expected time of transmission to ultimate destination

(Couto, D. S. J. D., Aguayo, D., Bicket, J., and Morris, R. A HighThroughput Path Metric for MultiHop Wireless Routing. In MOBICOM (Sep 2003))

  - WCETT –
    - Chooses a channel diverse path

(Draves, R., Padhye, J., and Zill, B. Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks. In MOBICOM (Sep 2004))

Related Work and Motivation: WSNs

- **Zhao and Govindan have shown:**
  - Absence of a *link abstraction*
  - Presence of a '*gray/transitional*' region
    - Outdoor – 1/5th of total communication range
    - Indoor – 1/3rd total communication range
    - Error rates – unpredictable, varying

("*Measuring packet delivery performance in dense wireless networks*", Sensys 2003)

  - Problem addressed by
    - Routing metrics to differentiate between links
      - Multi-hop LQI (Link Quality Indicator)
      - 1/PSR (Packet Success Rate)

Related Work – Summary

- **Most literature reports –**
  - The absence of link abstraction
  - Links with intermediate delivery rates
  - Routing metrics that choose the best link amongst them

- **Our work suggests –**
  - Link abstraction is ‘*feasible*’
  - It can be used to build predictable links
  - This simplifies things like routing

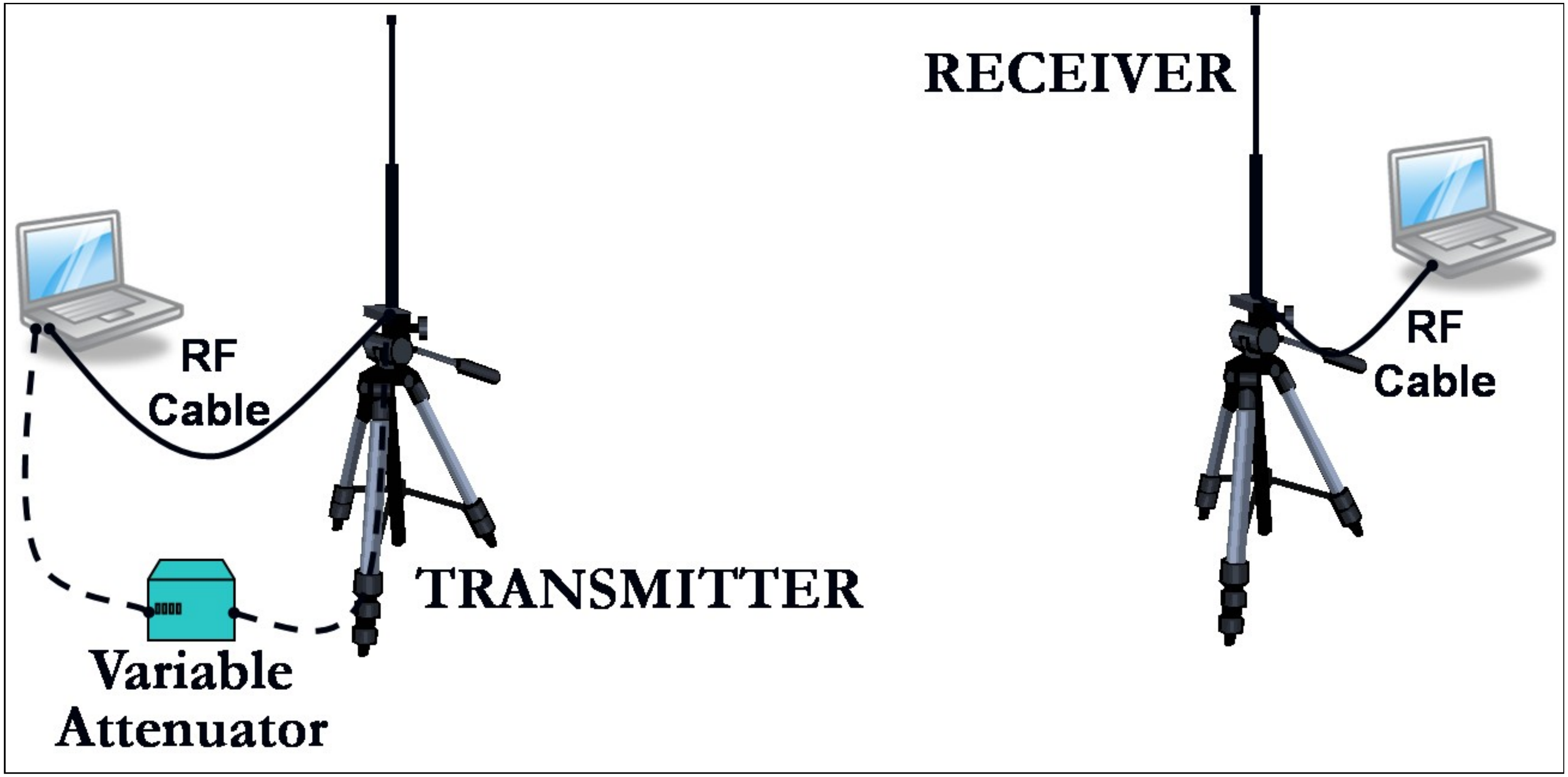
Experimental Setup
And
Methodology

Experimental Setup – WMNs

- **Hardware –**
  - Senao 2511CD Plus 802.11b PCMCIA cards
  - Laptops
  - Antennas
    - Sector Antenna (***Sector***) – 17 dBi
    - Omni Directional Antenna (***Omni***) – 8 dBi

- **Software –**
  - Linux – kernel 2.6.11
  - Modified HostAP driver – ver 0.4.9

Experimental Setup: WMNs

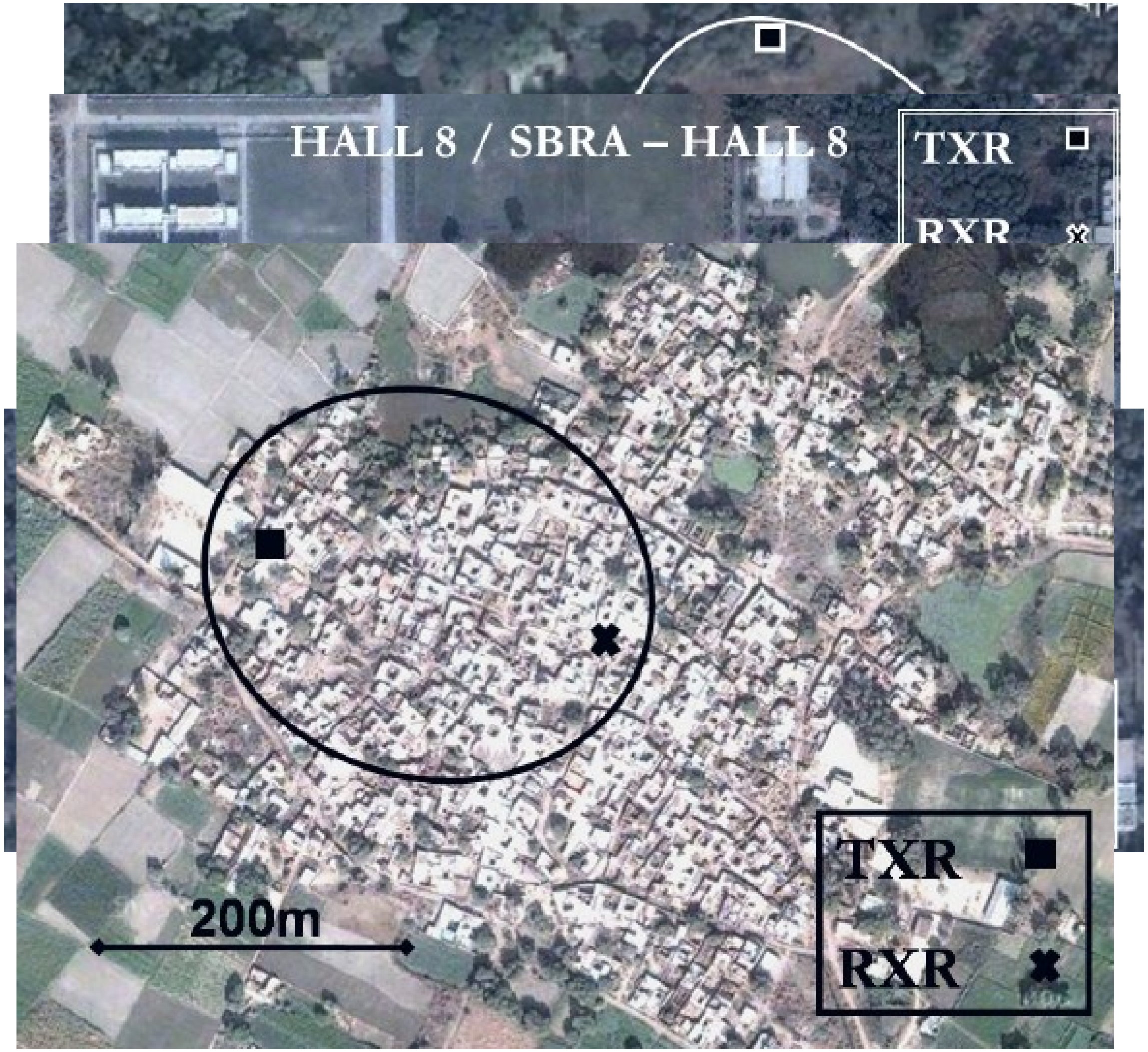


Experiment Locations: WMNs

- **Experiment Locations –**
  - On Campus – 5
  - Village – 1
- **Fixed one transmitter position**
- **Varied up to 6 receiver positions**
- **Receiver position classification –**
  - Good – Avg. RSSI ≈ -70 dBm
  - Medium – Avg. RSSI ≈ -75 dBm
  - Bad – Avg. RSSI ≈ -80 dBm
- **At each location – combination of Rx positions**

Experiment Locations: WMNs

- ACES Type II – ***Apt***
- Staff Ground – ***Gnd***
- Hall 8 – ***dorm***
- *SBRA* – ***Apt2dorm***
- Academic Area – ***corridor***
- Village Amaur – ***Vill***



Images Source : http://earth.google.com

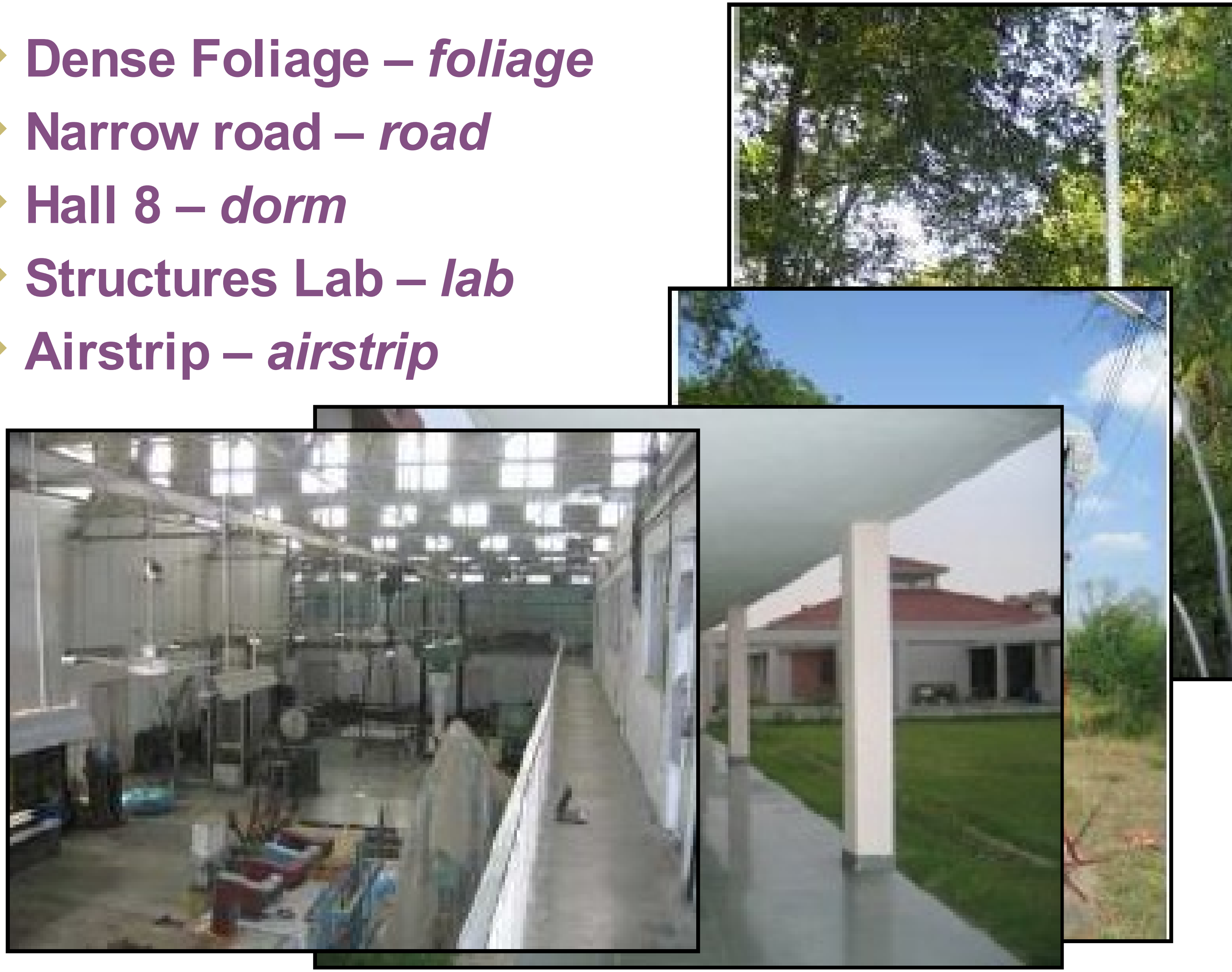
Experimental Setup – WSNs

- **Hardware –**
  - Tmote Sky motes
    - CC2420 Zigbee compliant 2.4GHz radio
  - Laptops
  - Antennas
    - Parabolic Grid Antenna (***Grid***) – 24 dBi
    - Sector Antenna (***Sector***) – 17 dBi
    - Omni Directional Antenna (***Omni***) – 8 dBi

- **Software –**
  - TinyOS – Open source OS

Experiment Locations: WSNs

- Dense Foliage – *foliage*
- Narrow road – *road*
- Hall 8 – *dorm*
- Structures Lab – *lab*
- Airstrip – *airstrip*

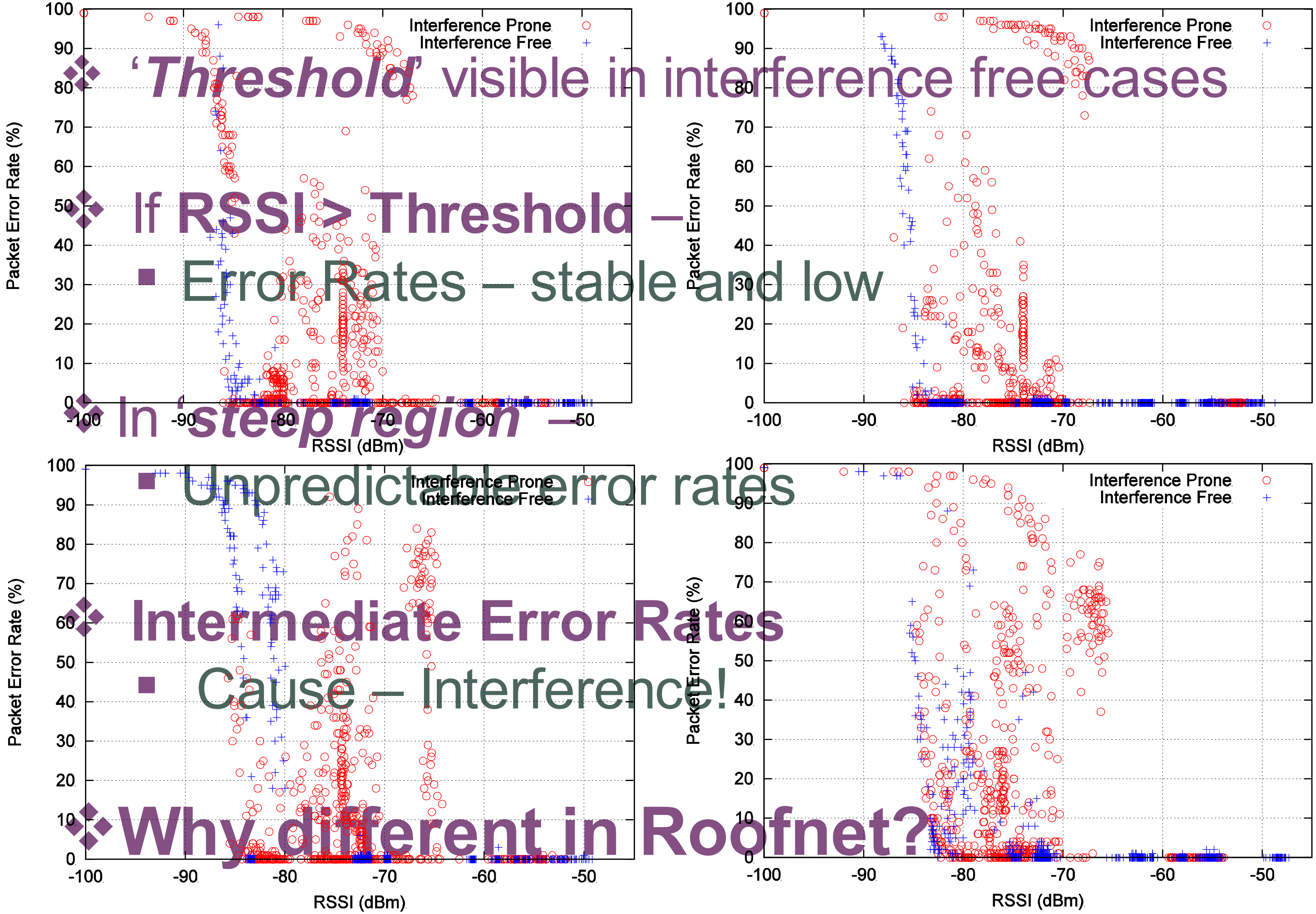


WMNs
Results and Implications

Error Rate vs RSSI

- Controlled experiment – cards + RF cable
- Experiments done at all 6 locations
- 6000 1400-byte broadcast pkts, 20ms gap between packets, 4 data rates
- Average values for 100 pkt bins
- Noise nearly constant (-94 to -95 dBm)

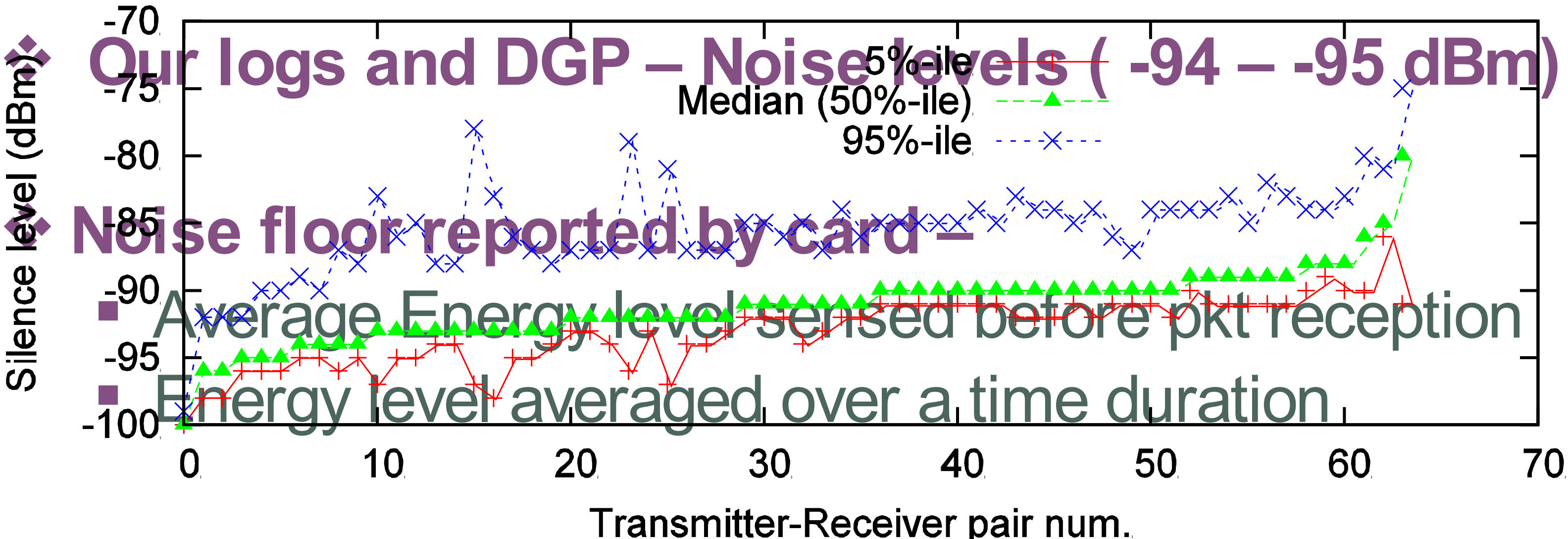
WMNs: Error Rate vs. RSSI



- ‘***Threshold***’ visible in interference free cases
- If **RSSI > Threshold** –
  - Error Rates – stable and low
- In ‘***steep region***’ –
  - Unpredictable error rates
- **Intermediate Error Rates**
  - Cause – Interference!
- **Why different in Roofnet?**

WMNs: Roofnet Data – A relook

- We observed high noise values in logs
- Our logs and DGP – Noise levels (-94 – -95 dBm)
- Noise floor reported by card –
  - Average Energy level sensed before pkt reception
  - Energy level averaged over a time duration



- In case of multipath, noise level should not be high

Noise Band ≈ 16 dB

Maximum Noise ≈ -75 dBm

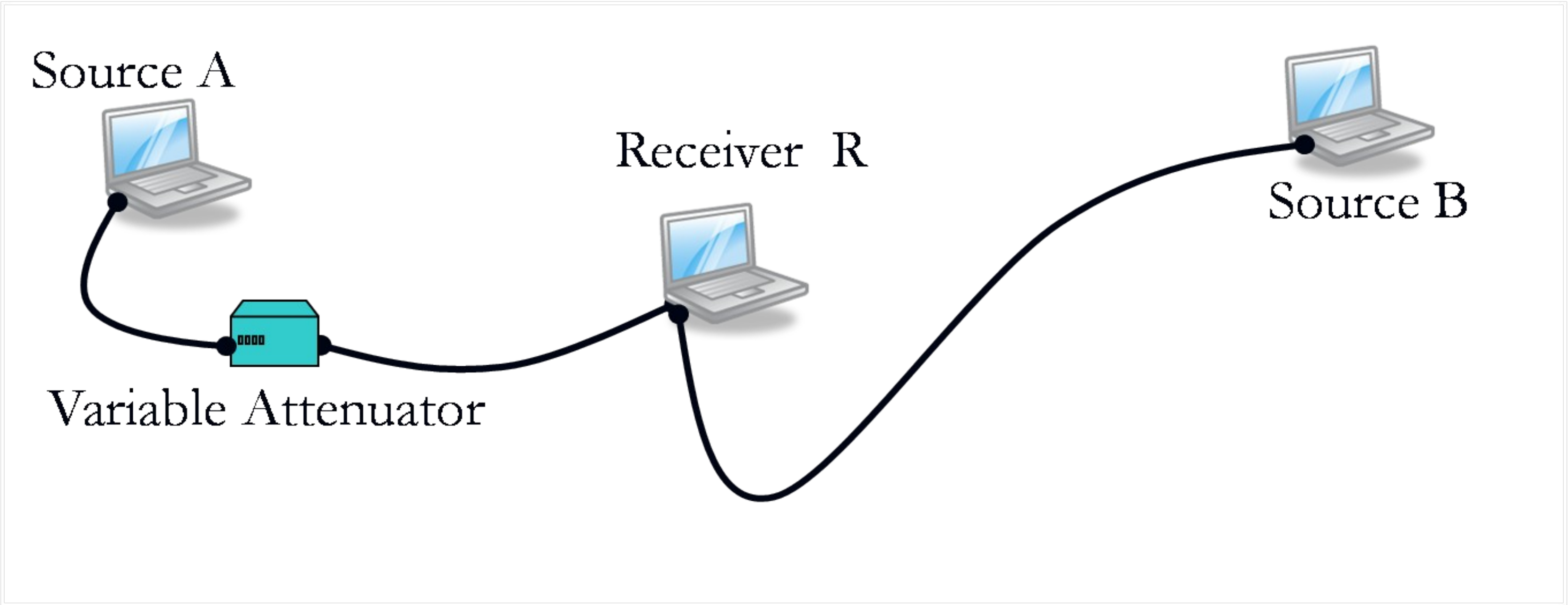
(**Note:** Data Rate: 1Mbps, Average RSSI > -80 dBm, 80%>Error Rate> 20 %)

- What is the cause of increased noise level
  - Interference ?

Max Noise Band in DGP / our expts ≈ 2 dB, Max Noise = -94 dB

Controlled Interference Experiment

- **Experimental Setup**



- **'A': 1400-byte packets, 2ms interval**
- **'*B*' : 1300-byte packets, 2ms interval**
- **'*B*' power fixed at -75 dBm**
- **'*A*' power varied: -90, -85, -80, -75 dBm**

Interference Experiment – Questions

- Does Interference increase the noise level reported by the card?
- Can packet loss be related to the number of foreign packets seen?
- Can the reported noise level be used to gauge the level of interference?
- *Can we estimate the link performance based on the ‘Average measured noise floor’?*

Interference Experiment – Answers

- Interference causes noise level to be high and variable

- Packet loss high even though number of observed foreign packets low
- Packet loss can be low even though number of observed foreign packets is high

- On this H/W, gauging level of interference is error prone

- It is not possible to estimate the link quality based on reported noise floor

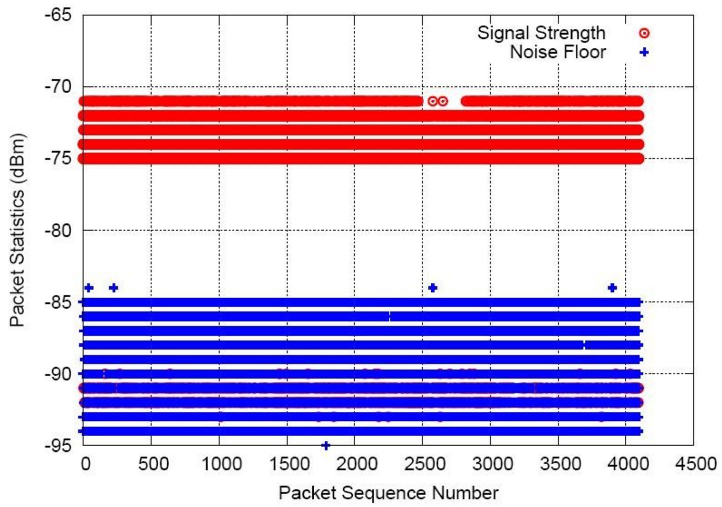
Controlled Interference Experiment

- Does Interference increase the noise level reported by the card?

Col-1 Expt No	Col-2 Src	Col-5 Mean Noise (dBm)	Col-8 Noise Band (dB)	Col-9 Max Noise (dBm)
1	A	-93.26	4	-88
1	B	-92.1	6	-88
2	A	-92.53	9	-85
2	B	-89.34	9	-84
3	A	-90.85	14	-80
3	B	-85.16	14	-80
4	A	-93.06	2	-74
4	B	-90.18	19	-74

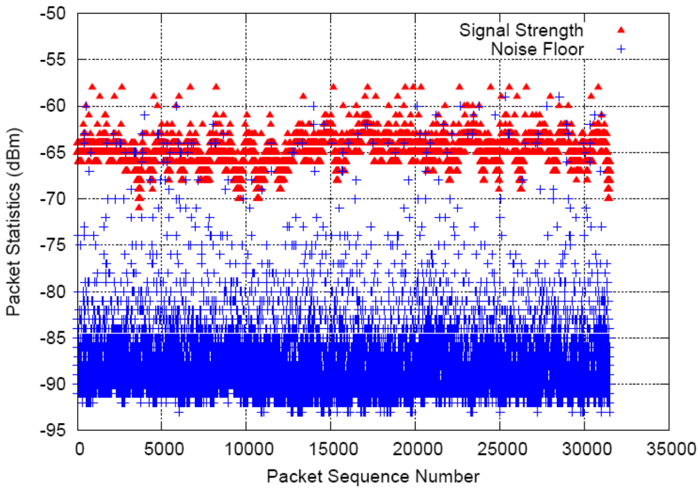
Controlled Interference Experiment

Controlled Experiment



- Avg RSSI
  - A : -85 dBm
  - B : -75 dBm

Roofnet



- Noise extends right up to -65 dBm

***P1*: Interference causes noise level to be high and variable**

Controlled Interference Experiment

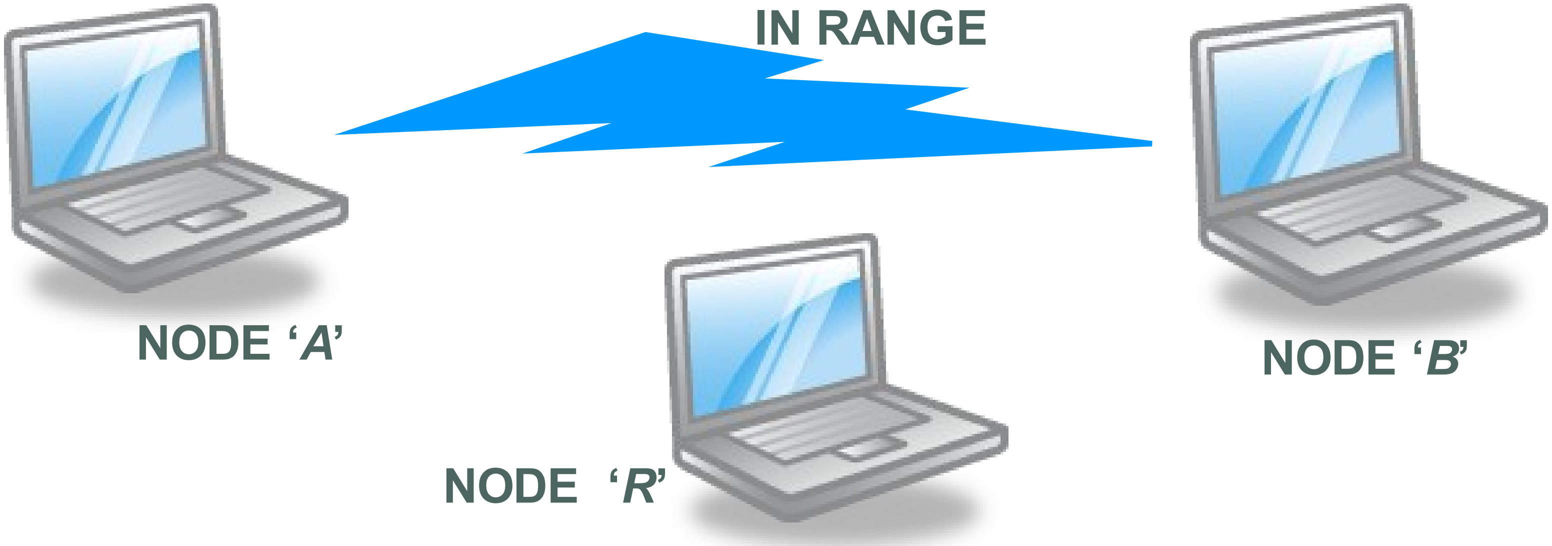
- Can packet loss be related to the level of interference seen?

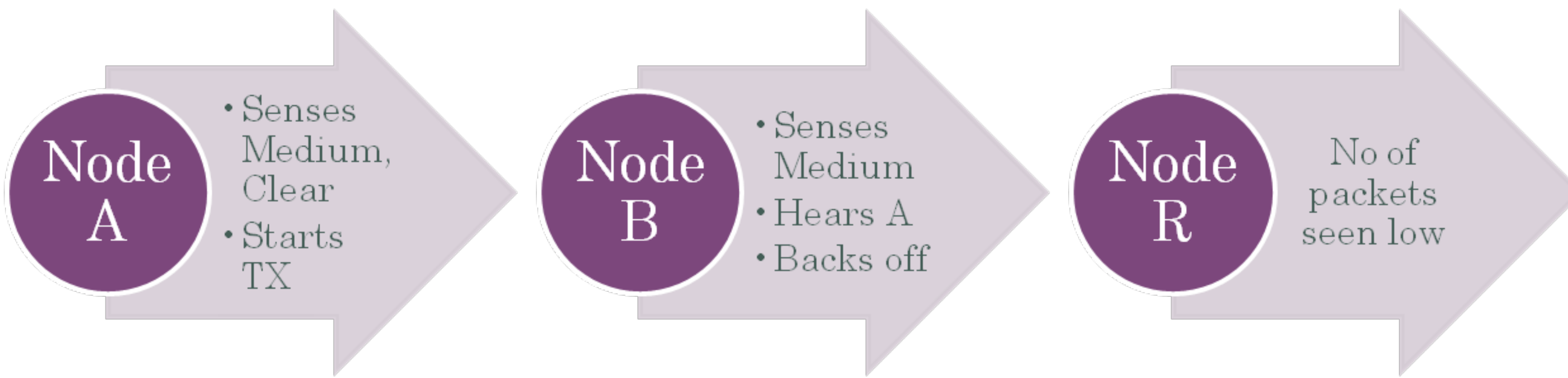
Col-1 Expt No	Col-2 Src	Col -3 Mean RSSI (dBm)	Col-4 Loss %	Col-5 Mean Noise (dBm)	Col-6 5 %-ile (dBm)	Col-7 95 %-ile (dBm)	Col-8 Noise Band (dB)	Col-9 Max Noise (dBm)
2	A	-85.23	99.2	-92.53	-94	-85	9	-85
2	B	-74.68	18.3	-89.34	-94	-85	9	-84

- B's loss = 18.3%; A's loss = 99.2%
- Even if B stops, A's loss = 99%

***P2*:** **Packet loss high even though number of observed foreign packets low**

Controlled Interference Experiment





***P3*: Packet loss can be low even though number of observed foreign packets is high**

Controlled Interference Experiment

P2

Packet loss high
Foreign Packets low

P3

Packet loss low
Foreign Packets high

Roofnet

No Correlation between loss rate & rate of foreign packet reception

Controlled Interference Experiment

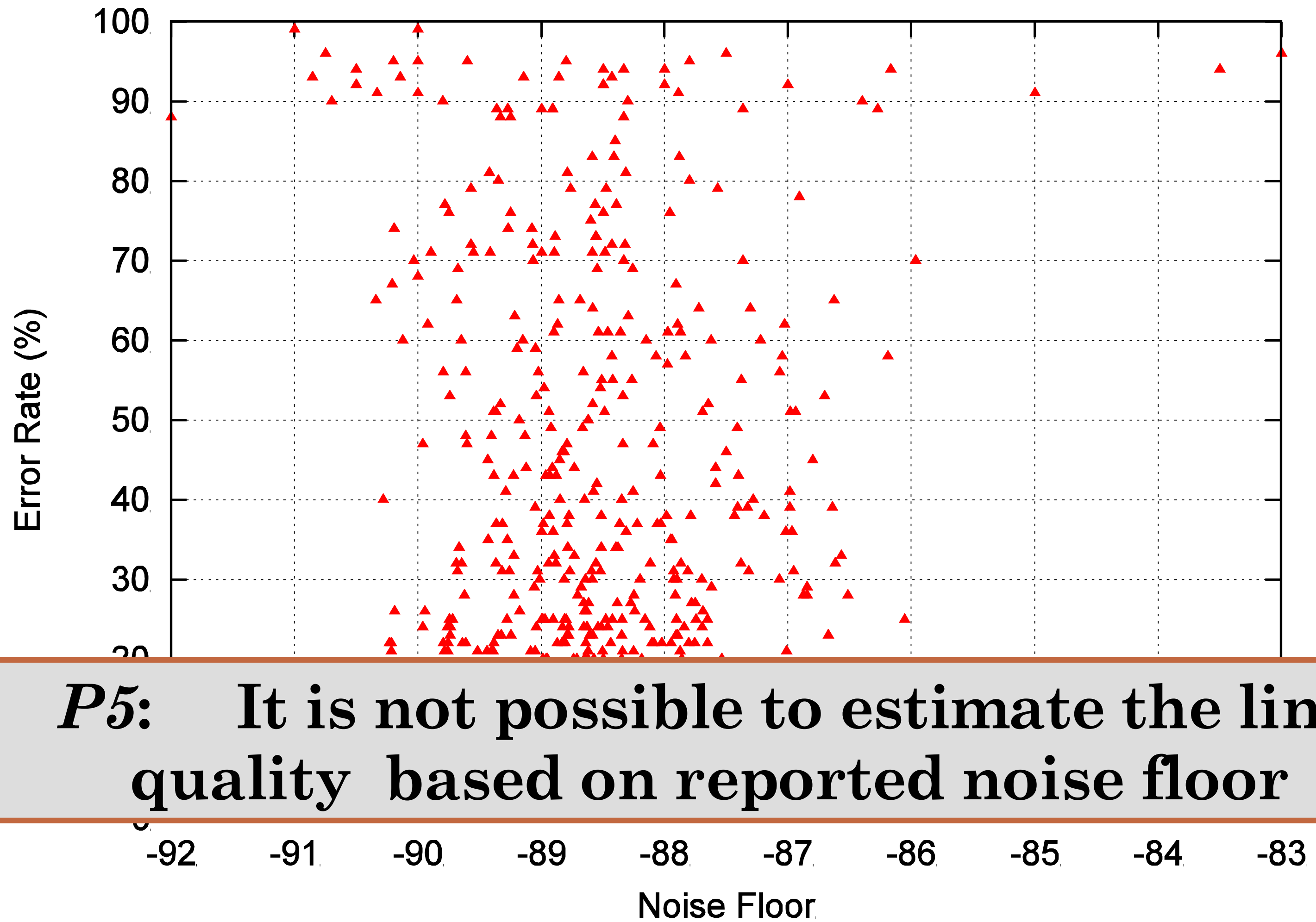
- **Can the reported noise level be used to gauge the level of interference?**
  - Instantaneous noise levels show variability
  - Noise levels reported differ from known level
  - Reason?
    - Method the card measures the noise floor
    - Timing decides reported value

Col-1 Expt No	Col-2 Src	Col-3 Mean RSSI (dBm)	Col-5 Mean Noise (dBm)	Col-6 5 %-ile (dBm)	Col-7 95 %-ile (dBm)	Col-8 Noise Band (dB)	Col-9 Max Noise (dBm)

***P4*: On this H/W, gauging level of interference is error prone**

Controlled Interference Experiment

❖ *Can we estimate the link performance based on the 'Average measured noise floor'?*

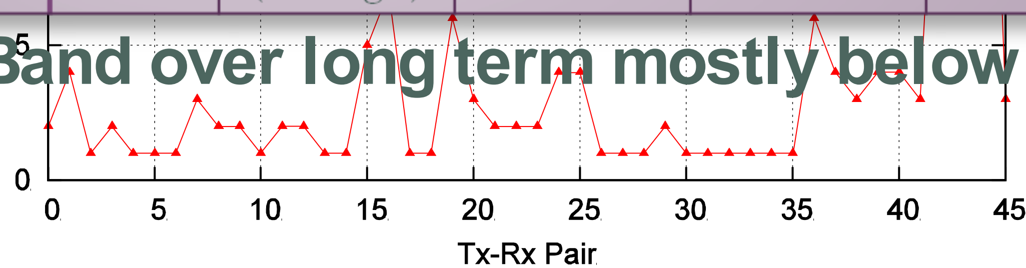


***P5*: It is not possible to estimate the link quality based on reported noise floor**

WMNs: RSSI Stability and Error Variability

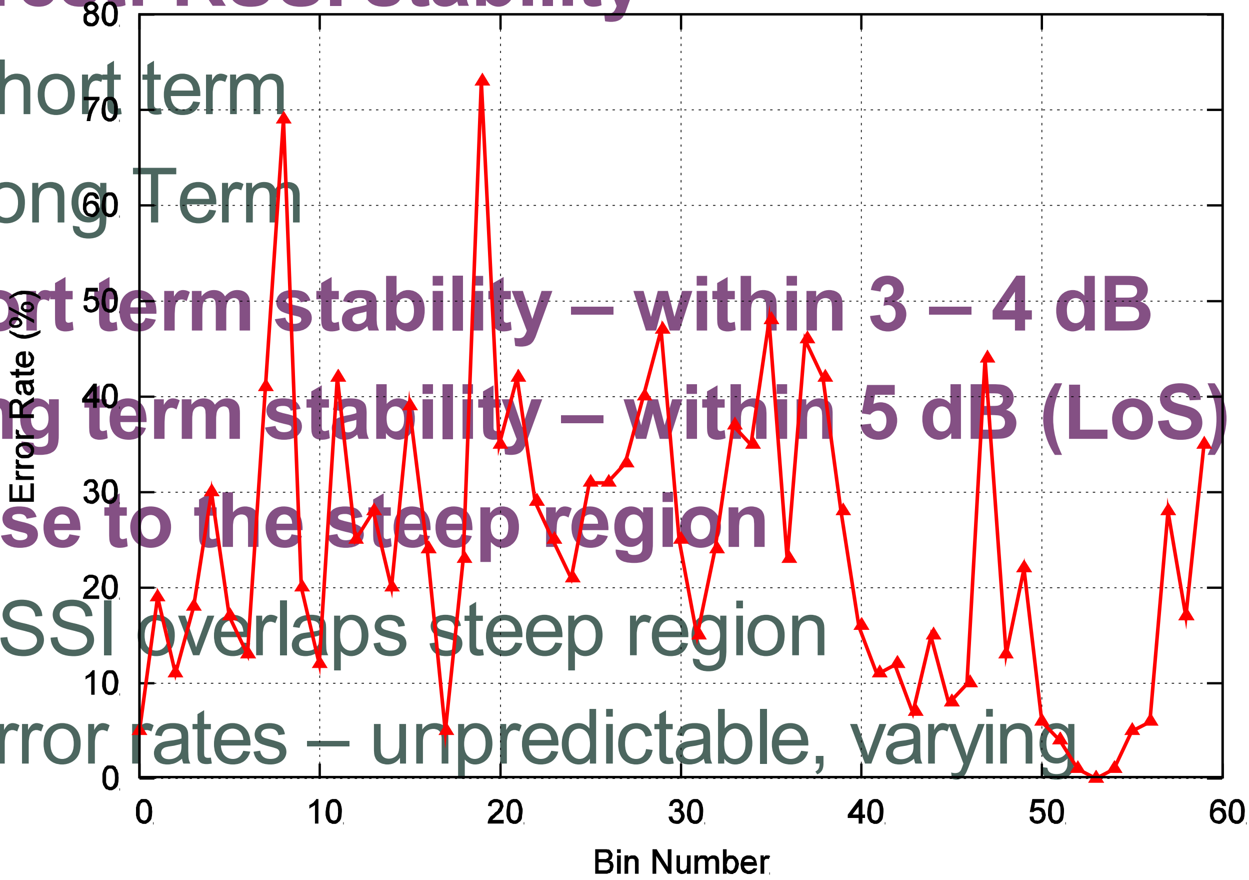
Location	Rx Posn	LoS ? (Y/N)	Dur. (hrs)	RSSI 95%-ile (dBm)	RSSI 5%-ile (dBm)	RSSI Band (dB)
Apt	1	Y	48	-66	-69	3
Apt	2	N (foliage)	48	-69	-77	8
Apt	3	N (foliage)	48	-76	-82	6
Apt2Dorm	1	Y	24	-75	-77	2
Apt2Dorm	2	Y	24	-70	-71	1
Apt2Dorm	3	N (foliage)	24	-79	-81	2

RSSI Band over long term mostly below 5 dB (LoS)



WMNs: RSSI Stability and Error Variability

- **Interest: RSSI stability**
  - Short term
  - Long Term
- **Short term stability – within 3 – 4 dB**
- **Long term stability – within 5 dB (LoS)**
- **Close to the steep region**
  - RSSI overlaps steep region
  - Error rates – unpredictable, varying



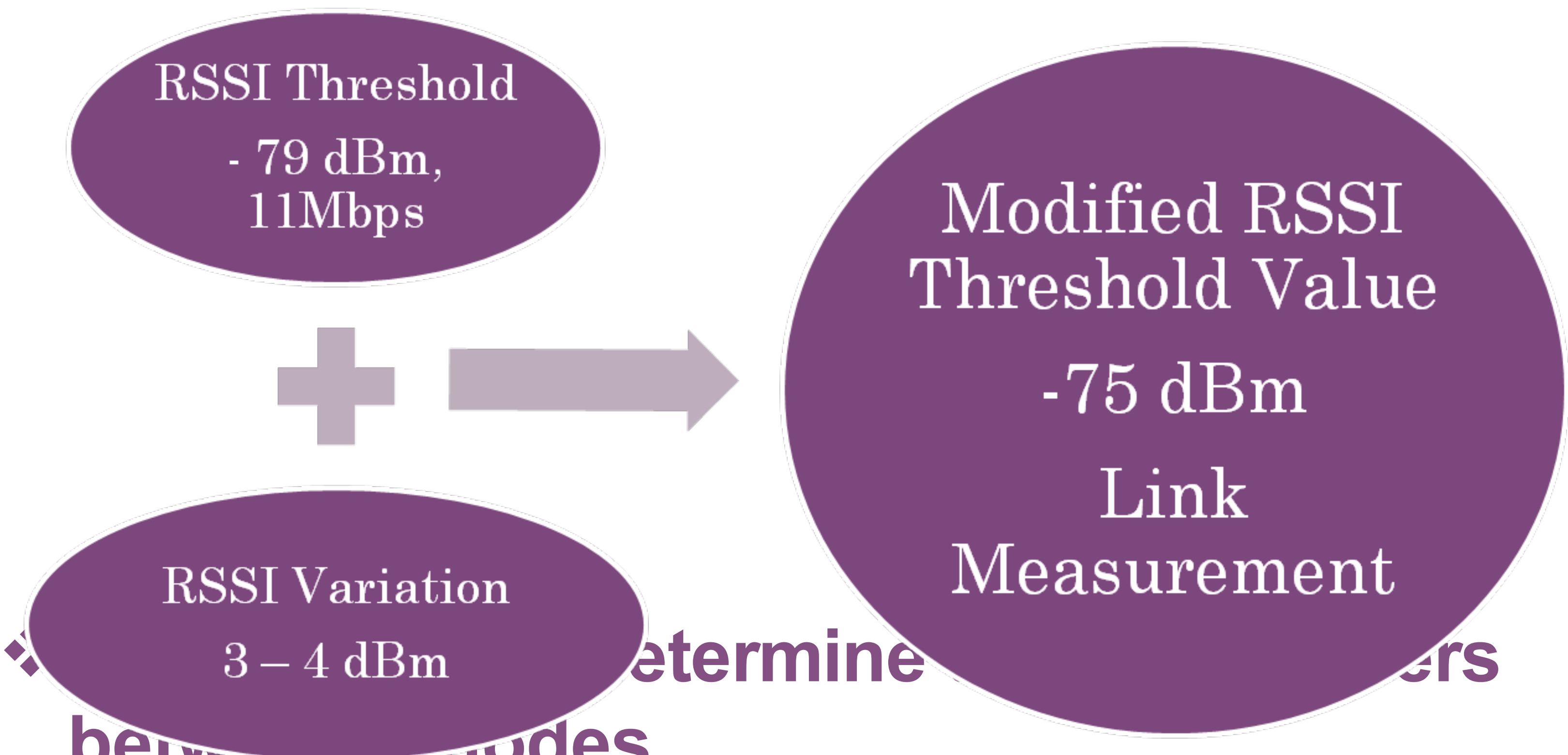
Error Rate vs Bin Number
Village, Avg RSSI = -80.5 dBm

WMNs: Summary of Results

- ***Interference****:* Major cause of *intermediate error rates* (neither close to 0% nor 100%)
- ***RSSI Threshold*** exists in absence of interference.
- Above the threshold, '***link abstraction***' holds.
- ***RSSI is stable over long and short durations***
- ***Error Rate is unpredictable and varies (close to the steep region)***
- Difficult to **gauge interference** using available hardware

Design Implications – Link Abstraction

- Allows us to plan links with predictable performance. How?

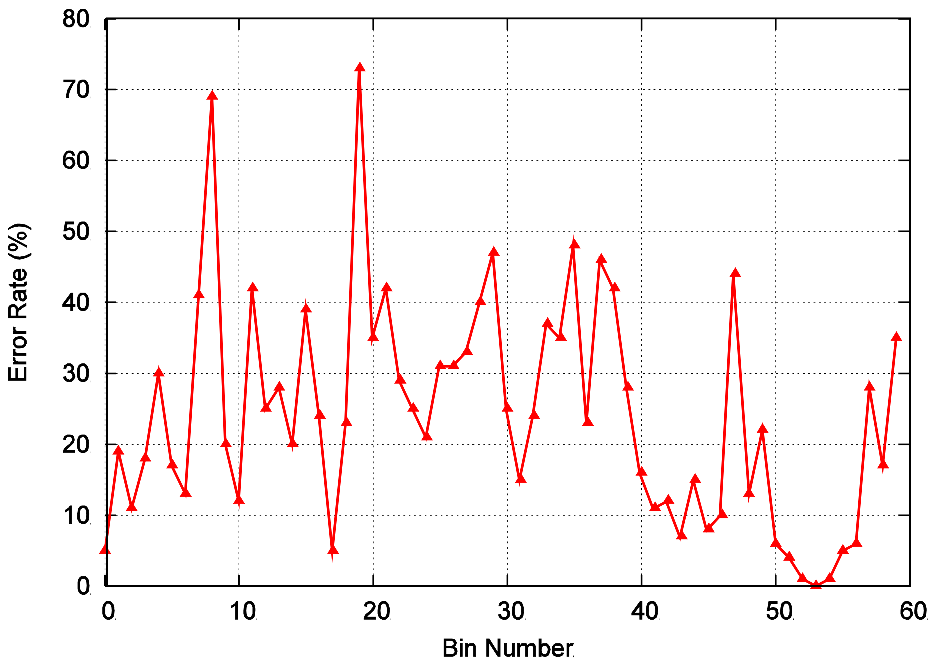


- … etermine … ers
  be… nodes

Design Implications – Routing Metrics

❖ Routing

- Proposed metrics like ETX and WCETT are unstable



Error Rate vs Bin Number
Village, Avg RSSI = -80.5dBm

Bin No	Error Rate
4	30 %
5	18 %
6	17 %
7	40 %
8	70 %

Design Implications – Routing

- **Opportunistic Routing (EXOR)**
  - Tries to work in presence of interference
  - Tries to take advantage of any abnormal link range that may be achieved
  - Source broadcasts packet
  - Based on who received packet, chooses who forwards packet on next hop
  - Difficult to achieve predictable performance

- **Better to avoid interference.**

Design Implications – Routing

- **Interference Aware Routing –**
  - Methods proposed in literature
  - Use the value of SNR to gauge level of interference

- **Our measurements using our H/W indicate that reported noise floor unreliable for:**
  - Inference of interference
  - Estimation of link quality

- **Possible with appropriate H/W ?**

Design Implications – MAC protocols

- **CSMA / CA MACs:**
  - Use CS and CA to avoid interference
  - RTS/CTS to overcome hidden node cases
  - However, not foolproof as

    Interference Range > Signal Range

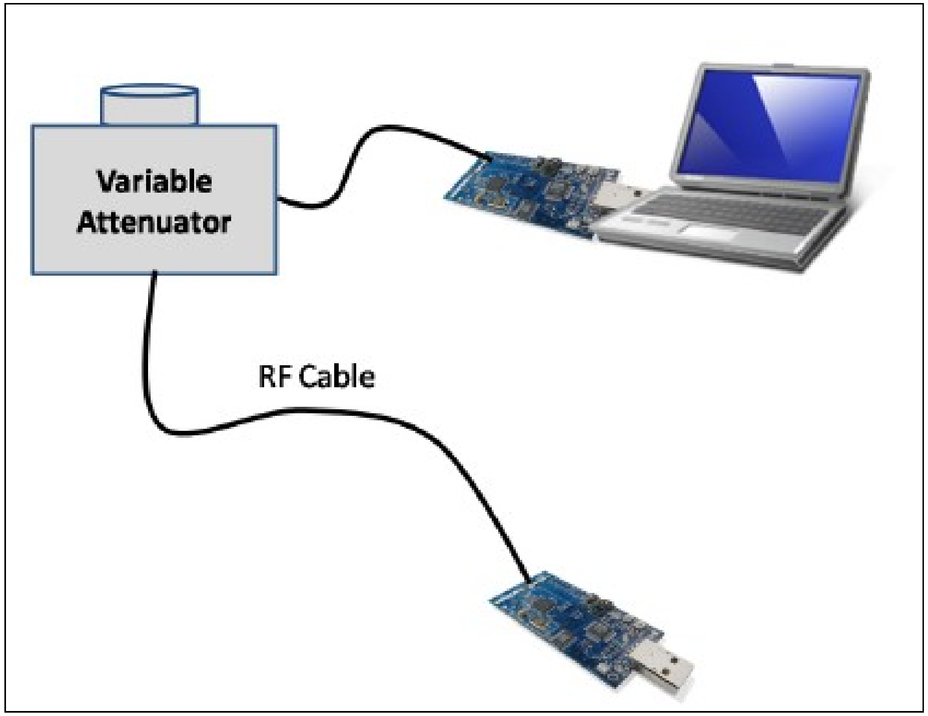
- **TDMA MAC**
  - Possible solution
  - May be suitable for FRACTEL

WSNs

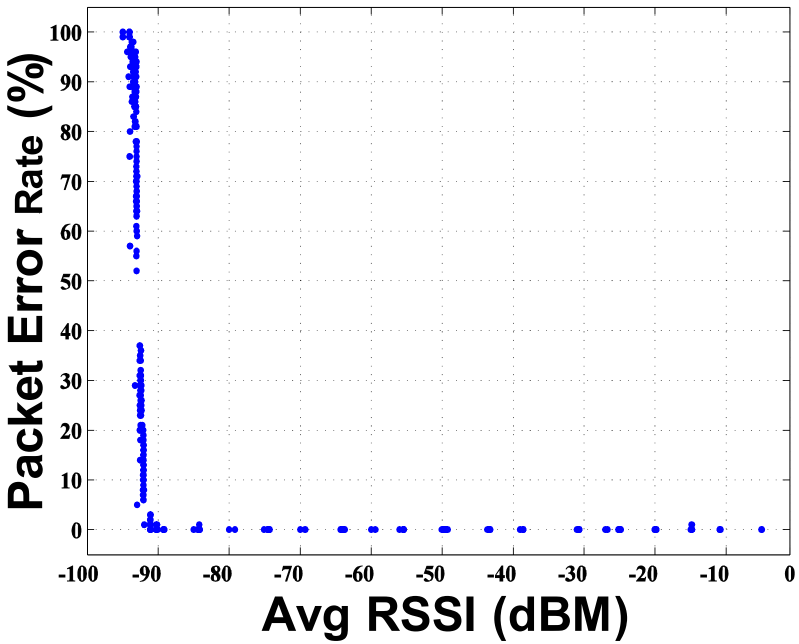
Results and Implications

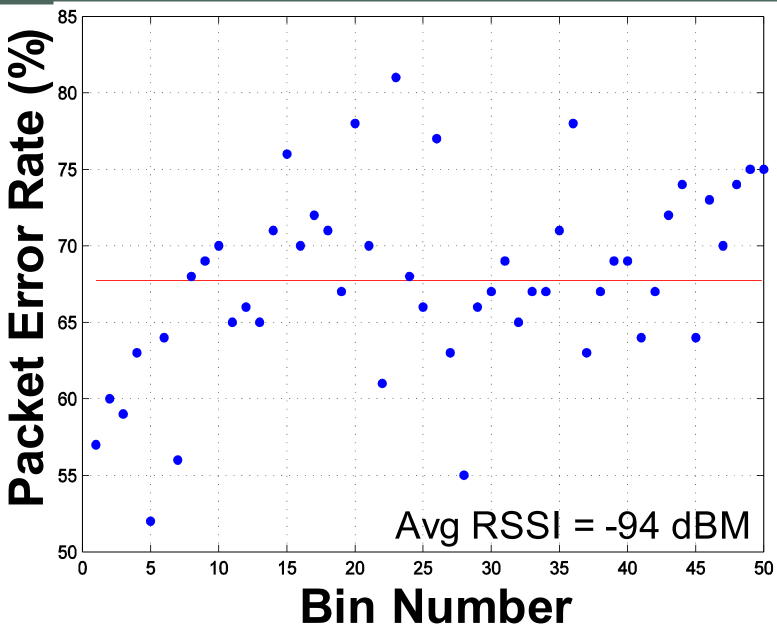
WSNs – Calibration Experiment

- 5000 packets, 20 ms interval
- *TOSBase* on mote connected to laptop
- Received packets logged on laptop



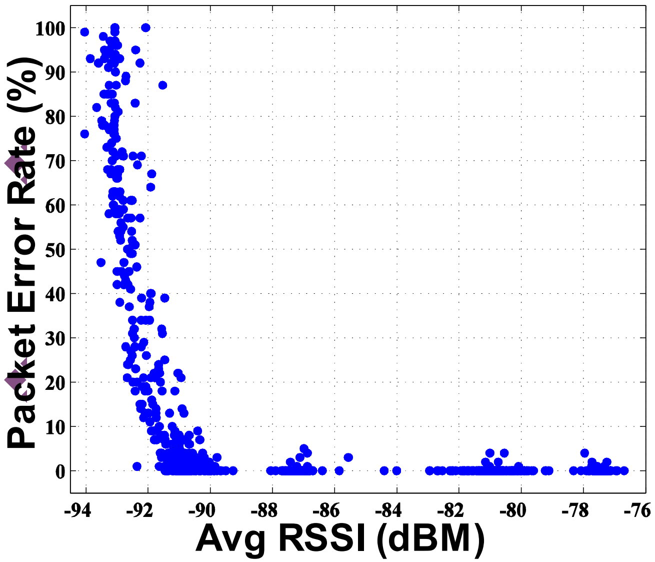
WSNs – Calibration



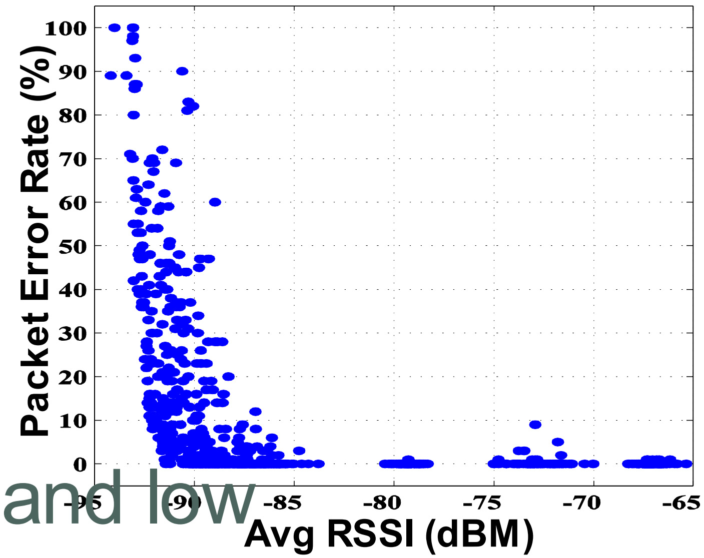


- Error rate rises sharply for small change in SNR. Gives rise to the 'steep region'
- Link abstraction holds
- Error Rate varies in the steep region
- Variability – Operation close to sensitivity of radio

Real Life Experiments: Error Rate vs RSSI

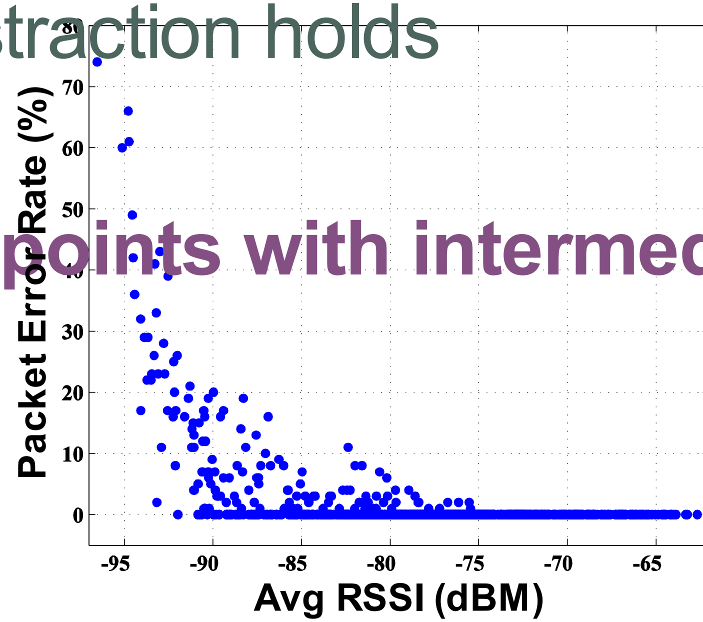


AIRSTRIP



ROAD

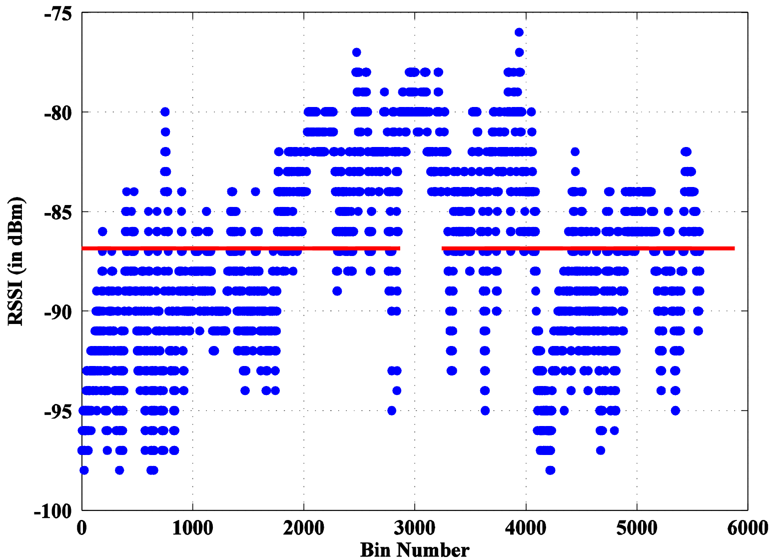
- xists
- –
- table and low
  - Link Abstraction holds



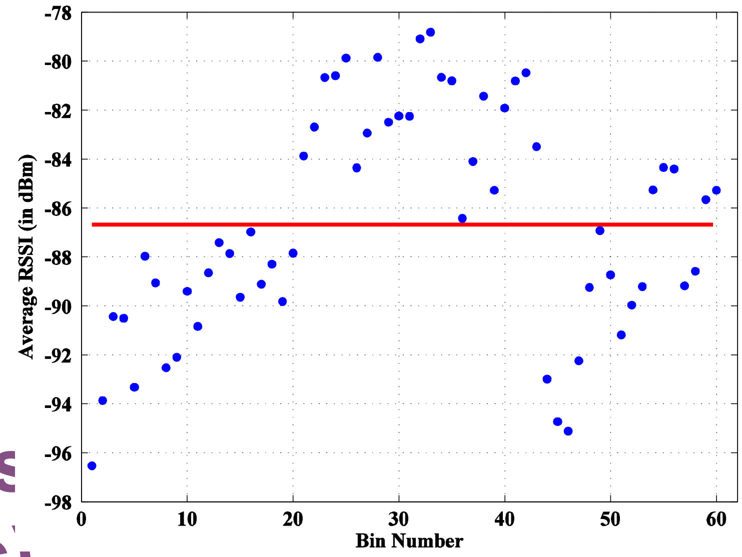
FOLIAGE

- Spread of points with intermediate error rate increases

Temporal Variability – RSSI



Foliage, 20 ms, Bin Size=1



Foliage, 2 sec, Bin Size=100

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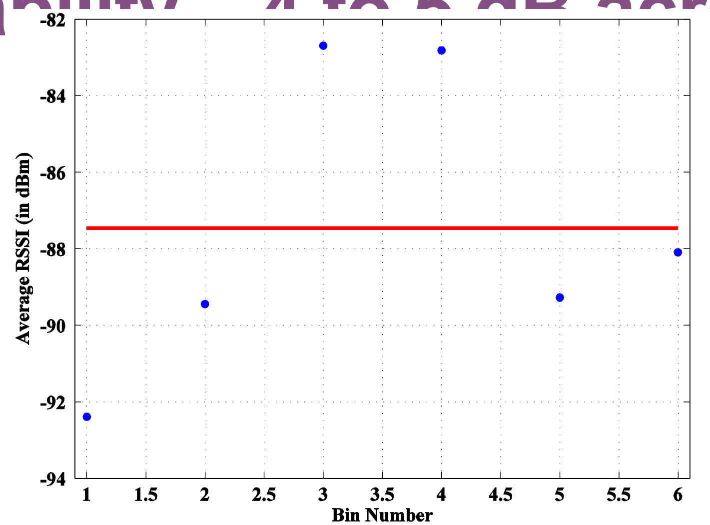
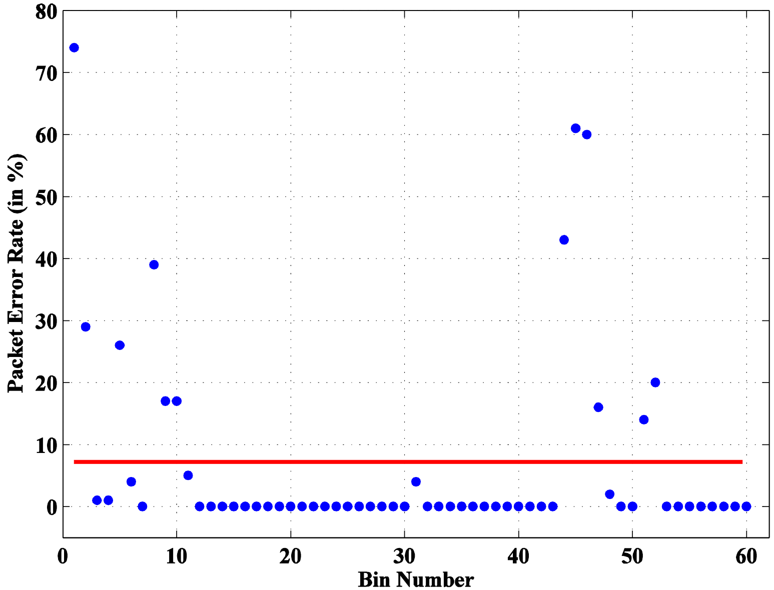
...long durations (20 sec)

❖ RSSI varia... across days

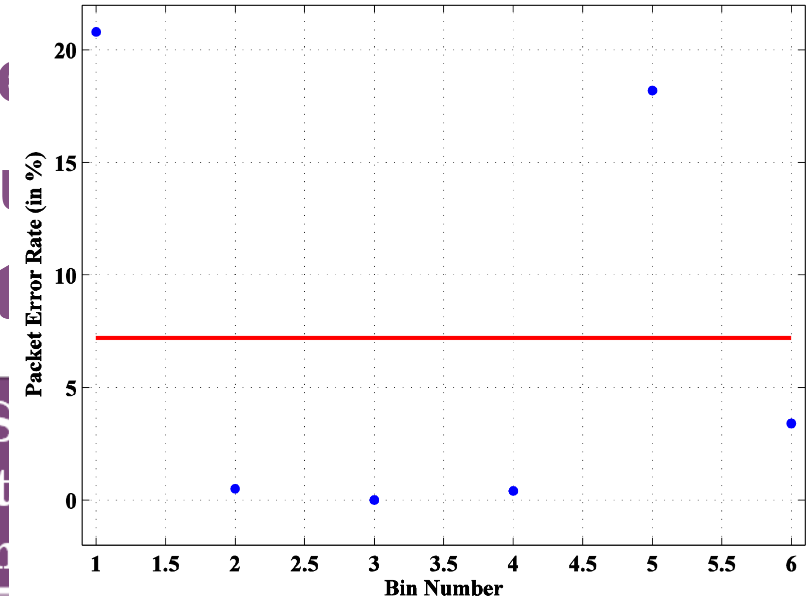


Foliage, 20 sec, Bin Size=1000

Temporal Variability – Error Rate

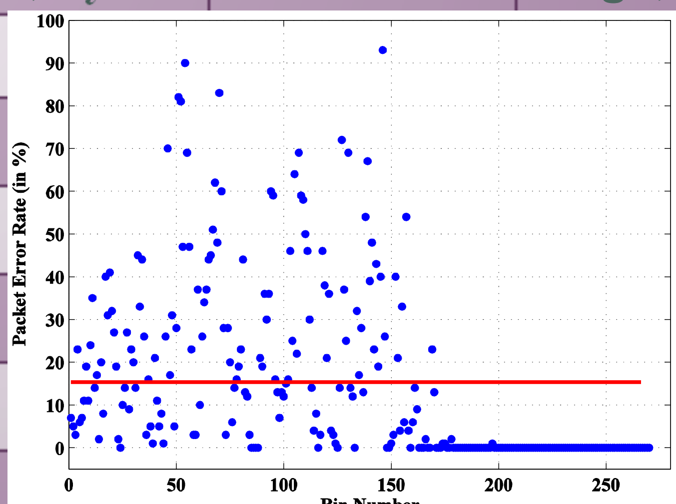


Foliage, BinSz=100, -87dBm



Foliage, BinSz=1000, -87 dBm

Foliage-40m			70	11
Corridor-60m			68	3
Corridor-60m			70	6
Corridor-60m			67	9
Lab Loc. 2			74	4
Lab Loc 2			73	7

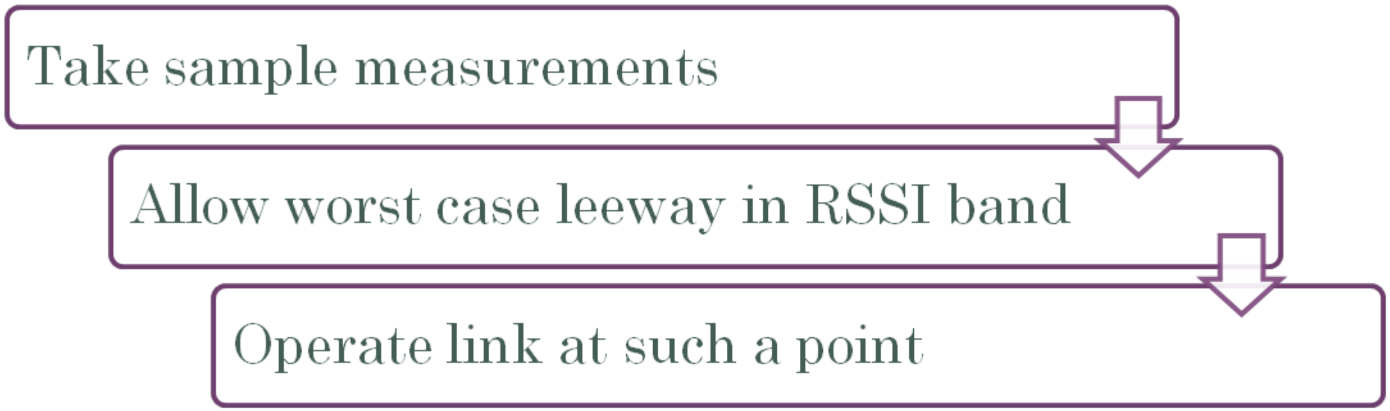


Road, Omni, BinSz=100, -89dBm

WSNs: Implications

- RSSI Threshold exists

- Planning Links – to build predictable links



- Classify links in an existing network

- Effect of variation (Time Scale)
  - Small – Routing metrics
  - Large – Old measurements invalid

Conclusion

CONCLUSION – Summary

- **In the absence of interference**
  - If RSSI > Threshold
    - Error rates are stable and low
    - ‘Link abstraction’ is feasible

- **Interference destroys correlation between error rate and RSSI / SNR**

- **Close to steep region error rate becomes variable and unpredictable**

Conclusion – Summary

- **Link Abstraction simplifies:**
  - Routing
  - Allows planning predictable links
  - Classifying existing links for predictable ops.
  - Helps achieve better and predictable network performance
  - ‘*BriMon*’ uses the concept of link abstraction.

Future Work

- Specific experiments to rule out multipath
- Experiments in the 5 GHz band
  - De-licensed in India in Jan 07
- Achieve finer time synchronisation and over multiple hops
- Effect of Interference on WSN links

Motivation and Related Work

- **Measurement studies shows ‘*absence of link abstraction*’**

- **Implications of absence -**
  - Intermediate error rates on a link
  - State of link needs to be tracked. Why?
  - Complex routing metrics required. Especially in multi-hop.

WSNs: Link Range Measurements

- **Predictable Operation → Lower Ranges**
- **Number of ways to Increase Range**
  - Increase Transmit Power
  - Use Multiple Hops
  - Use External Antennas
- **Link Range Experiments:**
  - Environments – Foliage, Road
  - Antenna Combinations (Tx – Rx)
    - Internal – Internal
    - Omni – Internal
    - Sector – Omni
    - Grid – Omni

WSNs: Link Range Measurements

Environment	Location – Distance	Avg Pkt Error (Std Dev) (%)	Avg RSSI (Std Dev) (dBm)
Foliage	Internal – 35m	0.3 (1.25)	-78.79 (3.43)
	Sector – 30m	0.53 (2.6)	-80.77 (3.55)
	Grid – 70m	1.6 (4.08)	-85.05 (4.19)
Road	Omni – 75m	0 (0)	-80.64 (2.47)
	Sector – 210m	0 (0)	-81.92 (0.49)
Airstrip	Grid – 500m	0 (0)	-85.67 (0.94)

- Substantial increase in range achieved

Implications

- **In WSNs, use of external antennas –**
  - Provides substantial increase in communication range
  - Allows predictable performance
  - Simplifies network architecture
  - Simplifies routing
  - Can help to increase network lifetime by reducing message overhead

Diagram

All Locations

5 locations

Interference Prone

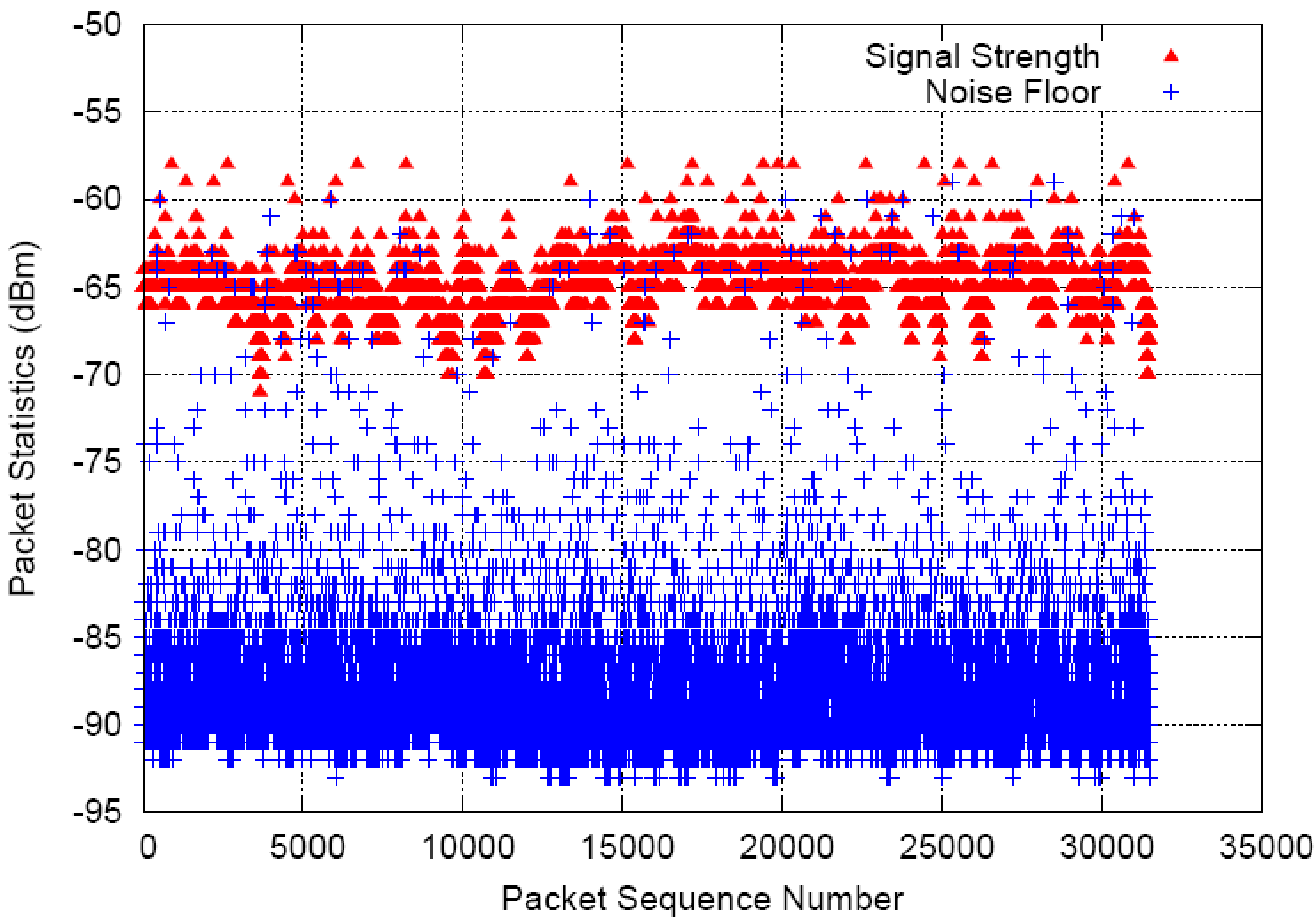
- No Correlation between SNR and Error Rate

Interference Free

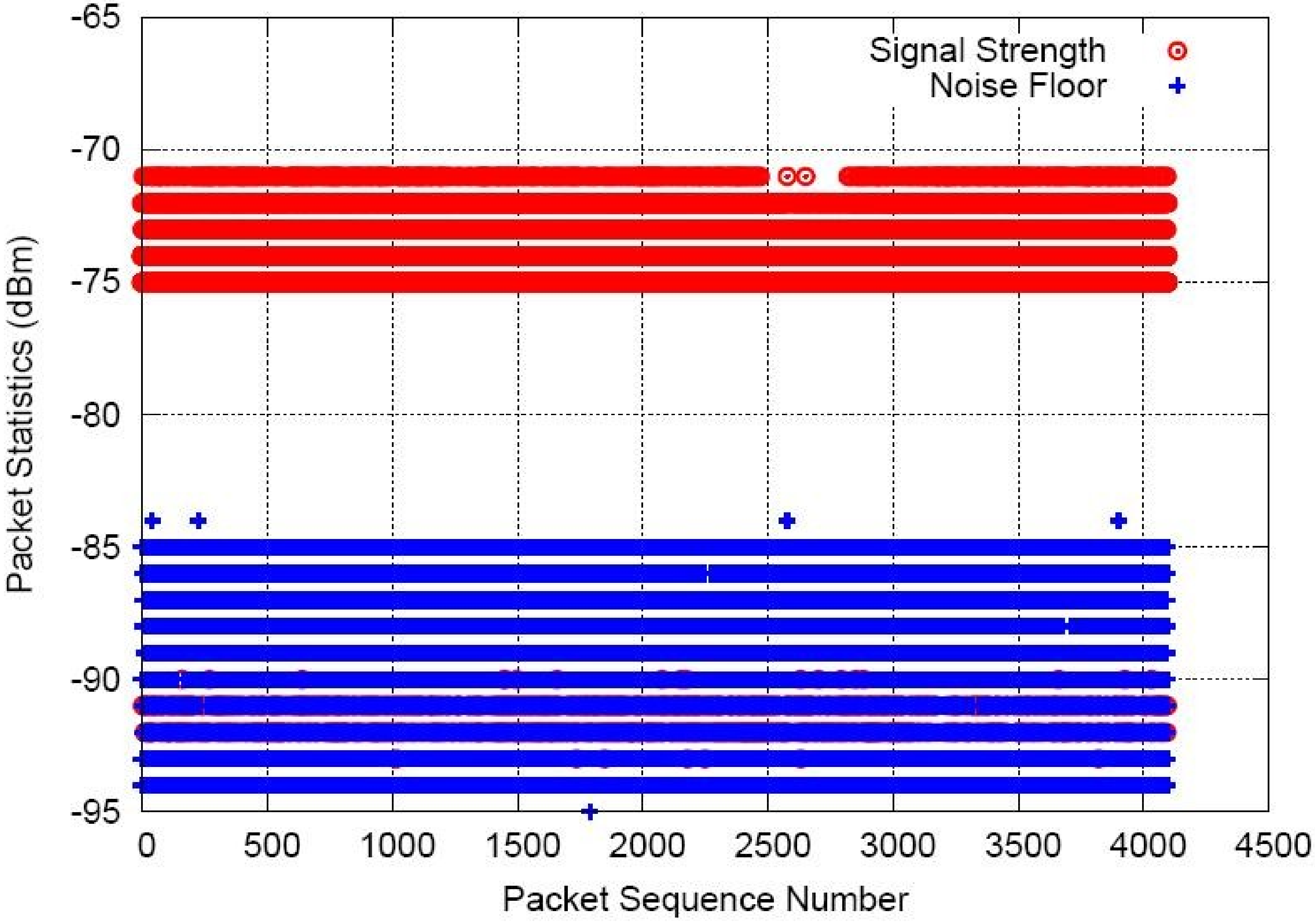
- Threshold exists
- Error rates low and stable
- Close to steep region -- Error rates varying and stable

Col-1	Col-2	Col -3	Col-4	Col-5	Col-6	Col-7	Col-8	Col-9
Expt No	Src	Mean RSSI (dBm)	Loss %	Mean Noise (dBm)	5 %-ile (dBm)	95 %-ile (dBm)	Noise Band (dB)	Max Noise (dBm)
1	A	-89.74	100	-93.26	-94	-90	4	-88
1	B	-75.59	0.5	-92.1	-94	-88	6	-88
2	A	-85.23	99.2	-92.53	-94	-85	9	-85
2	B	-74.68	18.3	-89.34	-94	-85	9	-84
3	A	-80.69	63.2	-90.85	-94	-80	14	-80
3	B	-75.73	37.2	-85.16	-94	-80	14	-80
4	A	-75.25	39.8	-93.06	-94	-92	2	-74
4	B	-75.11	61.3	-90.18	-94	-75	19	-74

roofnet



Signal Strength
Noise Floor
Packet Statistics (dBm)
Packet Sequence Number
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
0
5000
10000
15000
20000
25000
30000
35000


Signal Strength
Noise Floor
Packet Statistics (dBm)
-65
-70
-75
-80
-85
-90
-95
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Packet Sequence Number