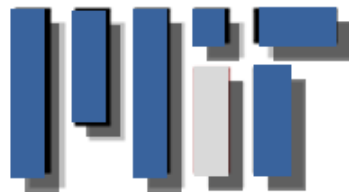


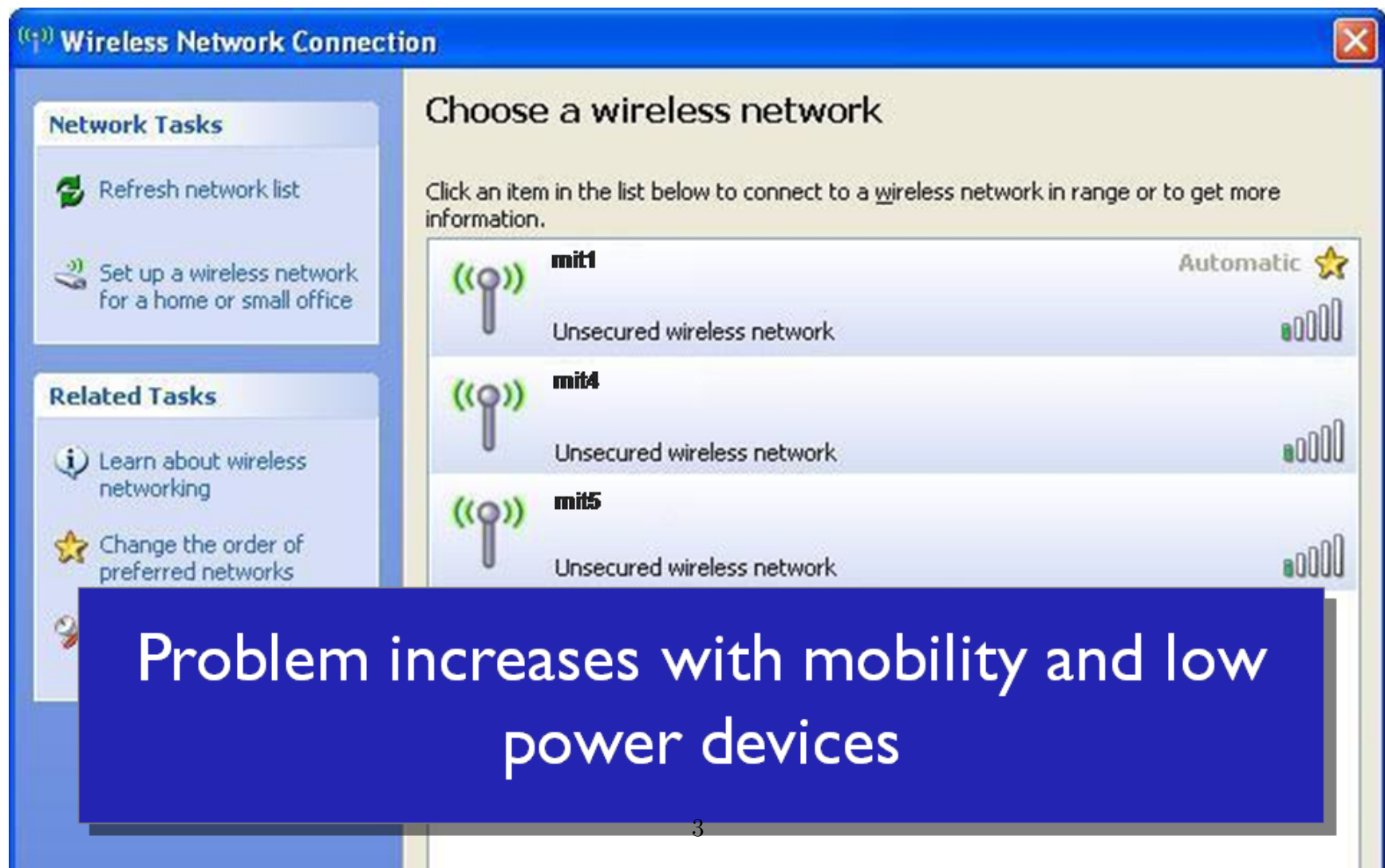
Bringing Life to Dead Spots

Grace Woo

Pouya Kheradpour, Dawei Shen, and Dina Katabi



Many APs But Still Poor Coverage



Poor Coverage Is Not No Coverage!

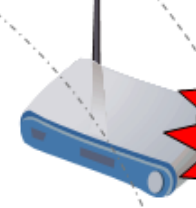
010101011X11



Loss

Currently High Bit Error
→ Persistent Loss
→ Dead Spot

01X101011011



Loss

Spatial Diversity
→ APs are unlikely to
have same bit error



Can recover a correct packet if we combine the correct bits from these receptions

But Which AP Got the Right Bit?



- Clearly can't have per bit checksum
- Prior work (MRD) tries all block combinations to satisfy checksum

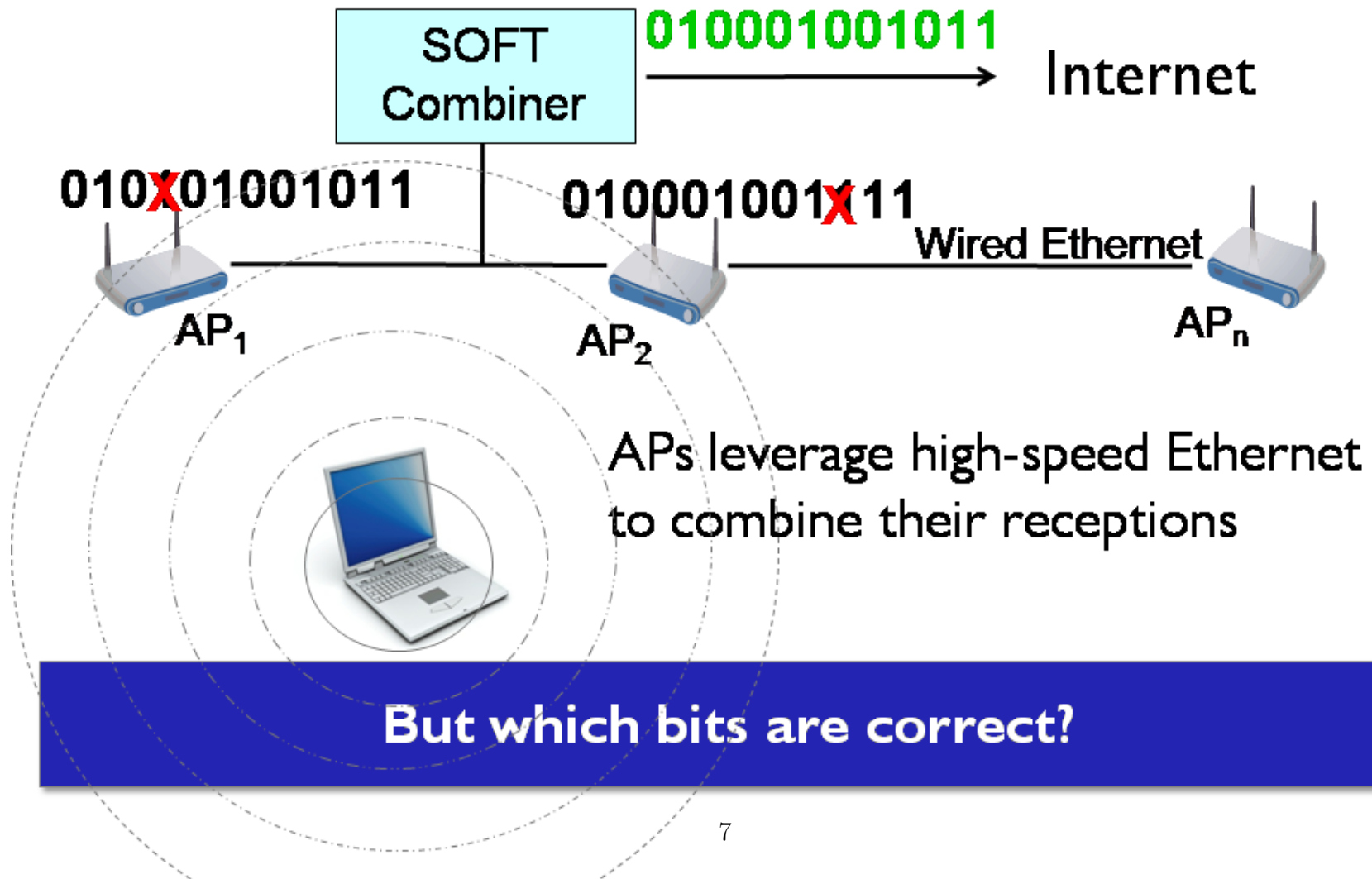


- **Exponential Complexity**
- Works for a few bit errors **But not dead spots**

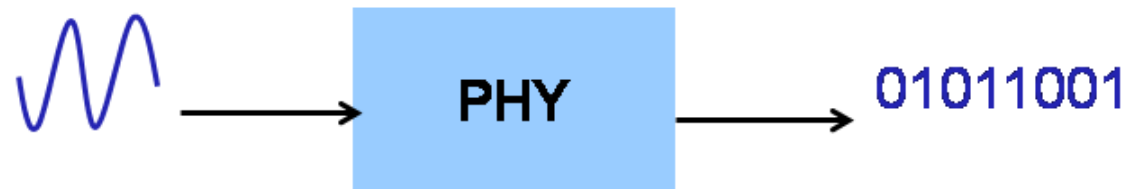
SOFT

- Recovers a correct packet from its faulty receptions at APs
- Leverages **physical layer hints** to identify correct bits
- SOFT's **delivery rate is up to 10x higher** than current WLANs and MRD

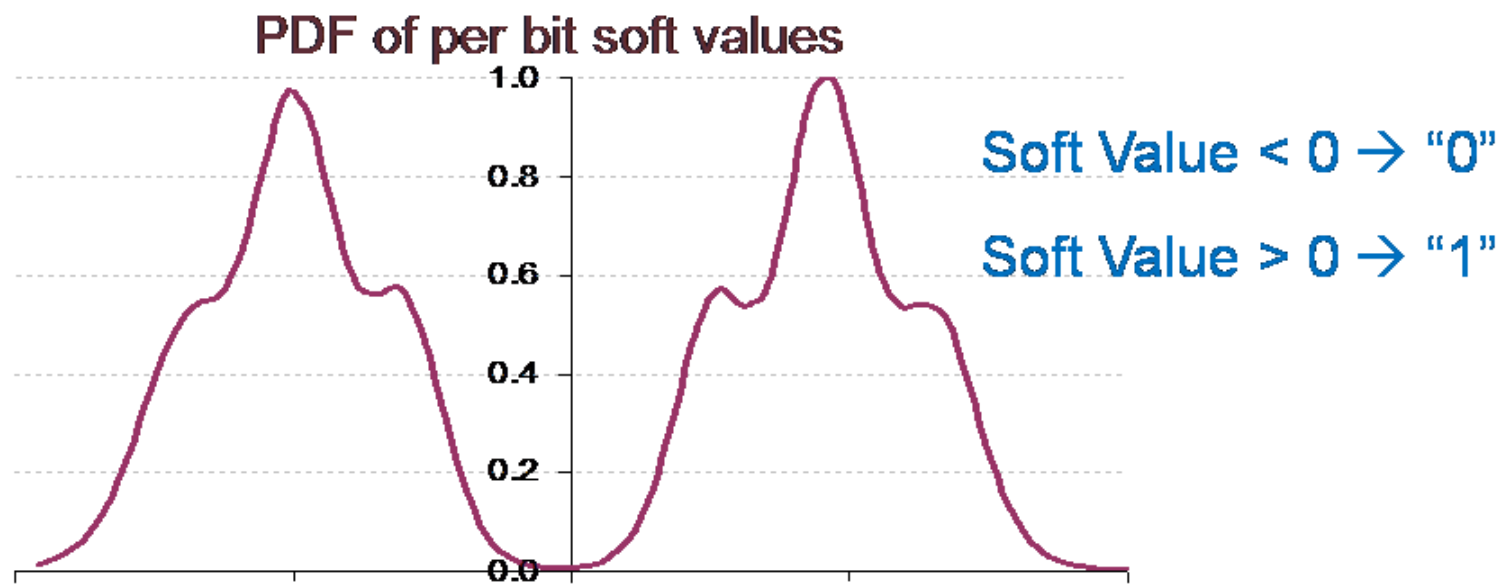
SOFT Architecture



Physical Layer Knows More!



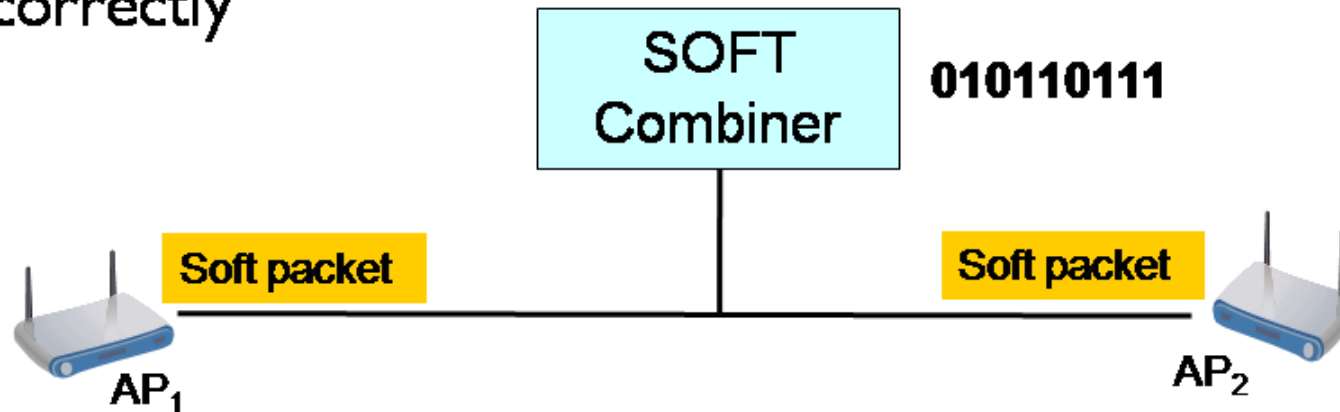
PHY **already estimates** a confidence in its 0-1 decision → **Soft Value**



Larger absolute soft values → More confidence in bit

We Use the Soft Values

- SOFT changes the PHY interface to expose the soft values to higher layers
- SOFT combines the soft values of a bit to decode it correctly



- The combiner forwards the decoded packet if it satisfies the 802.11 checksum

How Do We Combine Soft Values?

Say for a particular bit, we got



0.4



- 0.1



- 0.2

How do we decode the bit?

- Maximum soft value \rightarrow Bit is “1”
- Majority vote \rightarrow Bit is “0”
- Average \rightarrow Bit is “1”

Different Combining Methods \rightarrow Different Answers!

SOFT Combining Algorithm

Intuitively, we want to favor less noisy channels

Let σ_i^2 be the noise variance on the channel to AP_{*i*}

Let S_{ij} be the soft value of bit *j* reported by AP_{*i*}

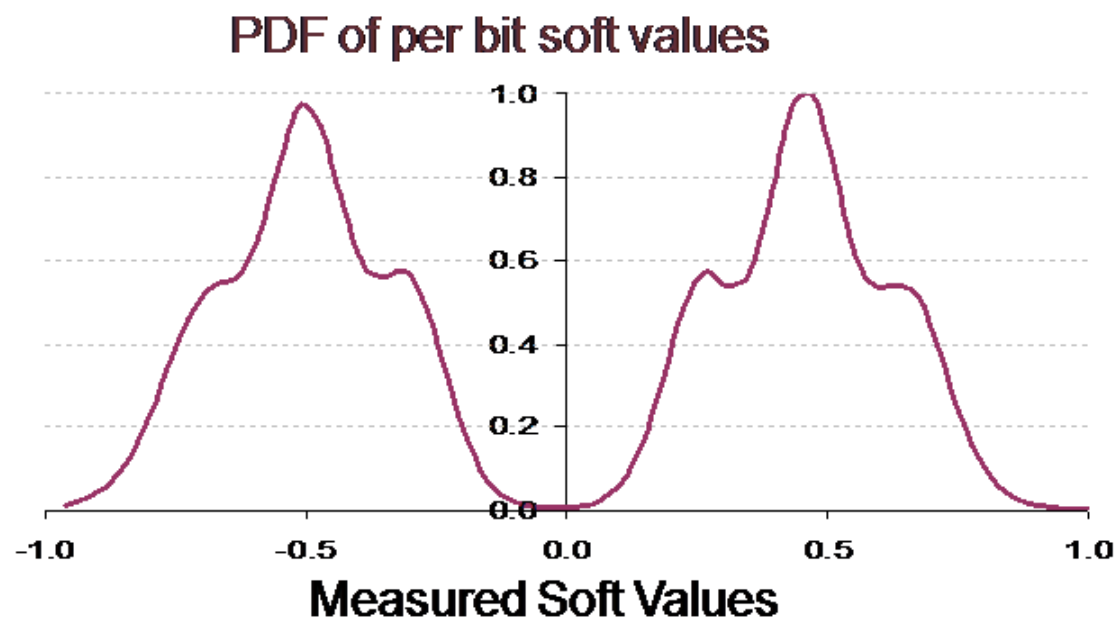
SOFT decision rule:

$$\sum_i \frac{S_{ij}}{\sigma_i^2} \geq 0 \Rightarrow \text{Bit } j \text{ is "1" else "0"}$$

For AWGN and dead spots rule is proven optimal.

But, How Does SOFT Get the Noise Variance?

Randomness in soft values is caused by channel noise



Estimate σ_i^2 from the PDF of the soft values in packet

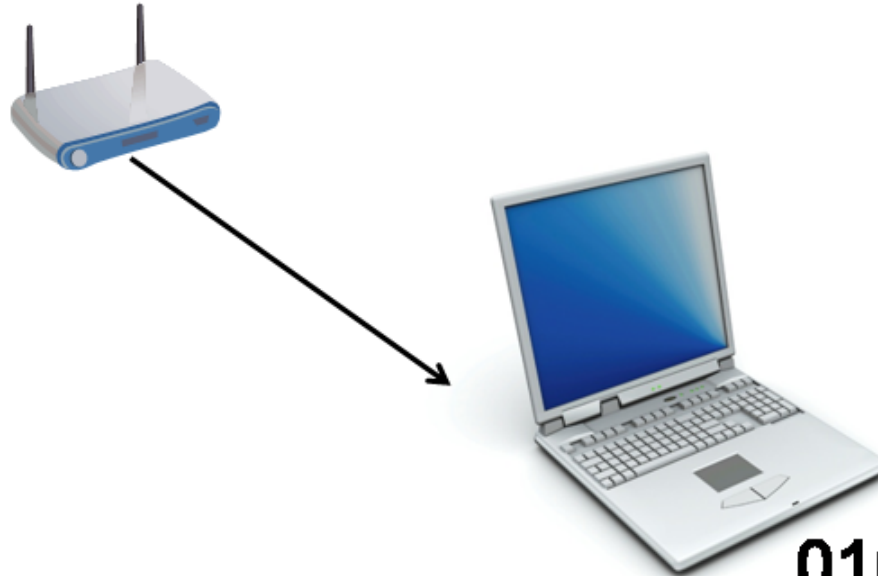
How About Overhead?

- PHY soft values can be 32-bit float
→ Excessive Ethernet traffic

Solution

- Invoke SOFT **only when associated AP can't decode**
- Quantize soft values (we used **3 bits**)

What About the Downlink?



010~~X~~01001011
01010100~~X~~011

Use Time Diversity
Combine a packet with its retransmission

Performance

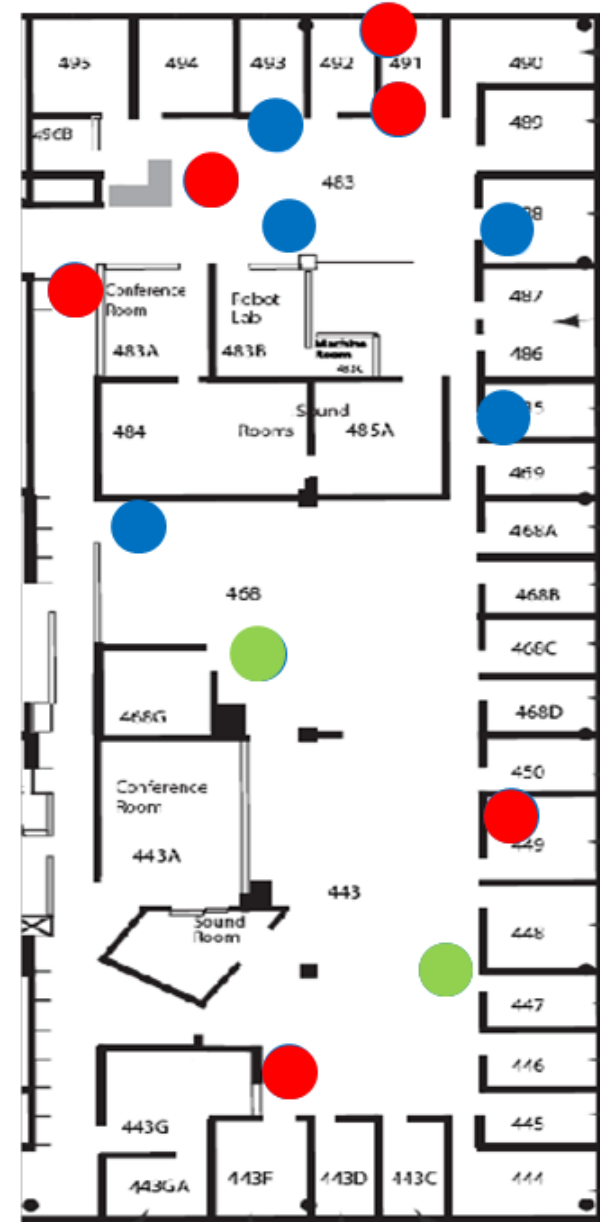
SOFT Implementation

- Software – GNURadio codebase
- Hardware – USRP frontend
- GMSK and DBPSK modulations
- Soft values are inputs to the slicer
- Poor Coverage:
 - SNR 5 – 12 dB
 - BER about 10^{-3}

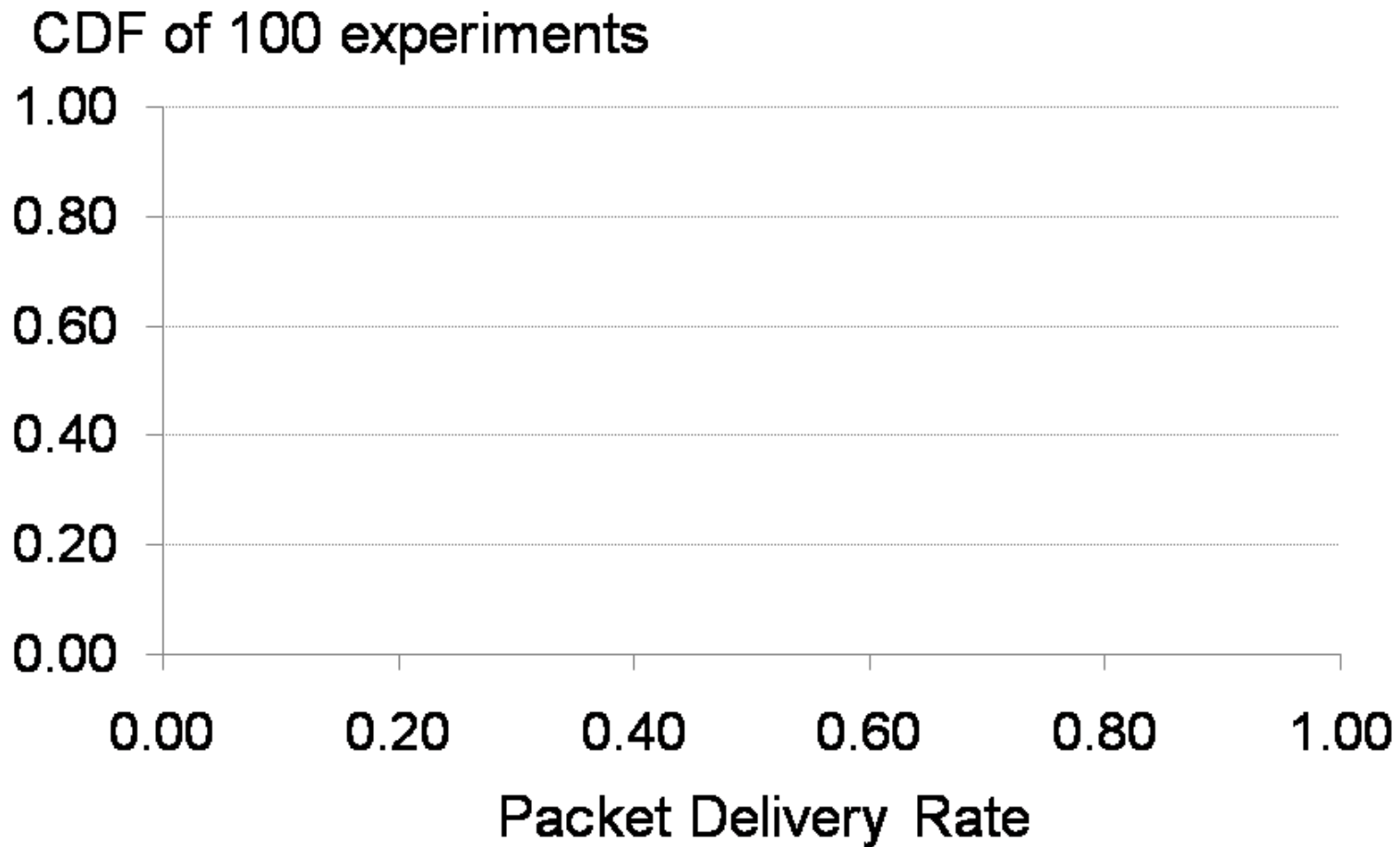


Experimental Setup

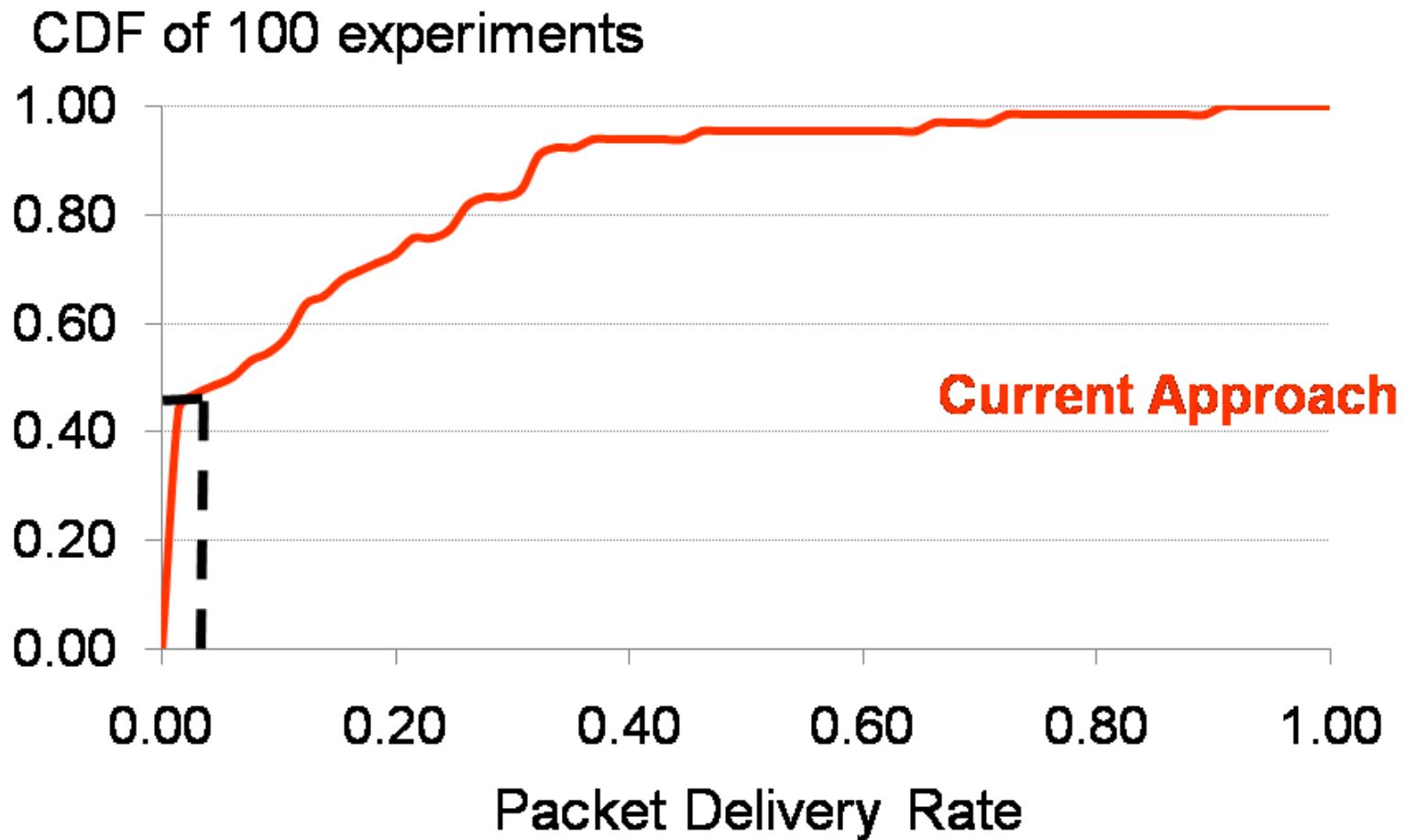
- 13 GNUMRadio nodes
- Compared
 - Current 802.11 WLAN (user associates with best AP)
 - MRD
 - SOFT
- Each Experiment
 - 3 random APs
 - Random source
 - Transmit 500 packets



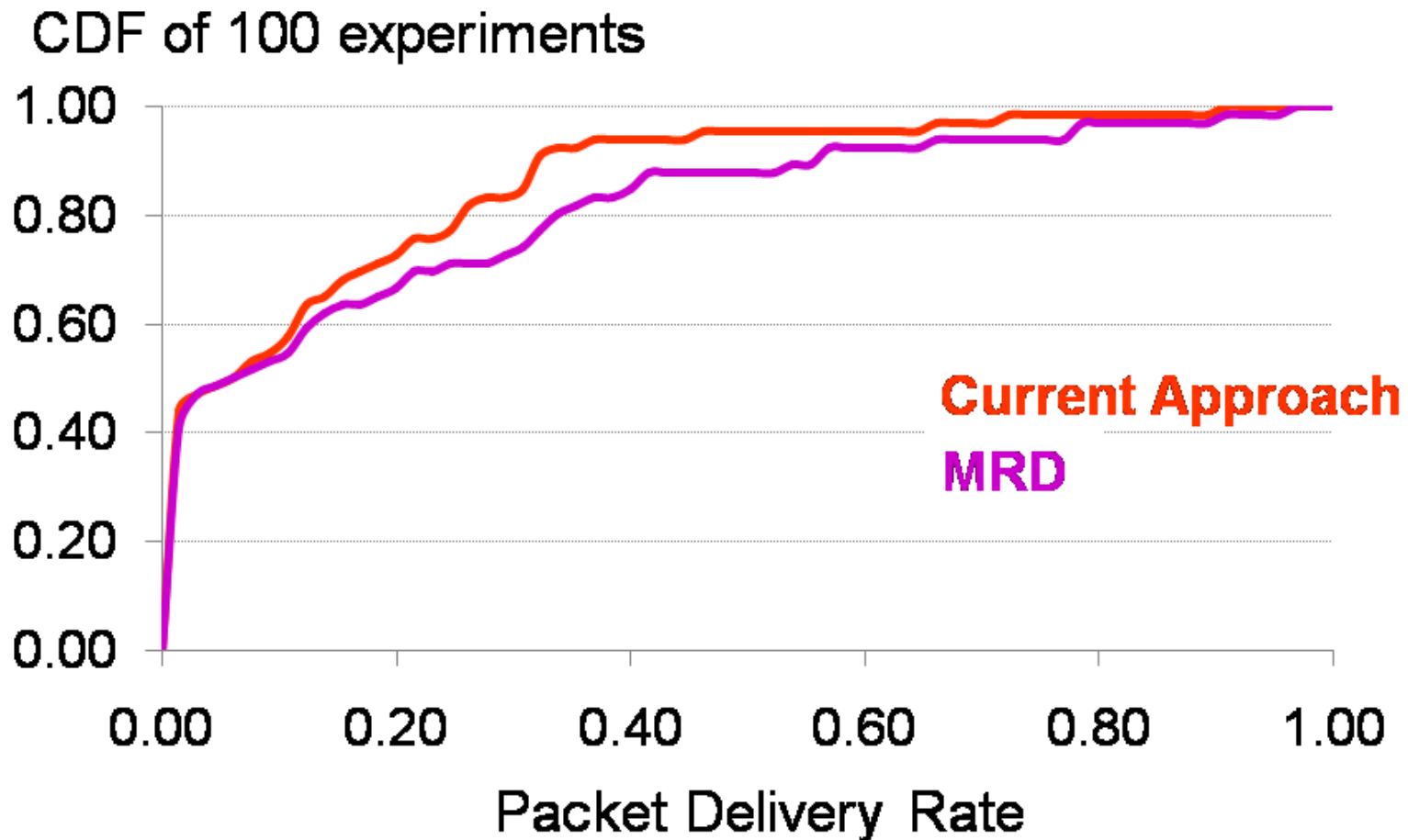
Does SOFT Help?



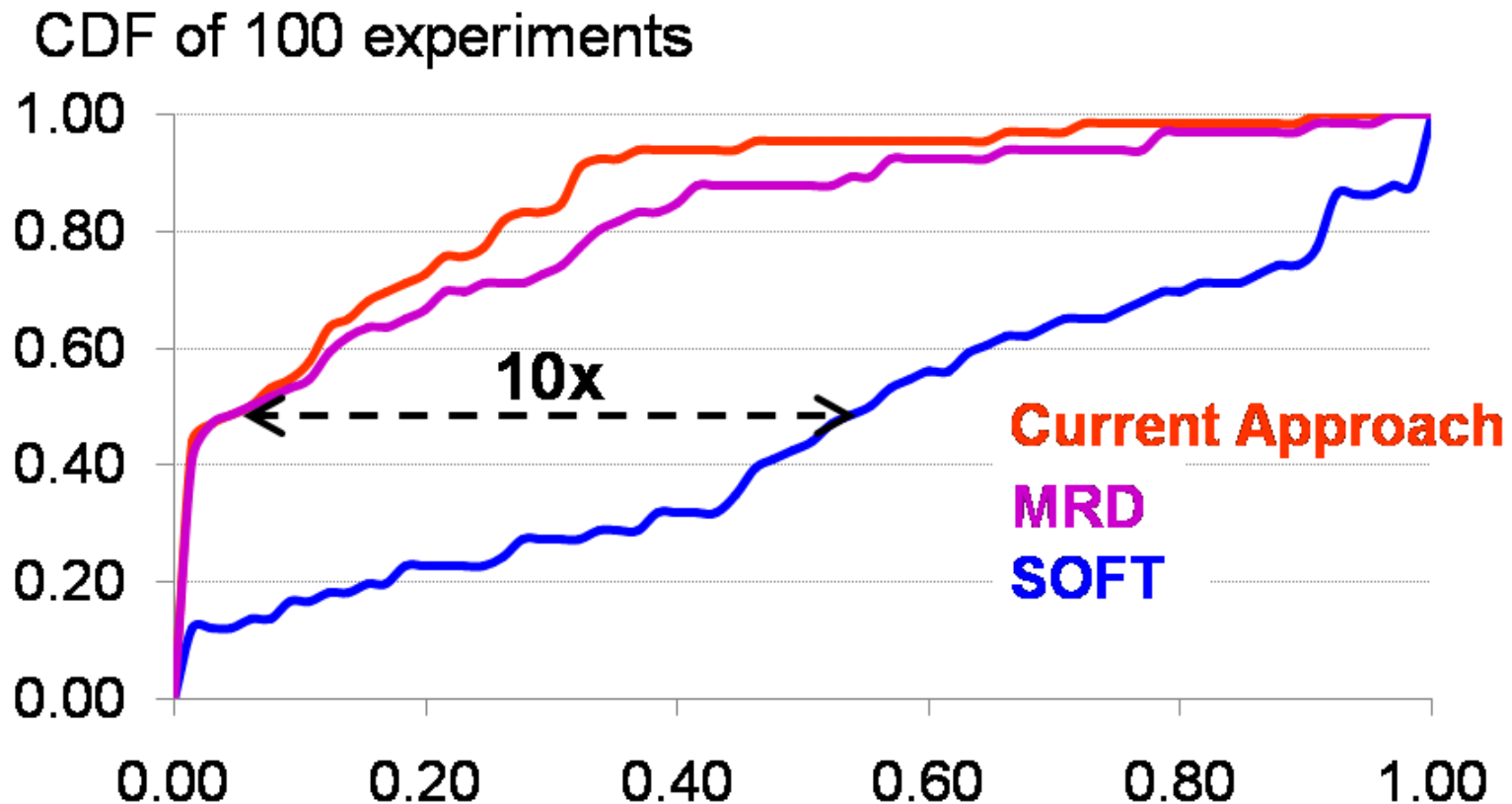
Does SOFT Help?



Does SOFT Help?

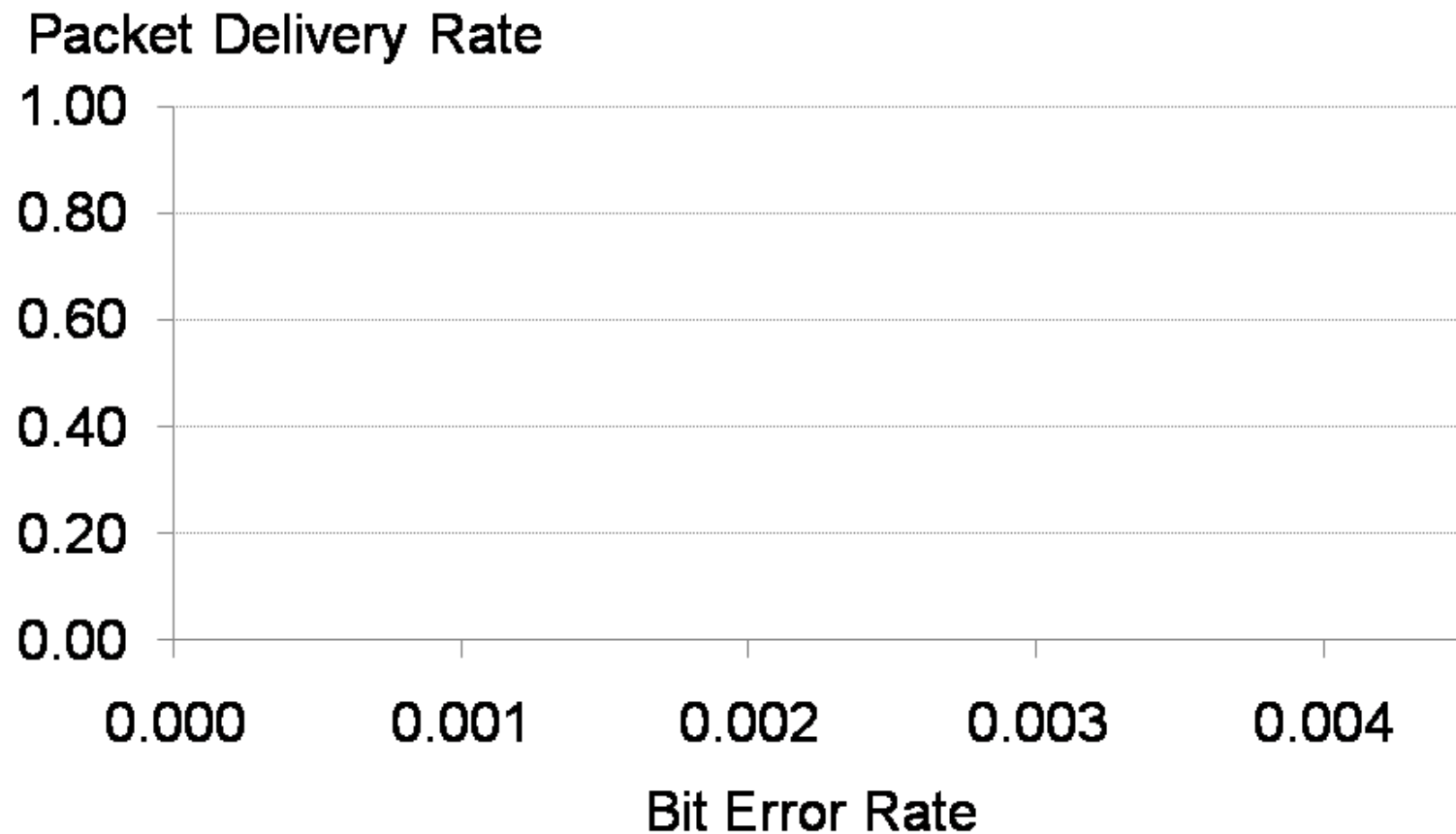


Does SOFT Help?

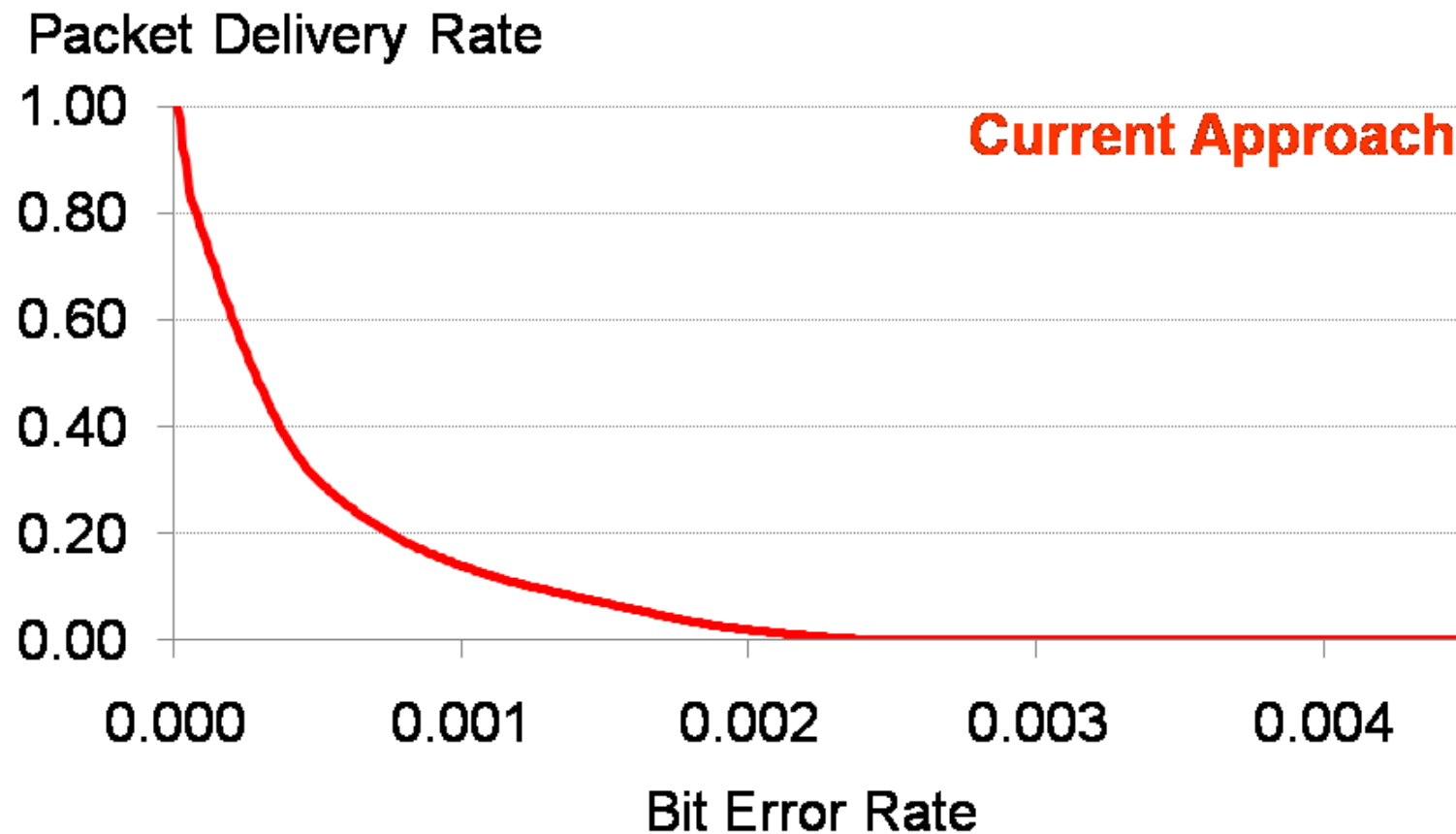


SOFT's delivery rate can be 10x higher

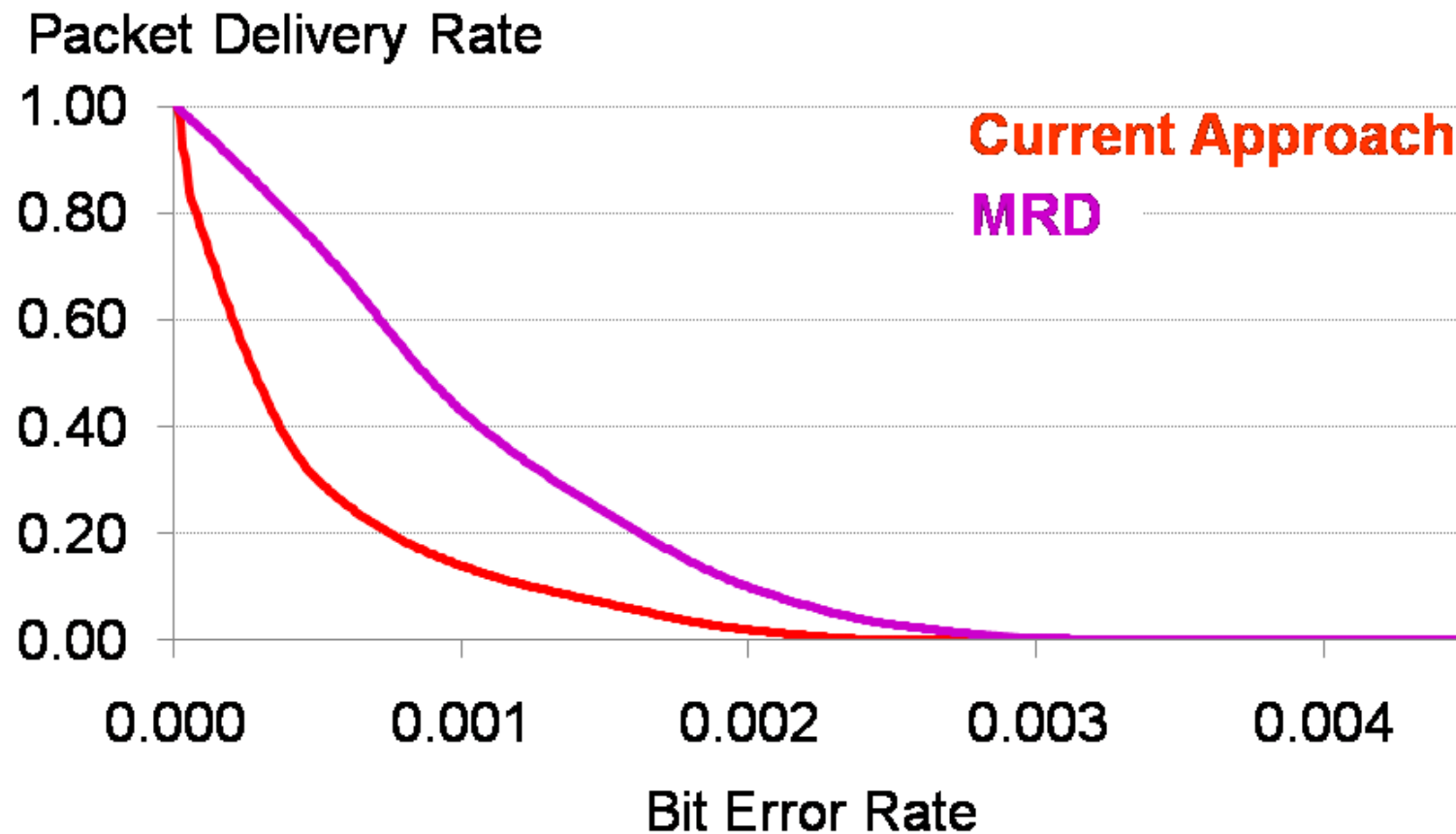
Performance with Increasingly Poor Coverage



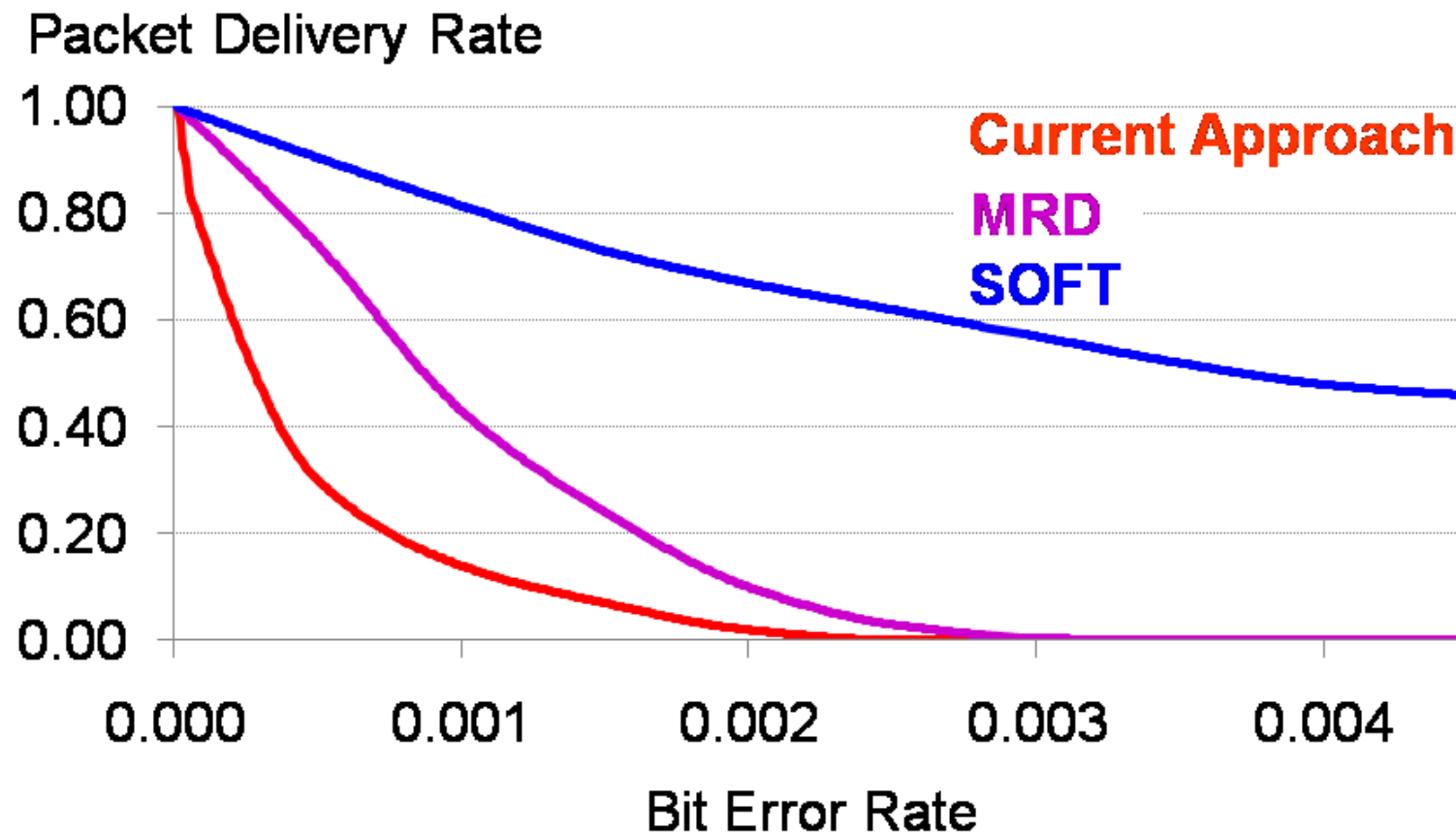
Performance with Increasingly Poor Coverage



Performance with Increasingly Poor Coverage



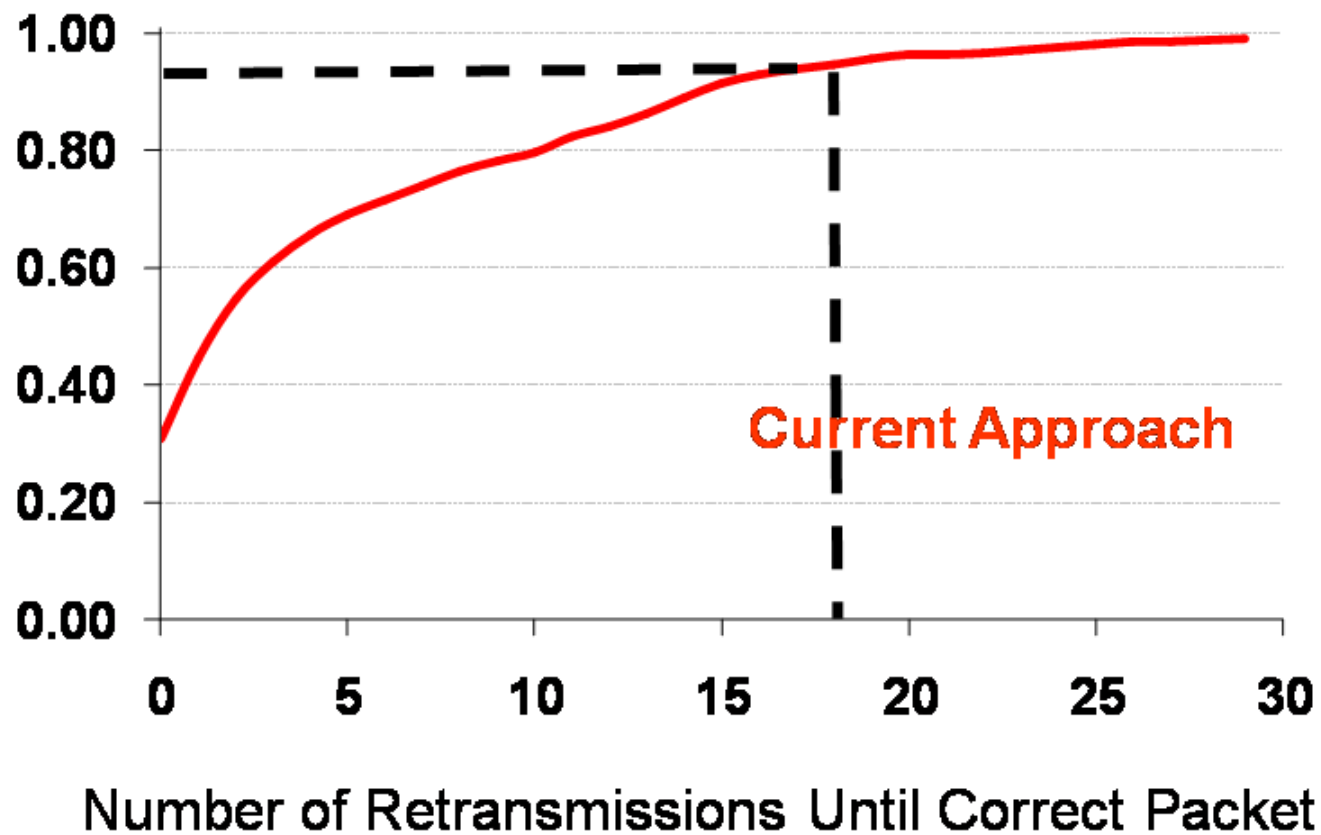
Performance with Increasingly Poor Coverage



SOFT Addresses Dead Spots

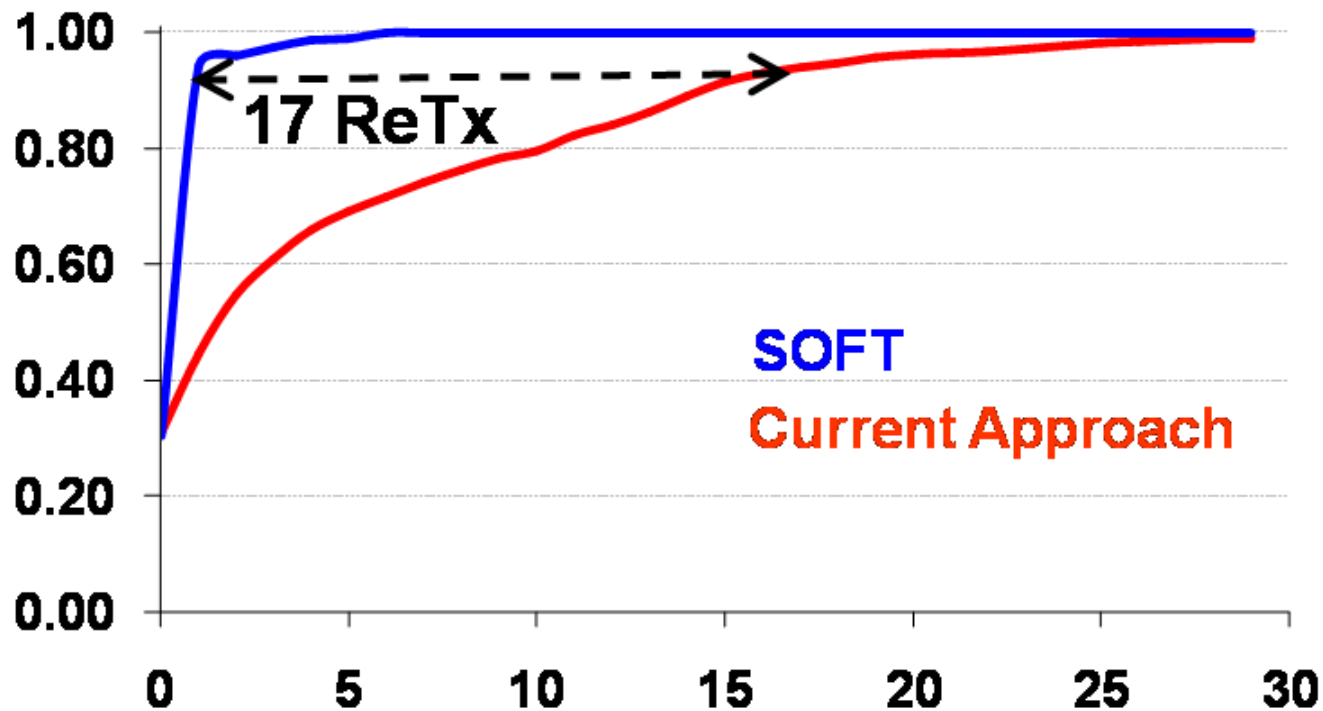
SOFT on Downlink

CDF over 50,000 packets



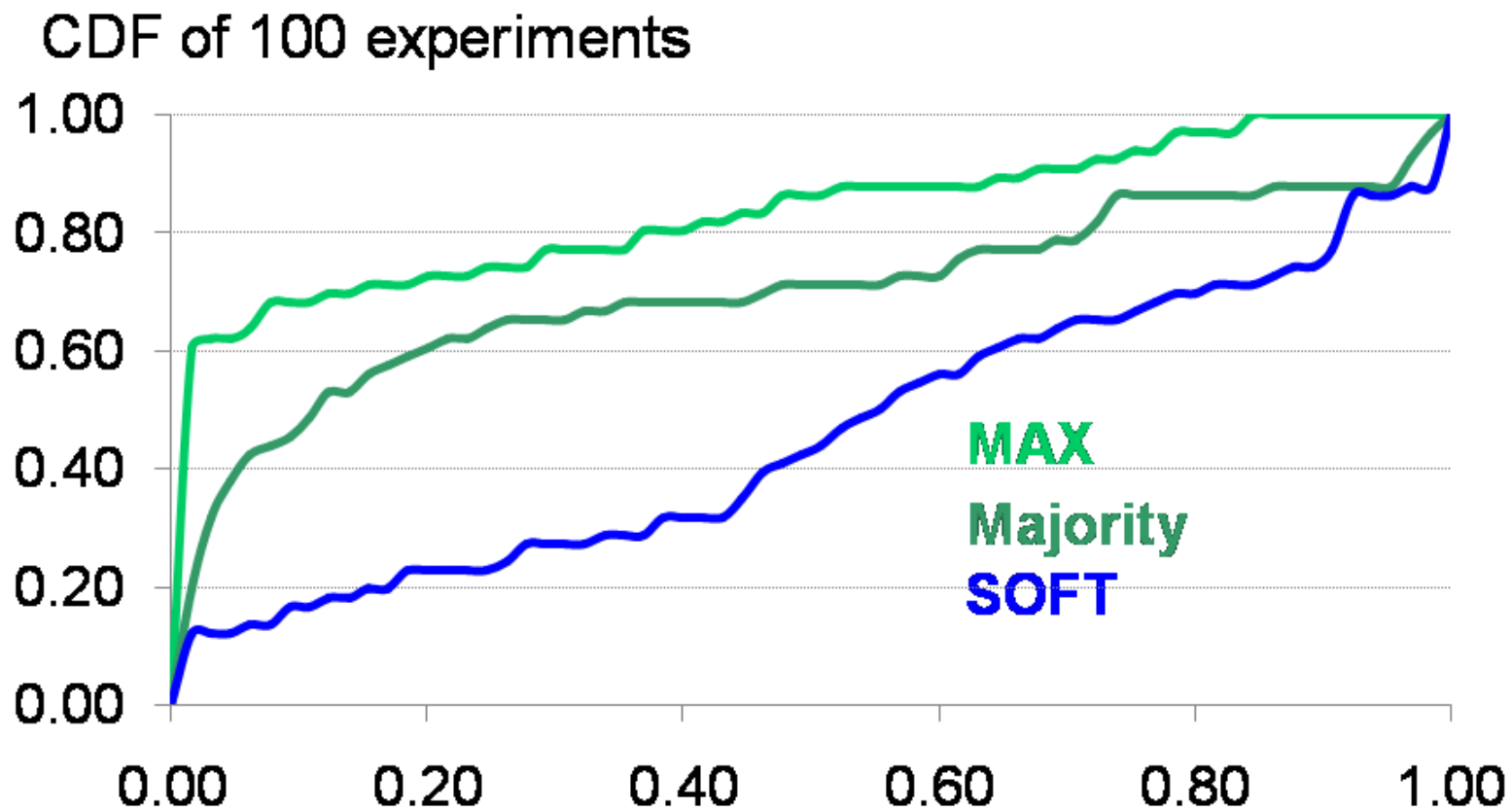
SOFT on Downlink

CDF over 50,000 packets



Much Higher Throughput!

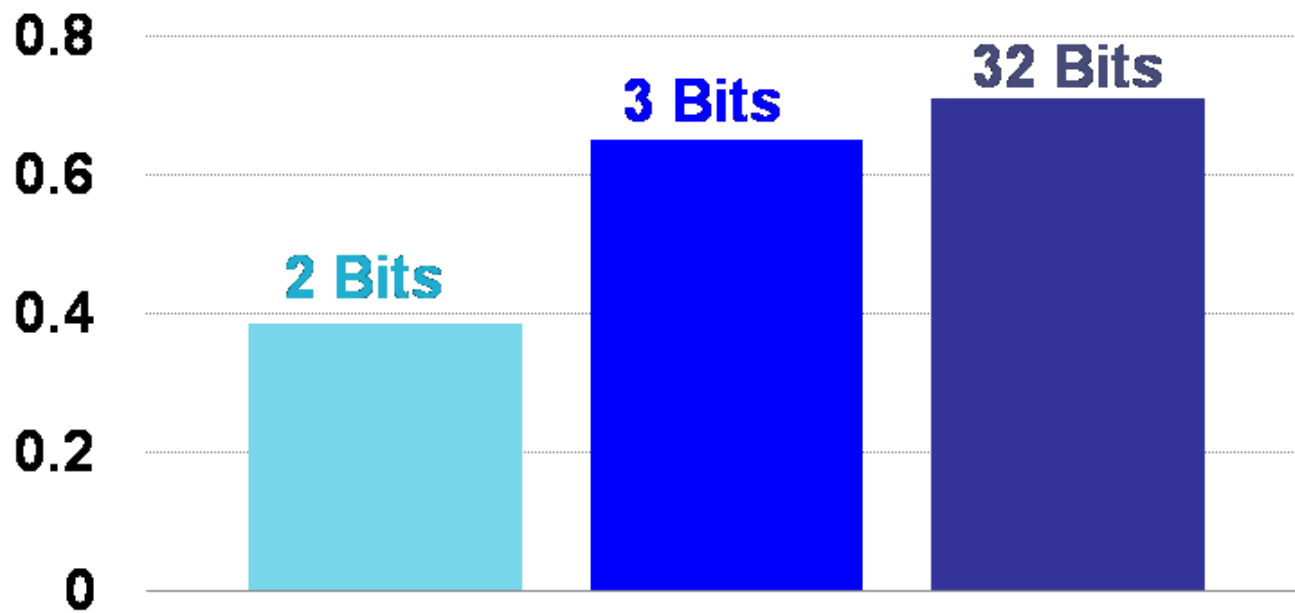
Combining Method Is Important



SOFT Outperforms MAX and MAJORITY

Effect of Quantization

SOFT Average Delivery Rate



Overhead on Wired Ethernet is Acceptable

Related Work

- Soft and softer handoff in cellular networks
- Theoretical Maximum Ratio Combining (MRC) [Brennan55,Yang99]
- H-ARQ & Chase Combining [ASX03]
- Partial Packet Recovery [Jam07]

Conclusion

- WLAN can have better coverage if the interface to the PHY exposes soft values
- Delivery rate can be up to 10x higher
- Ethernet overhead is acceptable
- The new architecture, SOFT, can co-exist with unmodified 802.11 cards and APs