

Implications of Link Range and (In)Stability on Sensor Network Architecture

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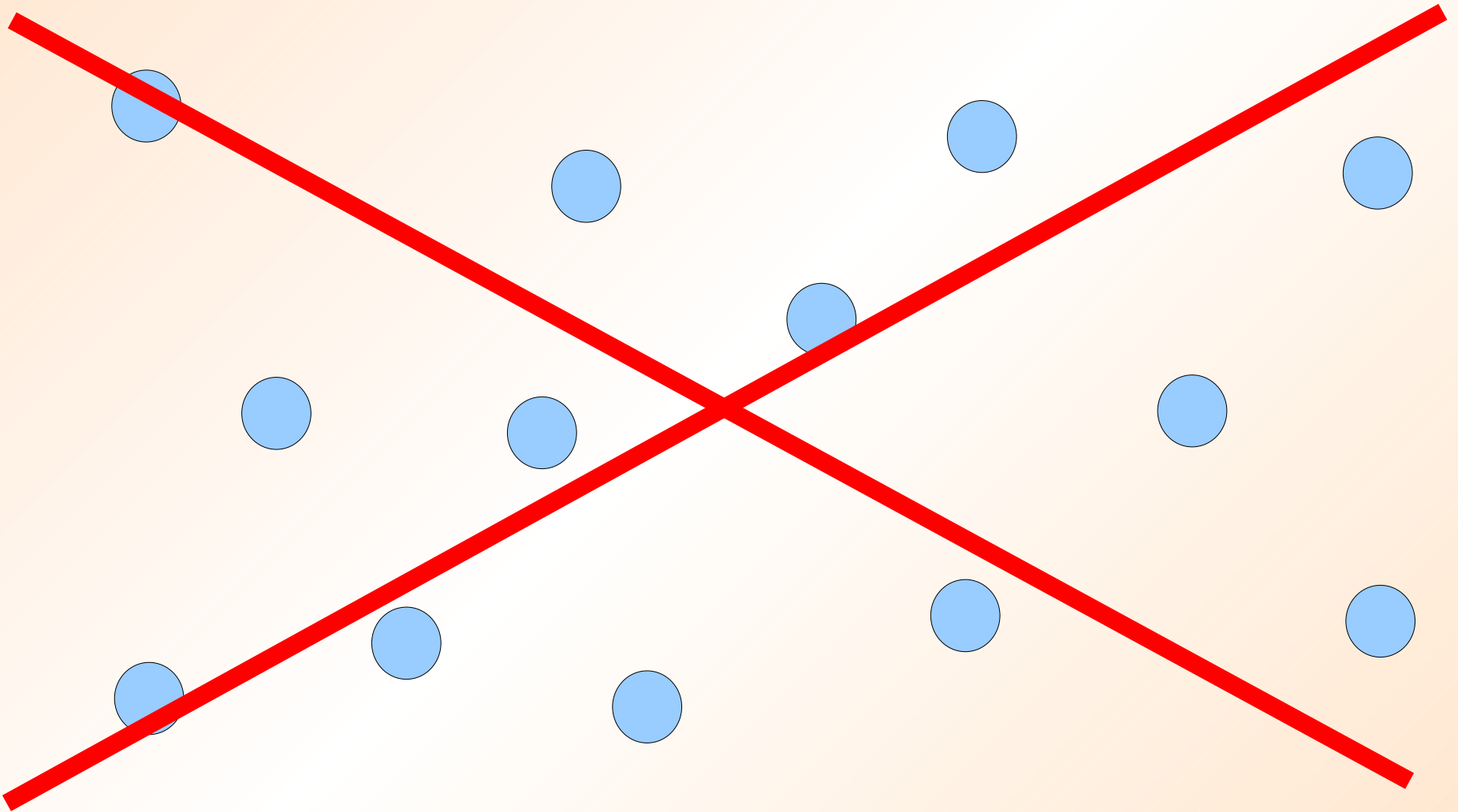
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Motivation: Wireless Sensor Network



Bottom-Up Approach: Start with Examples

- Wireless Sensor Networks for scientific monitoring applications
- Some examples:
 - **Habitat** monitoring in Great Duck Island
 - **Redwood** micro-climate study
 - **Volcano** monitoring
 - **Industrial** monitoring (motor vibrations)
 - **SenSlide**: landslide detection
 - **BriMon**: Railway bridge monitoring (IITK)

First things First

- What should be the network architecture?
 - What is the radio **communication range**?
 - Expected number of hops from/to *base* node
 - Does dynamic distributed **routing** make sense?
 - If so, at what time scale? If not, what else?
- ~~Sensor networks: randomly deployed (thrown), self-configuring, distributed system~~

Goals of the Study

- Study communication range, with the use of external antennas
- Temporal stability of error rate, RSSI, LQI
- Implications on sensor network architecture
 - Answers to questions raised earlier

Outline

- Motivation, goals of the study
- External antenna communication range study
- Link stability measurements
- Implications
- Conclusion
- Questions

External Antennas: Preliminaries

- **Cost:** \$50-\$120
- **Form factor:** < 1m, < 5kg
- Should not be an issue at least in the base
 - In some apps.: extnl. antenna ok in other nodes too
- We focus on 2.4GHz operation only (CC2420)
- Note: **link symmetry** is *not* affected by antenna type

Experimental Setup: Hardware

- Tmote sky with CC2420 (802.15.4 compliant)
- Internal antenna: 3.1dBi gain
- External connector: SMA
 - *Grid (24dBi, 8°), sector (17dBi, 90°), omni (8dBi)*
- Several antenna combinations

Experimental Setup: Software

- **Transmitter:**
 - 24 byte packet broadcast every 20ms
 - Sequence number
 - Configurable number of packets: few thousand
 - Transmit power: 0dBm (max. possible)
- **Receiver:**
 - TOSBase, connected to laptop
 - Collect RSSI, LQI values

Experimental Setup: Environment



Dense foliage



Narrow road

Range in Dense Foliage

- Receiver: on tripod (1.5m)
 - Internal only
- Transmitter: 1.5m
- 6000 packets
 - 60 bins x 100 pkts
- Computer error rate over 100 packet bins

Tx Antenna-Dist.	Avg. Pkt. Error % (Std. Dev)	Avg. RSSI (dBm) (Std. Dev)
Internal-20m	0.03 (0.26)	-74.98 (2.37)
Internal-25m	0.15 (0.63)	-74.41 (3.64)
Internal-30m	0.08 (0.53)	-79.44 (2.35)
Internal-35m	0.3 (1.25)	-78.79 (3.43)
Omni-20m	0.2 (1.1)	-72.97 (3.43)
Omni-30m	0.18 (0.81)	-76.75 (3.94)
Omni-40m	0 (0)	-79.42 (2.35)
Omni-50m	7.22 (16.5)	-86.68 (4.57)
Sector-30m	0.03 (0.26)	-67.76 (3.15)
Sector-40m	0.07 (0.52)	-69.33 (2.92)
Sector-50m	2.27 (4.55)	-82.76 (3.7)
Sector-60m	0.53 (2.6)	-80.77 (3.55)
Sector-70m	13.01 (14.37)	-90.01 (3.91)
Grid-70m	1.5 (3.61)	-79.79 (5.03)
Grid-80m	0.28 (0.99)	-77.07 (3.11)
Grid-90m	1.6 (4.08)	-85.05 (4.19)

Range in Narrow Road (1 of 2)

- Transmitter at 3.8m for sector/grid antennas

Tx Antenna-Dist.	Avg. Pkt. Error (%) (Std. Dev)	Avg. RSSI (dBm) (Std. Dev)
Internal antenna at receiver		
Internal-60m	0.18 (1.03)	-81.11 (2.97)
Internal-75m	1.37 (4.34)	-83.74 (3.61)
Omni-60m	0 (0)	-77.45 (2.17)
Omni-75m	0 (0)	-80.64 (2.47)
Omni-90m	35.92 (33.42)	-94.91 (1.6)
Sector-210m	0 (0)	-81.92 (0.49)
Sector-310m	1.02 (4.3)	-91.85 (0.81)
Sector-400m	0.62 (2.24)	-92.33 (1.03)
Sector-500m	0 (0)	-90.12 (0.5)
Grid-90m	0 (0)	-75.35 (1.36)
Grid-210m	0.03 (0.18)	-75.82 (2.37)
Grid-300m	0 (0)	-80.42 (1)
Grid-400m	0 (0)	-82.21 (0.9)
Grid-500m	0 (0)	-85.67 (0.94)

Range in Narrow Road (2 of 2)

- Beyond 500m, expts. in nearby air-strip
- We verified symmetry in some cases

Tx Antenna-Dist.	Avg. Pkt. Error (%) (Std. Dev)	Avg. RSSI (dBm) (Std. Dev)
Omni antenna at receiver		
Omni-90m	0.04 (0.33)	-80.92 (0.88)
Omni-150m	7.63 (12.46)	-90.86 (0.64)
Sector-500m	0.13 (0.68)	-82.16 (0.37)
Sector-600m	0.07 (0.25)	-89.48 (0.35)
Sector-700m	0.5 (1.05)	-91.22 (0.34)
Sector-800m	3.42 (4.83)	-91.58 (0.41)
Grid-500m	0.12 (0.49)	-75.25 (0.07)
Grid-600m	0.07 (0.25)	-79.85 (0.24)
Grid-700m	0.15 (0.61)	-82.07 (0.2)
Grid-800m	0.13 (.39)	-85.76 (0.31)

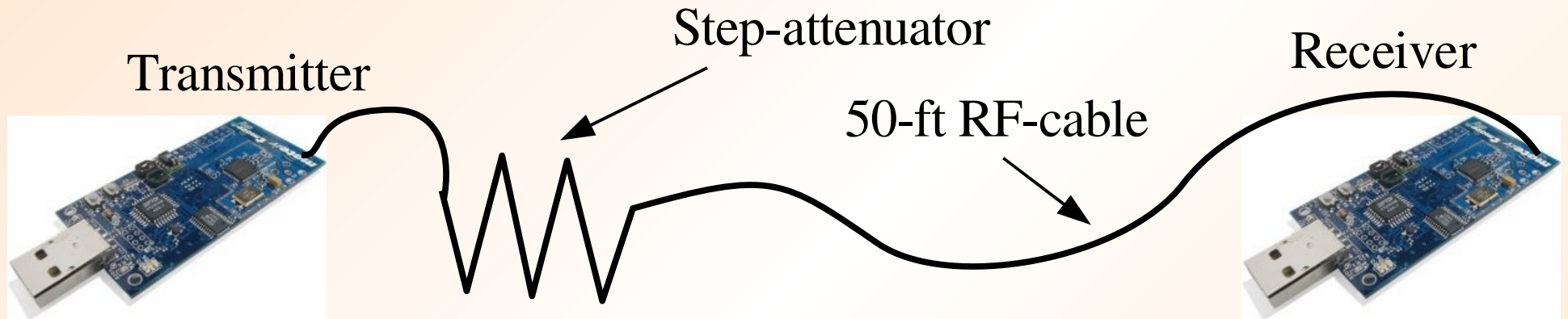
Implications of Link Range

- More one-hop nodes, lesser # hops ==> better network lifetime
- Foliage: range of about 90m
 - Useful for applications such as the redwood study
 - Can have just a **single-hop** network!
- Volcano monitoring: 200-400m range reported
- Range of about 800m with grid antenna
 - Useful in situations like Volcano monitoring, BriMon
- Sector antenna range:
 - Implications for Habitat study, SenSlide

Outline

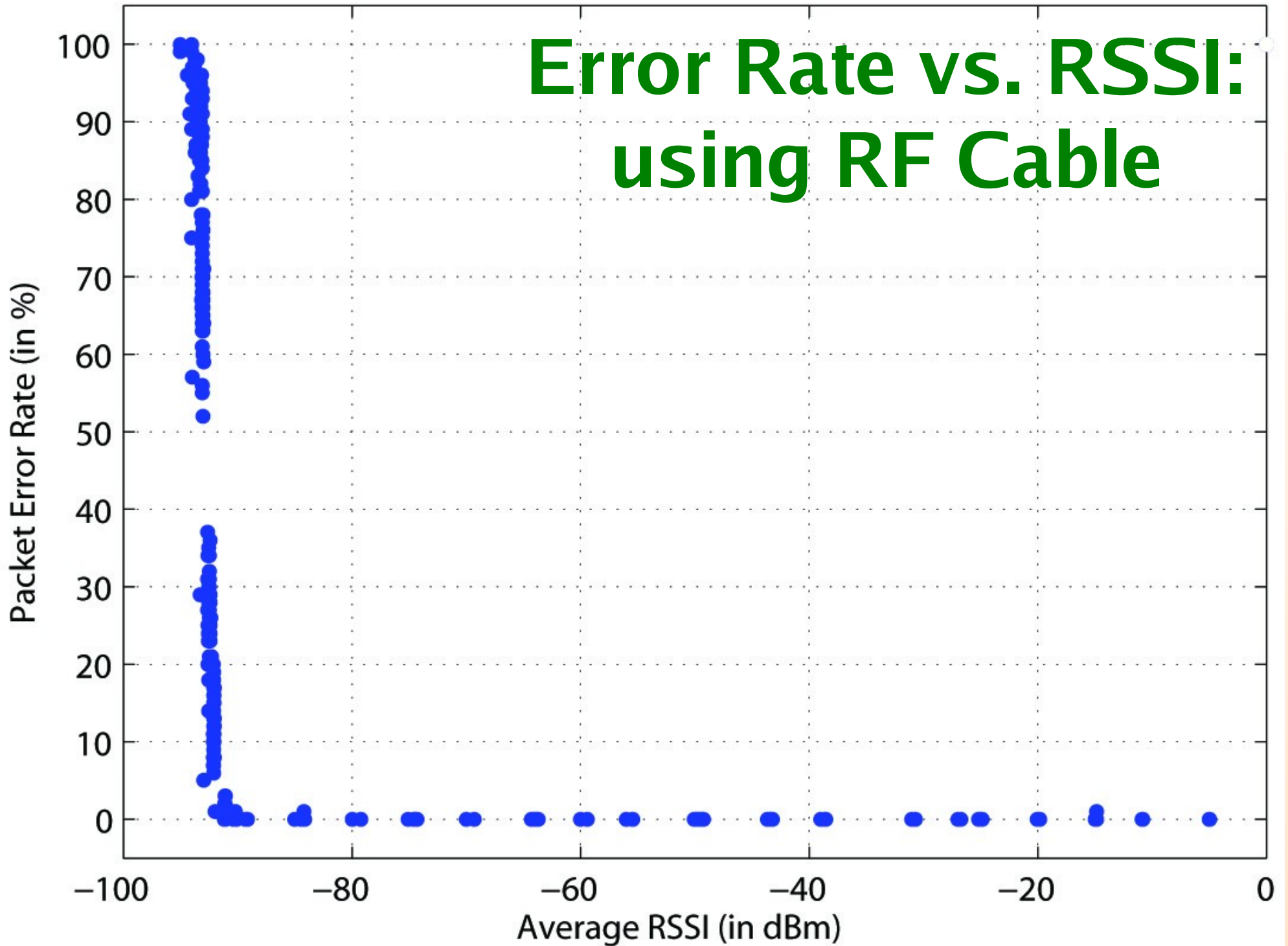
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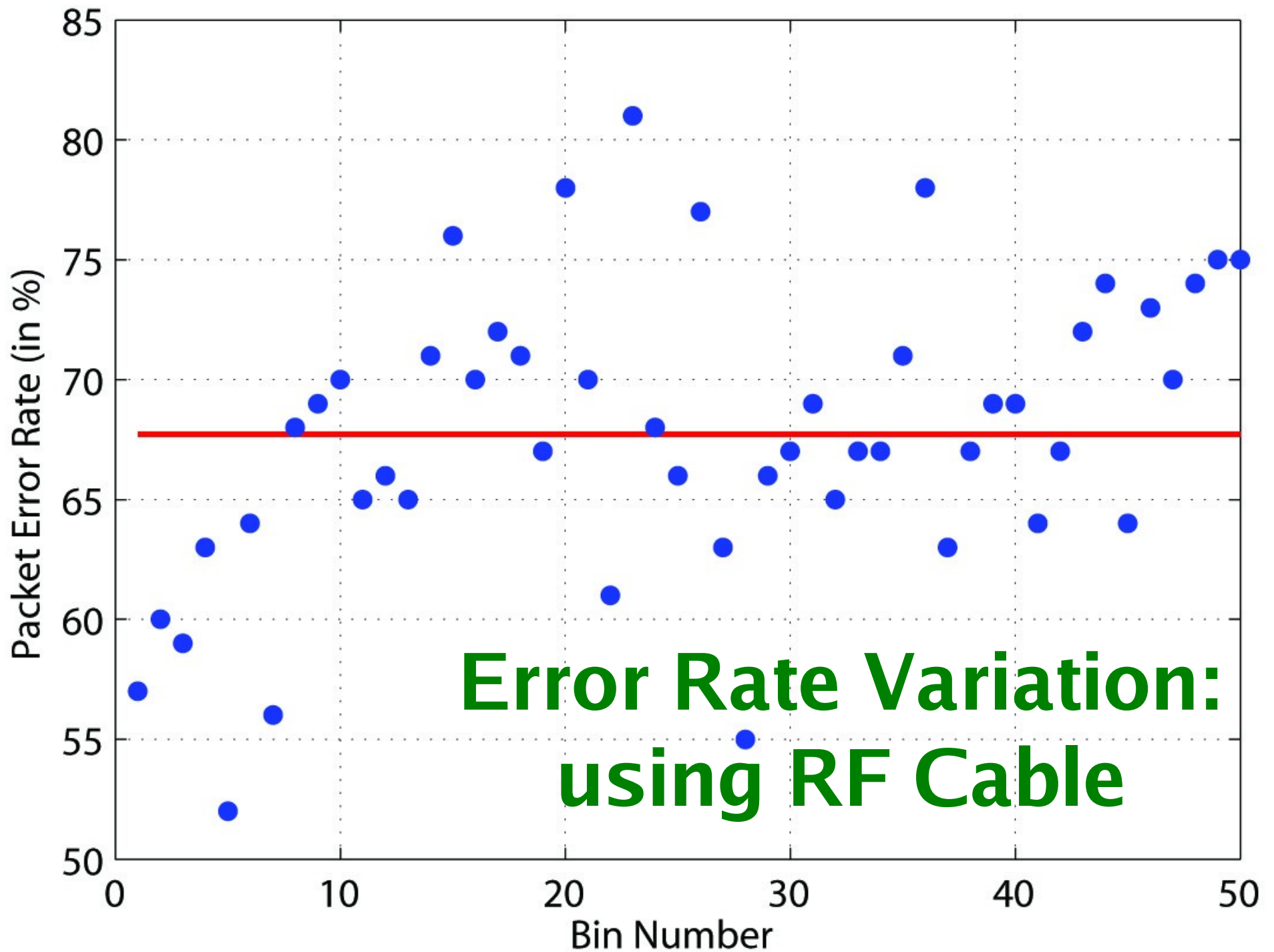
Controlled Calibration: Setup



- Step attenuator: varied from 0dB to 93dB
- 5000 packet expts. = 50 bins x 100 packets
- For each bin: error rate, and avg. RSSI

Error Rate vs. RSSI: using RF Cable

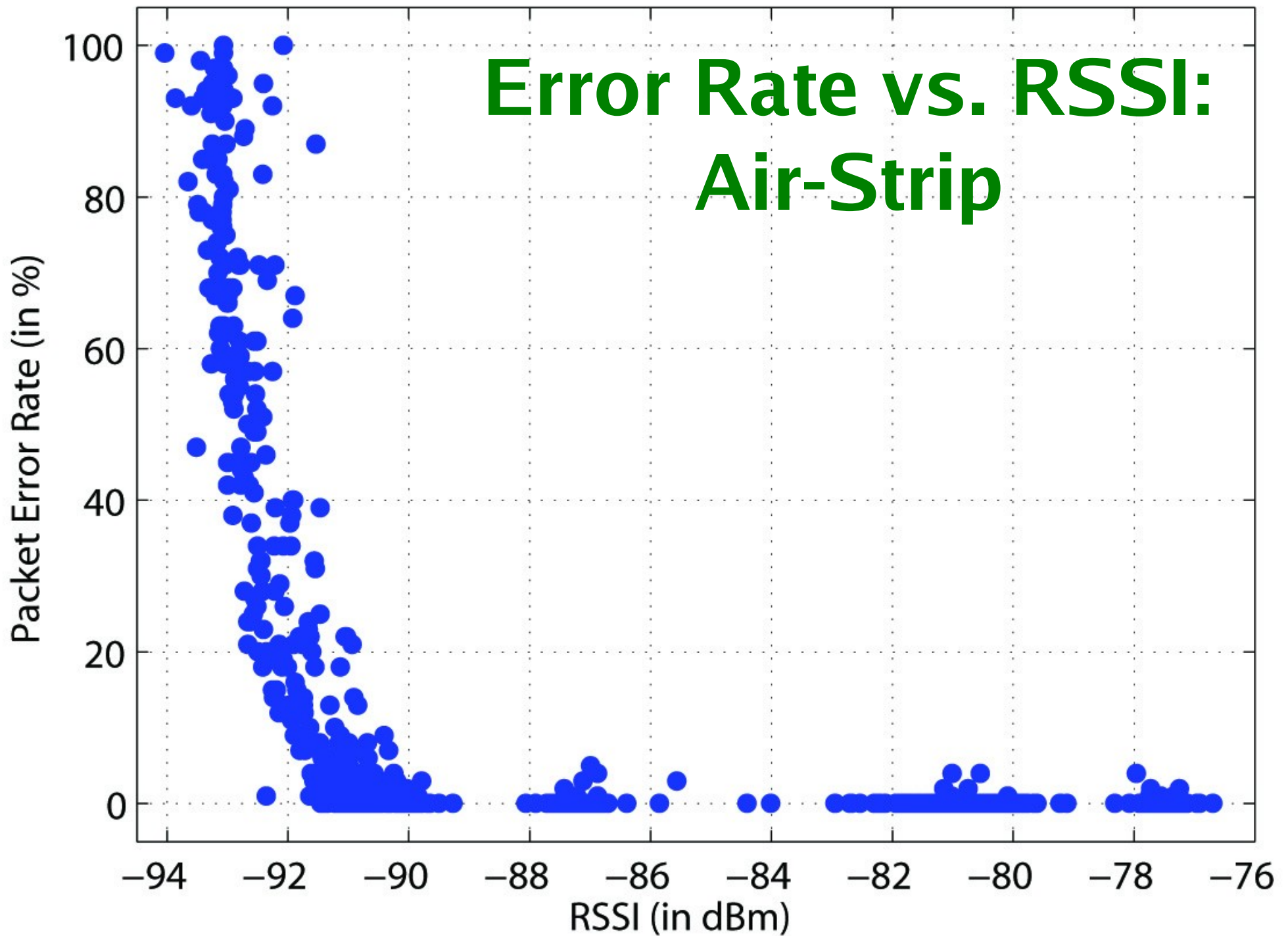




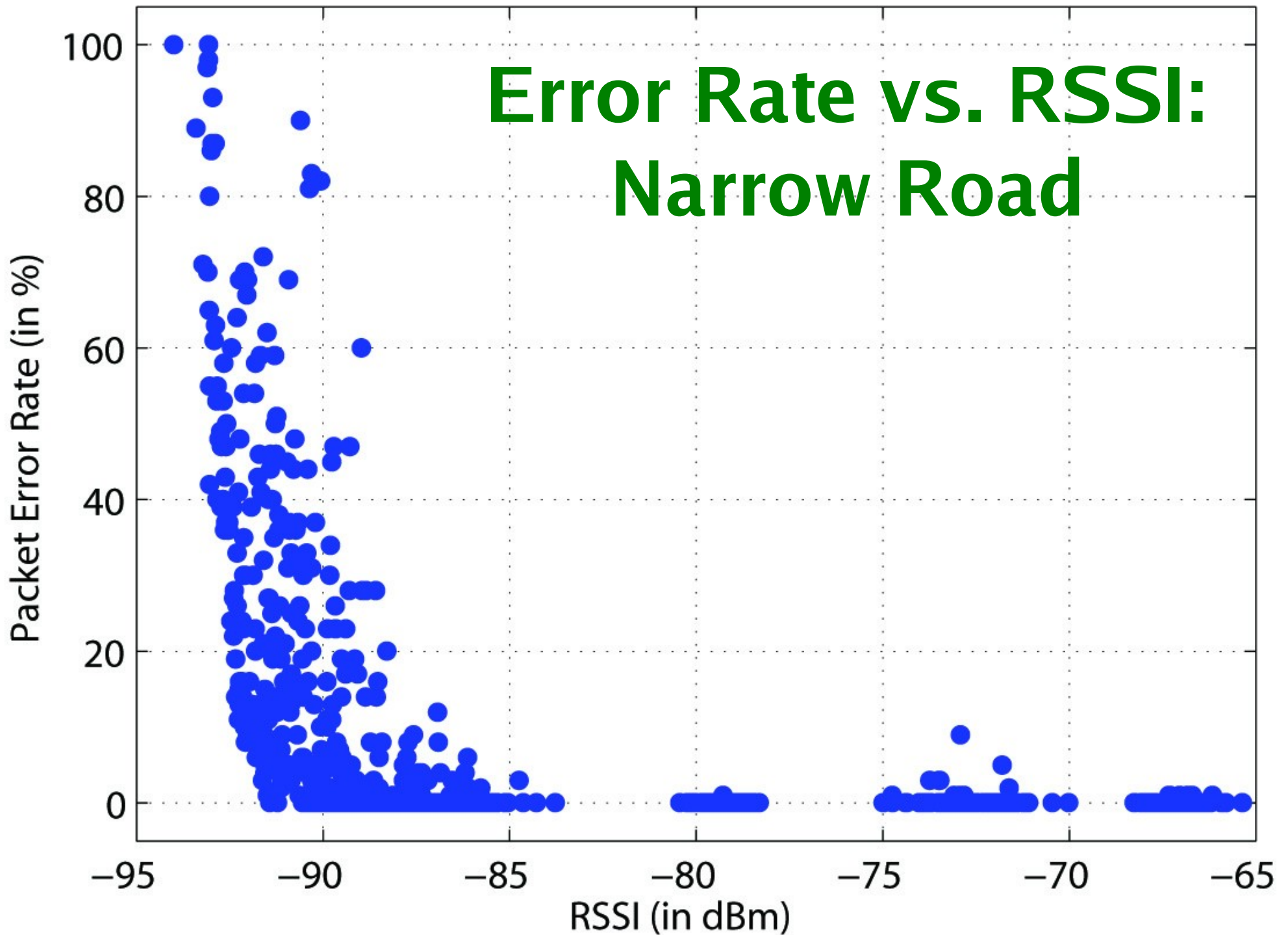
RSSI Variability in Other Env.

- Road and air-strip env.:
 - Experiments repeated over three days at about the same time (6-8am)
 - Using omni-antennas only
- Foliage env.:
 - Same data as earlier (single day only)

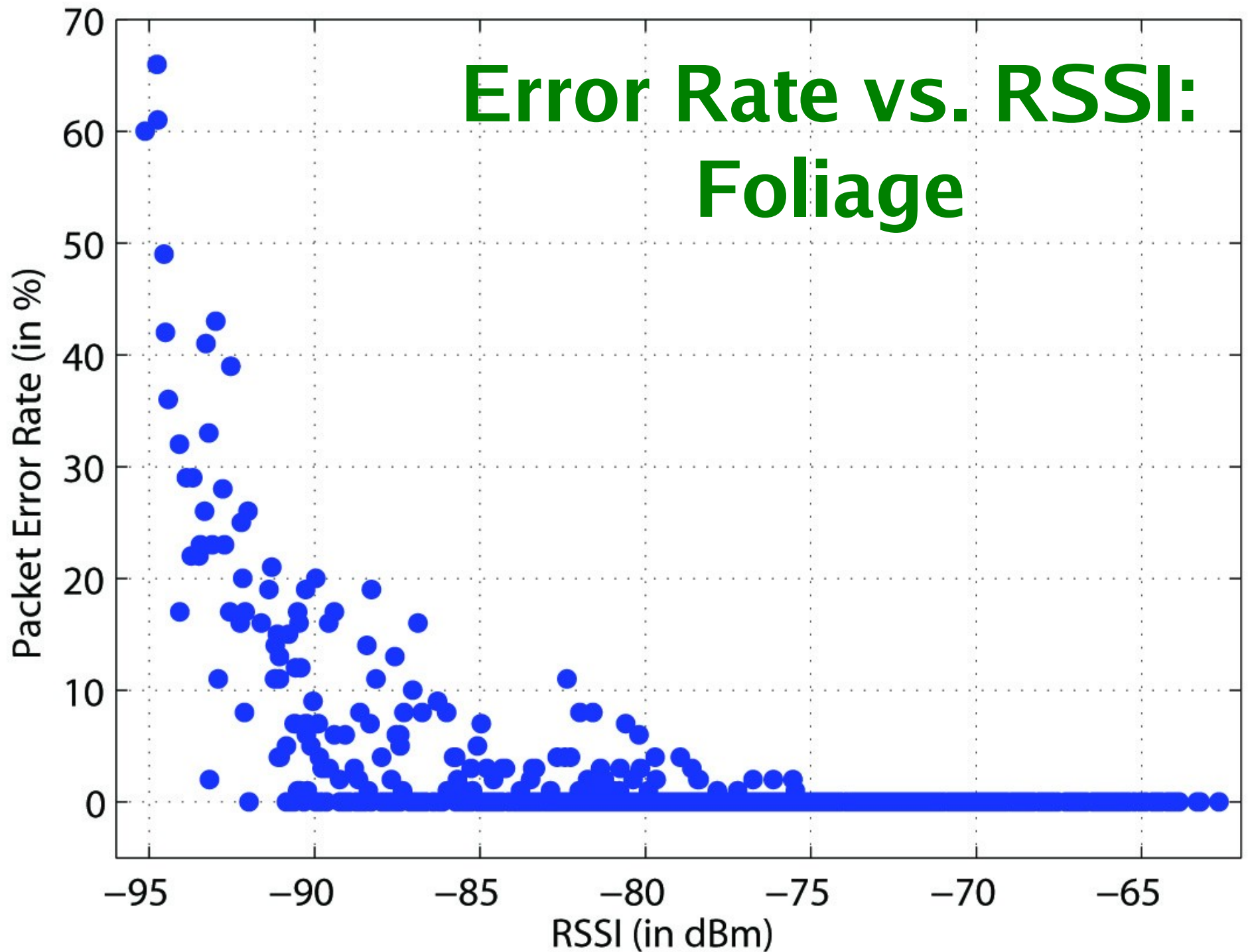
Error Rate vs. RSSI: Air-Strip



Error Rate vs. RSSI: Narrow Road



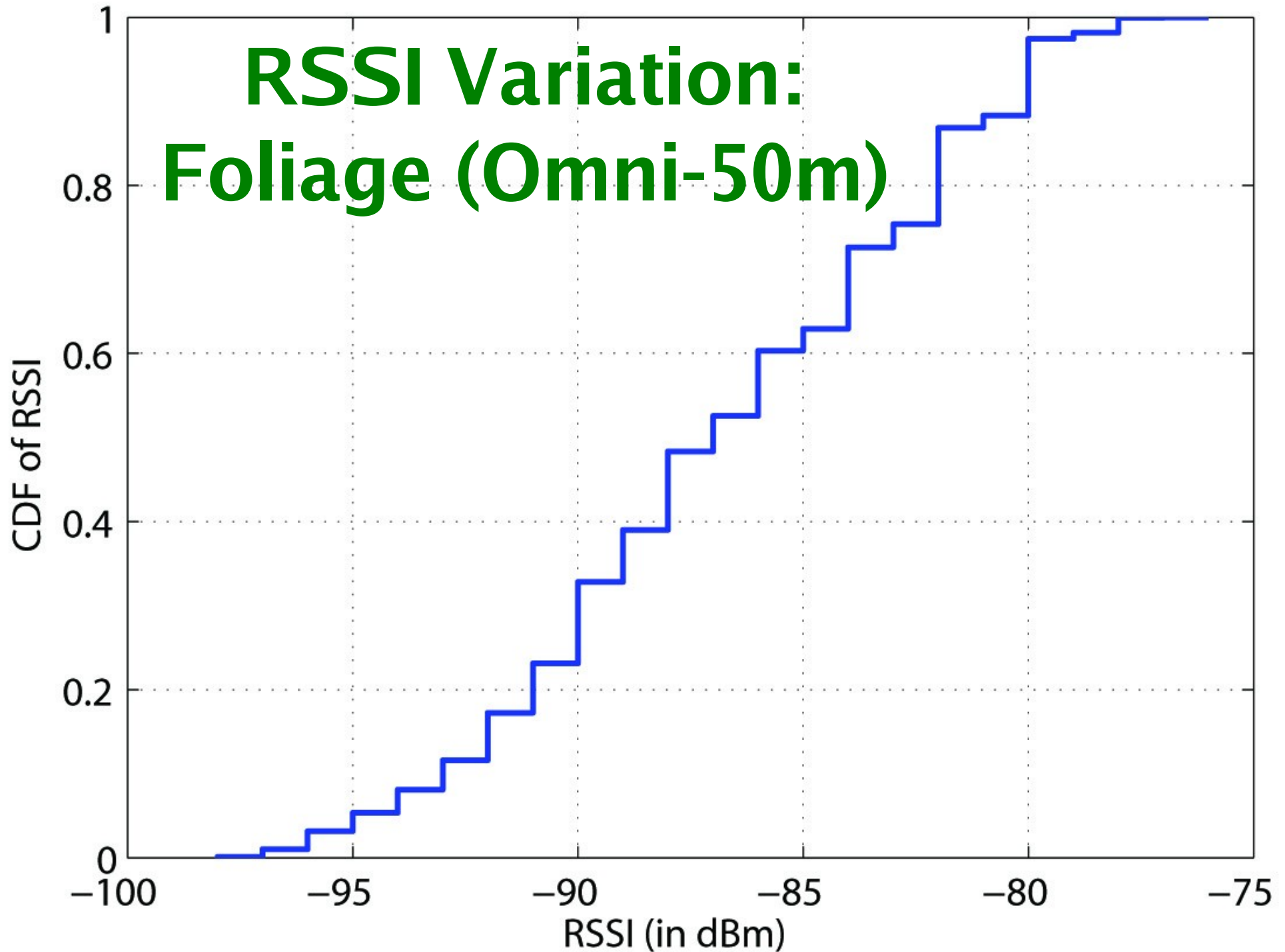
Error Rate vs. RSSI: Foliage

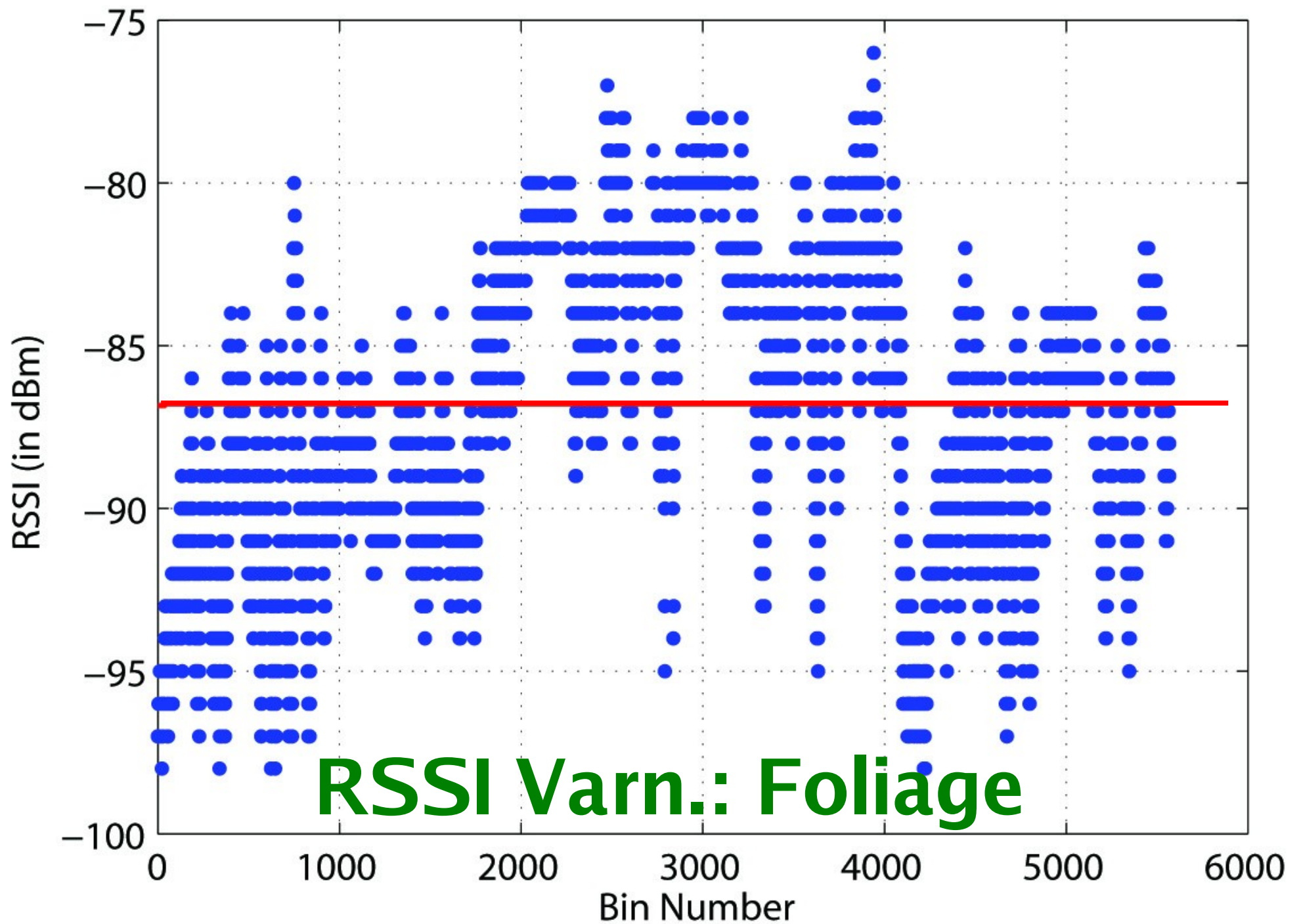


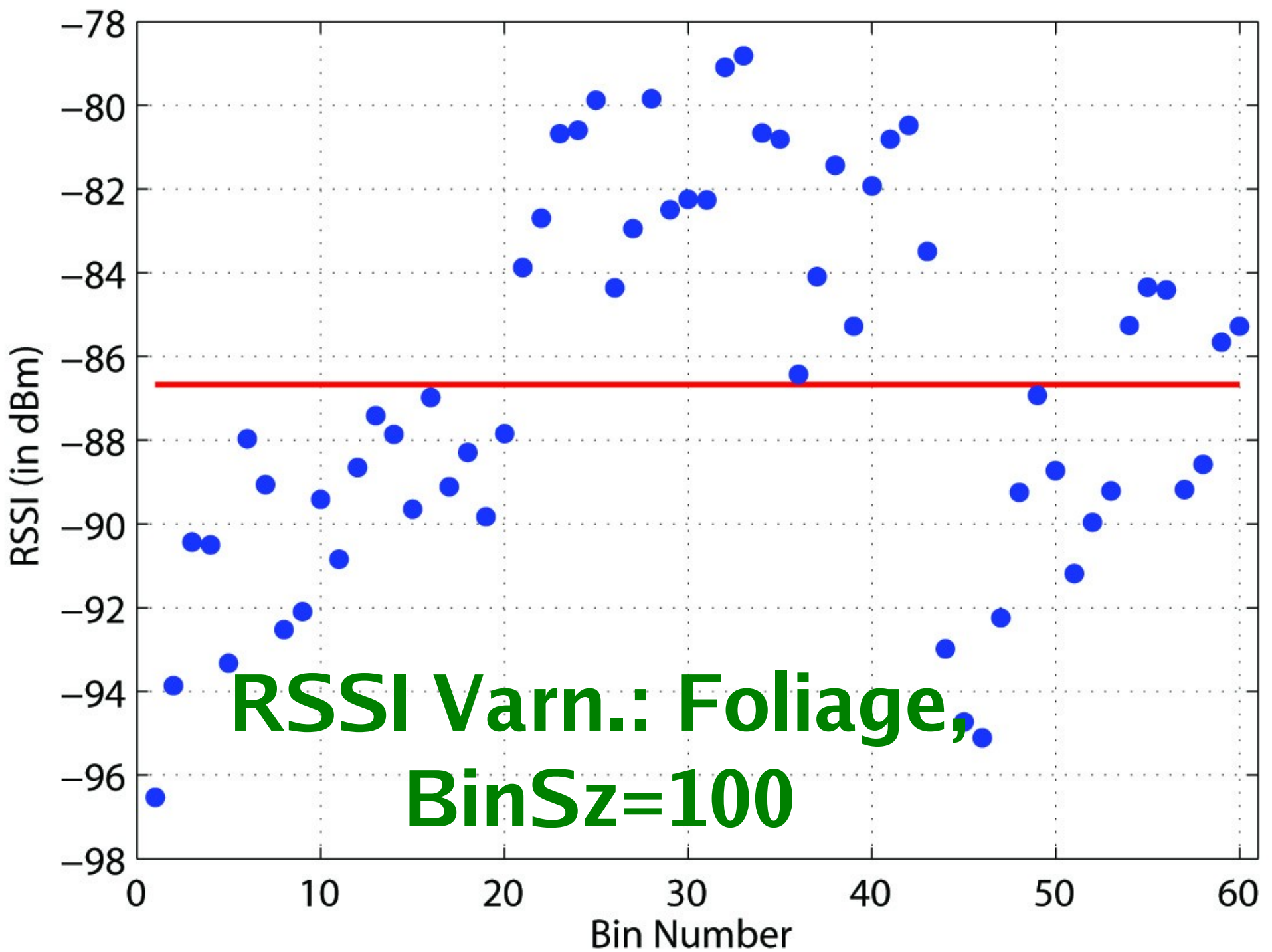
RSSI vs. Error Rate

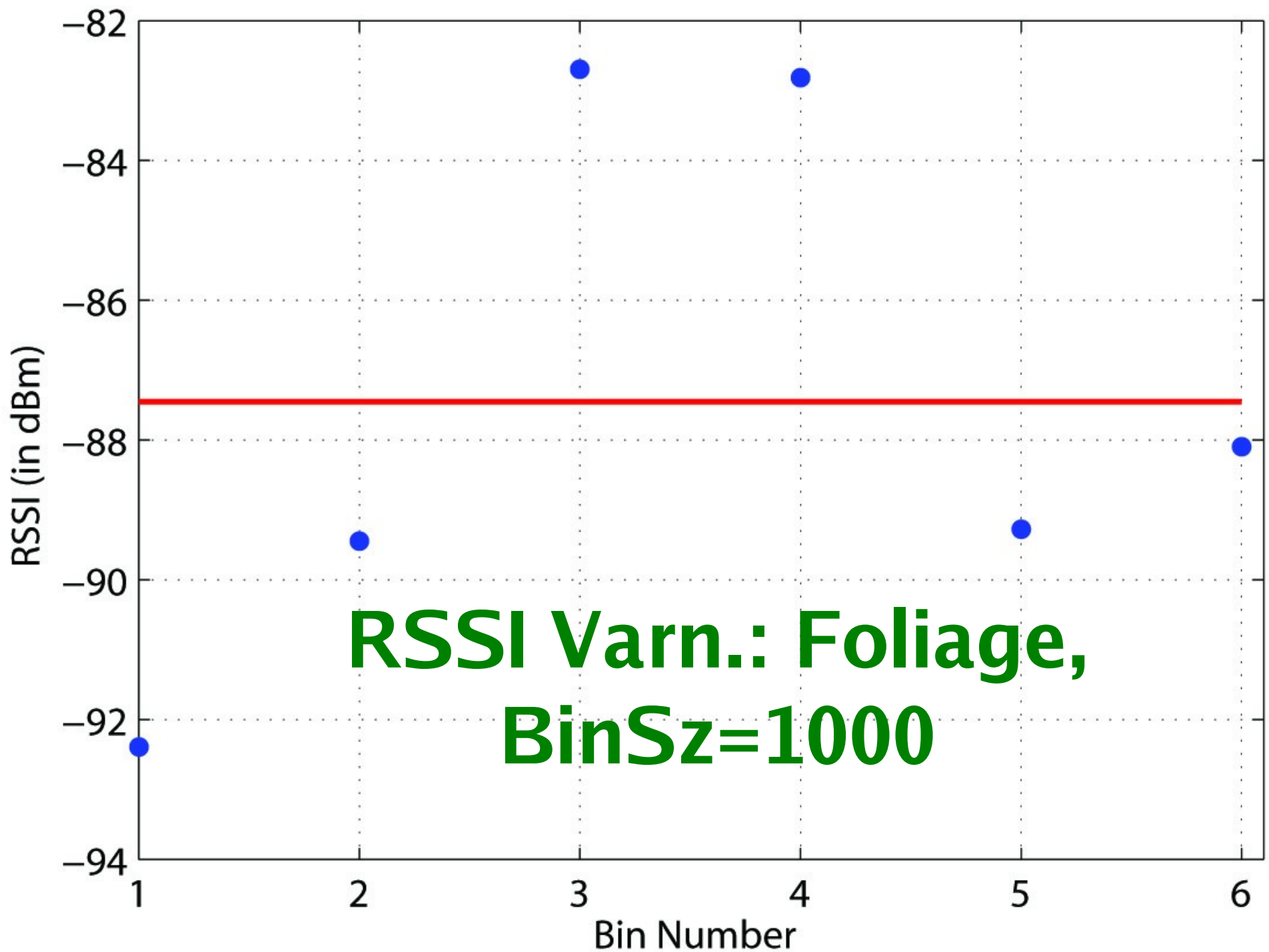
- Results similar to [Srinivasan & Levis 2006]
 - Strengthens conclusion that RSSI & error-rate are strongly correlated (more data)
- But...

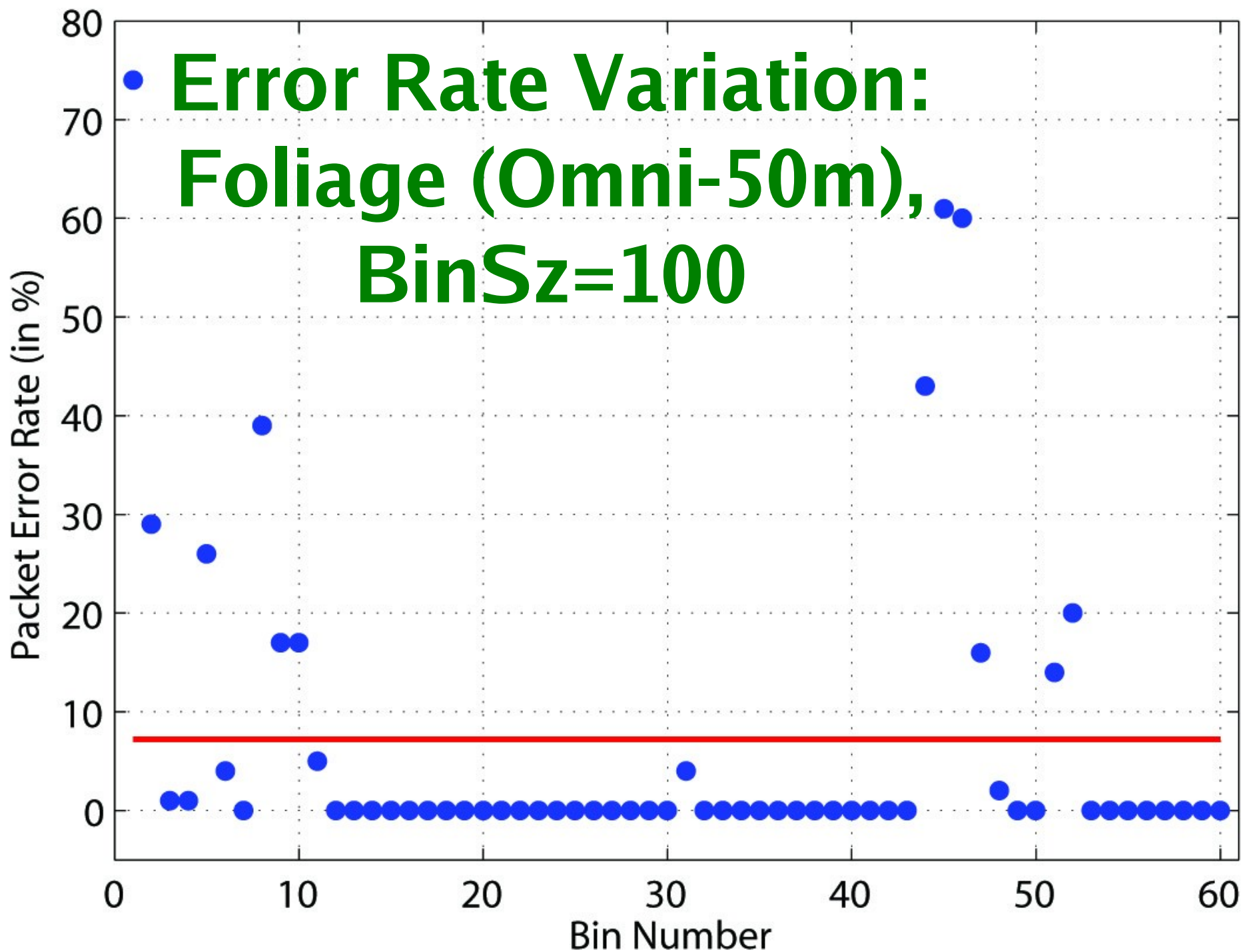
RSSI Variation: Foliage (Omni-50m)



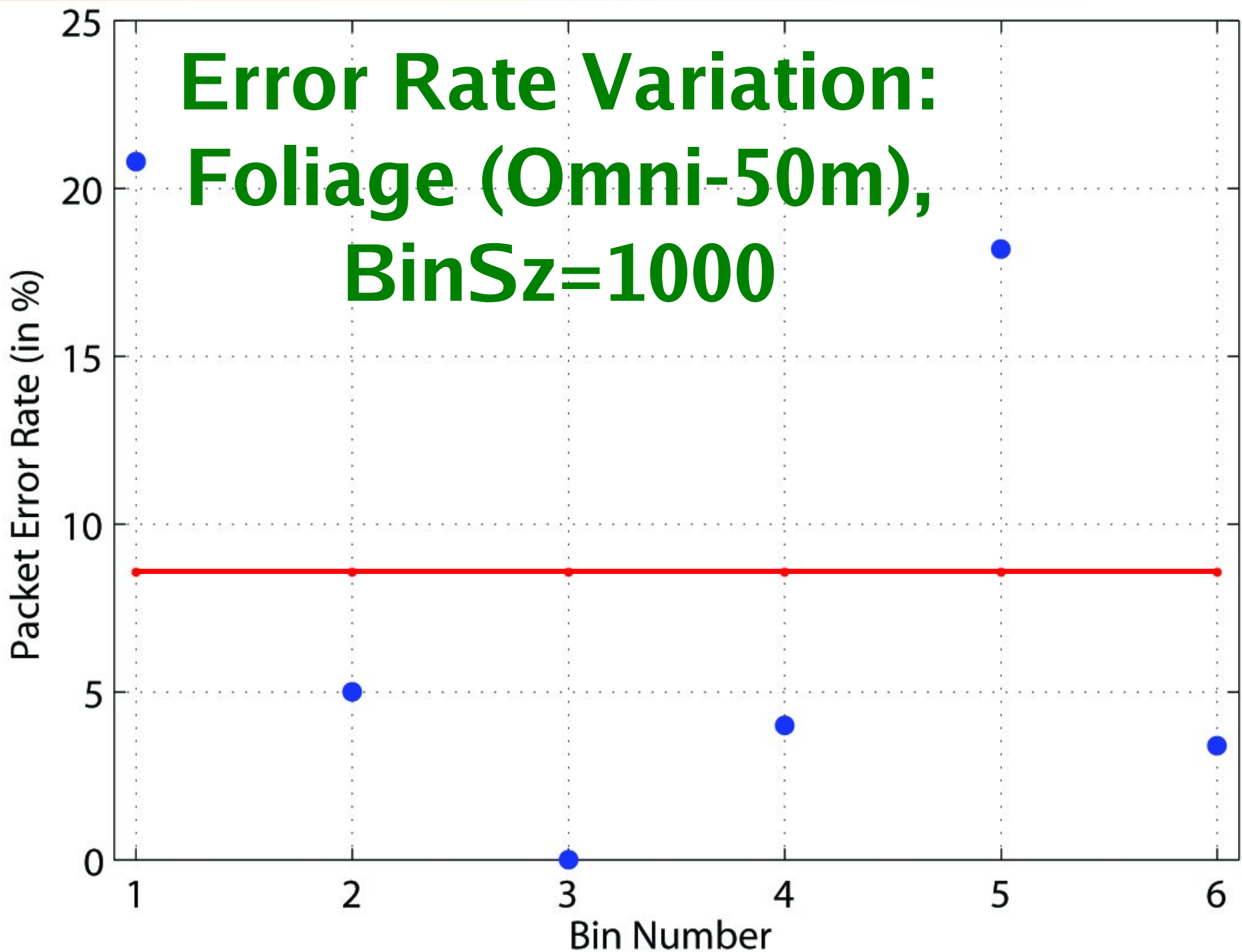


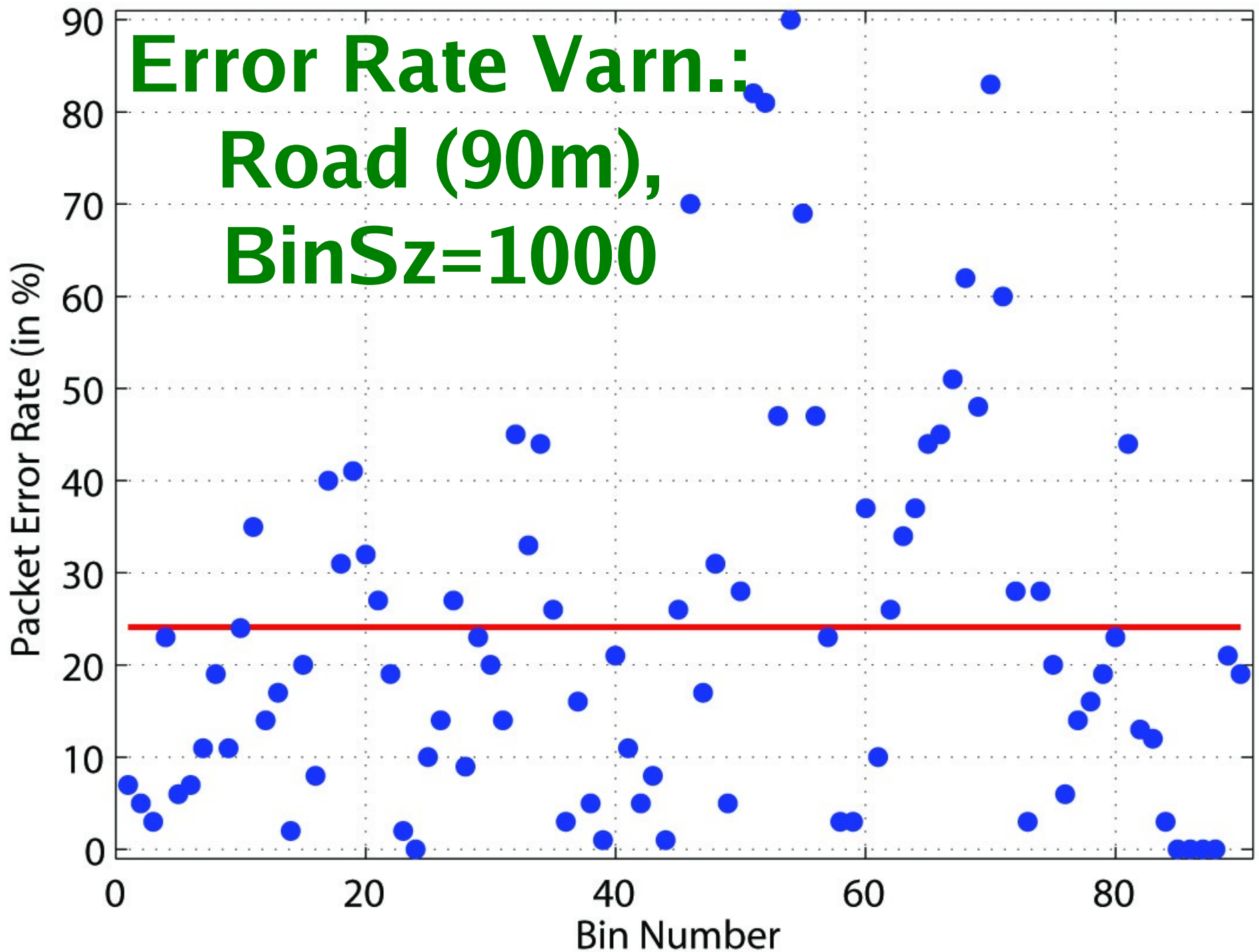






Error Rate Variation: Foliage (Omni-50m), BinSz=1000





More on RSSI Variability



Hostel Corridor

Structures Lab



RSSI Varn.

Location	Tx ant.	Rx ant.	Day/time	5 th perc. (dBm)	95 th perc. (dBm)	Diff. (dB)
Airstrip-90m	Omni	Omni	Day 3	-84	-80	4
Foliage-20m	Internal	Internal	Day 1	-81	-70	11
Foliage-40m	Omni	Internal	Day 1	-86	-76	10
Foliage-40m	Sector	Internal	Day 1	-76	-66	10
Road-210m	Grid	Internal	Day 4	-80	-70	10
Corridor-60m	Internal	Internal	Day 1	-71	-68	3
Corridor-60m	Internal	Internal	Day 3	-76	-70	6
Corridor-30m	Internal	Internal	Day 5	-76	-67	9
Road-55m	Omni	Omni	Day 2	-69	-66	3
Road-90m	Omni	Omni	Day 3	-82	-79	3
StrLabLoc1	Internal	Internal	Day 1 15:45	-76	-66	10
StrLabLoc1	Internal	Internal	Day 1 23:30	-71	-66	5
StrLabLoc2	Internal	Internal	Day 1 15:45	-87	-78	9
StrLabLoc2	Internal	Internal	Day 1 23:30	-78	-74	4
StrLabLoc3	Internal	Internal	Day 1 15:45	-80	-73	7
StrLabLoc3	Internal	Internal	Day 1 23:30	-78	-76	2
StrLabLoc3	Internal	Internal	Day 2 11:15	-84	-76	8
StrLabLoc4	Internal	Internal	Day 1 23:30	-89	-82	7
StrLabLoc4	Internal	Internal	Day 2 11:15	-88	-78	10

Implications

- LQI variability similar to RSSI variability
 - $1/\text{LQI}$, $1/\text{PSR}$ metrics would be **unstable**
- **Variability over hours:** cannot use past measurement during next wake-up period

Implications (continued)

- Problems arise when RSSI window overlaps with the **steep region**
 - Provide sufficient link margin
 - Plan the deployment to have “good” links
 - Sophisticated dynamic routing metrics unnecessary
- Base node is a powerful node anyway
 - Can do **centralized routing**
 - Fault-tolerance, scaling unlikely to be issues
 - Design, implementation, network mgmt. easier

Conclusion

- **Range:** 500-800m
 - Number of one-hop nodes can be increased
 - Better life-time
- **Variability** in time-scales of 2s, 20s, hours
 - Dynamic metric-based routing may not be useful
 - Plan for “good” links, use centralized routing
- **Think real hard before falling for:** randomly deployed sensor nodes, self-organizing, distributed dynamic routing
 - Good for solving nice problems on paper
 - Practical value questionable