Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Network-to-network interference measurements]

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Abstract: [Network-to-network interference measurements for nearby, uncoordinated BANs, where the networks cause co-channel interference. Implications for interference mitigation]

Purpose: [To promote discussion of the dynamic channel model in 802.15.6.]

Network-to-network interference measurements

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David Rodda, Ben Gilbert

Outline

- Network-to-network interference measurements
- Implications for direct sequence spread spectrum techniques

More info:

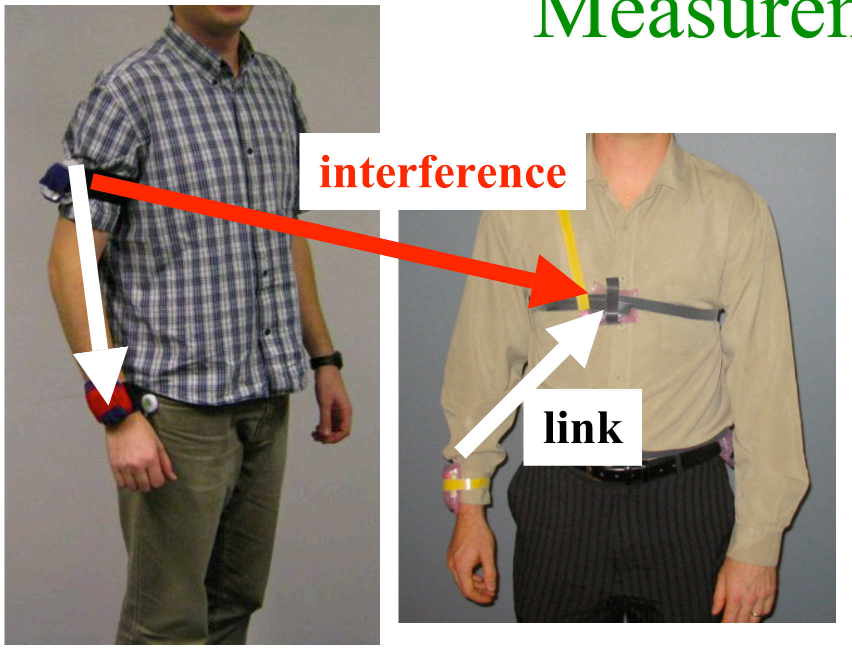
Interference in Body Area Networks: Are signal-links and interference-links independent?, Zhang, Hanlen, Miniutti, Rodda, Gilbert, *NICTA tech-report CRL-2177*

Interference in Body Area Networks: Distance does not dominate*,* Hanlen, Miniutti, Rodda, Gilbert, *NICTA tech-report CRL-2175*

Objective

- Addresses questions:
  - How severe is interference from adjacent body area networks?
    - We will show:
      - Typical BAN-to-BAN interference
      - Collective (10 users) interference.
  - Do we need to measure signal & interference simultaneously for Signal-to-Interference-Ratio estimates?

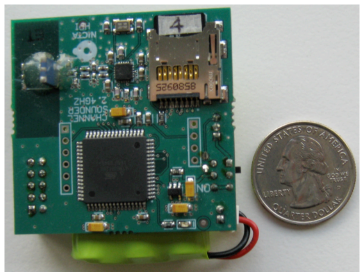
Measurement Technique



Wearable channel measurement device

- 2360MHz Carrier frequency, 10kHz BW
- 0dBm transmit power, -95dB receiver sensitivity
- 60minutes of data with 5 test subjects walking in office environments
- Subjects wore one or two devices each

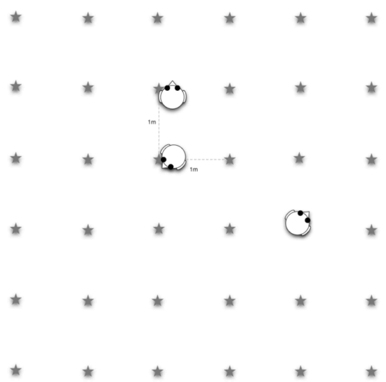
- Body surface to body surface: CM3, Scenarios S4, S5
- **And** Body surface to external: CM4, Scenarios S5, S6



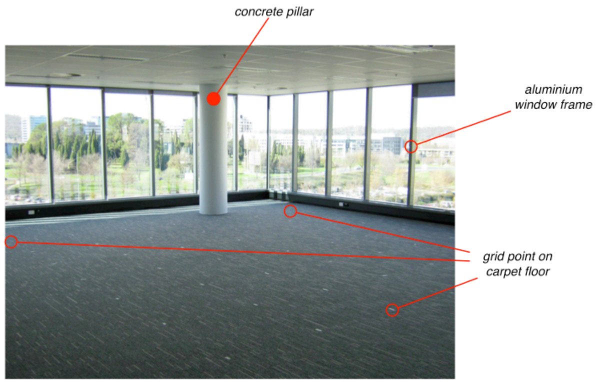
- Received Signal Strength Indicator (RSSI) quantifies attenuation
- On-body to on-body (person A to person A) link gives signal strength
- On-body to on-body (person A to person B) links give interference strengths

Measurement Technique
Scenario 1: random movement in office area

- 5 male subjects moving in pseudo-random arrangement
  - 6m x 6m grid layout with 1m gradation
  - Subjects stood at grid points and faced random directions
  - Subjects walked slowly between grid points at fixed time intervals
- Transceivers worn on upper arm, wrists and in hip pockets
- RSSI measurements give direct power ratio of signal and interference

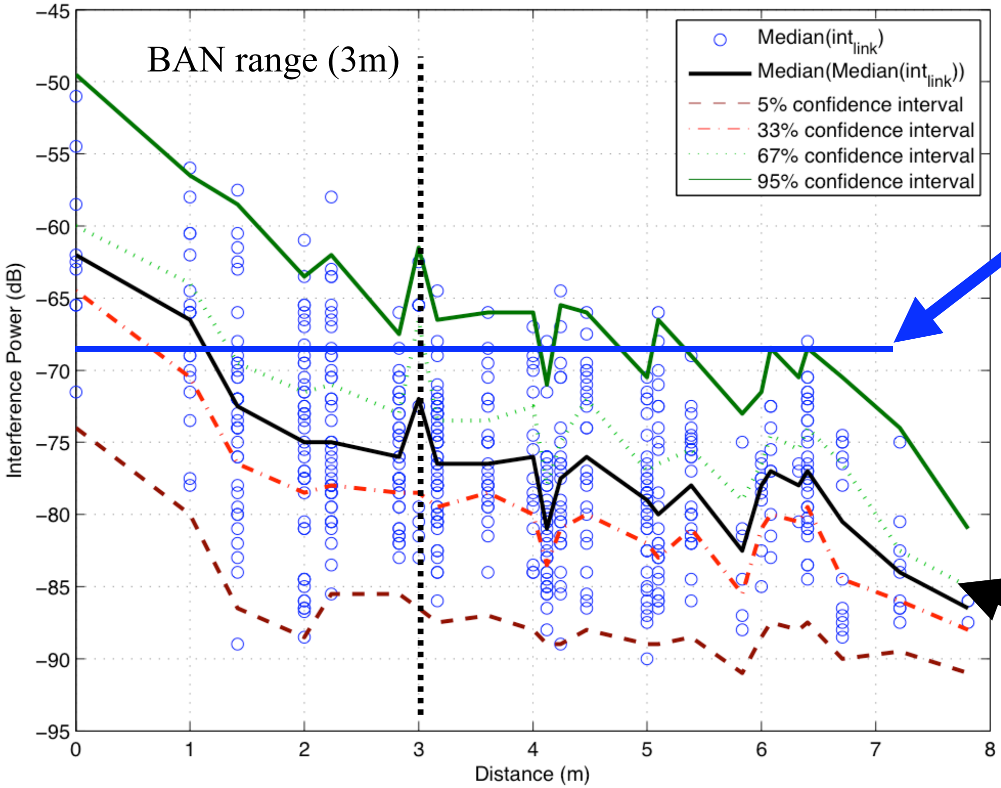


Subject	1	2	3	4	5
Tx	(1) right hip	(2) right hip			
Rx	(a) right shoulder	(b) left wrist (f)* right hip	(c) left hip	(d) left hip	(e) left hip



Interference Power vs Distance

No strong correlation between distance to interferer and received interference power



Median operating point at 0m is -67.7dB

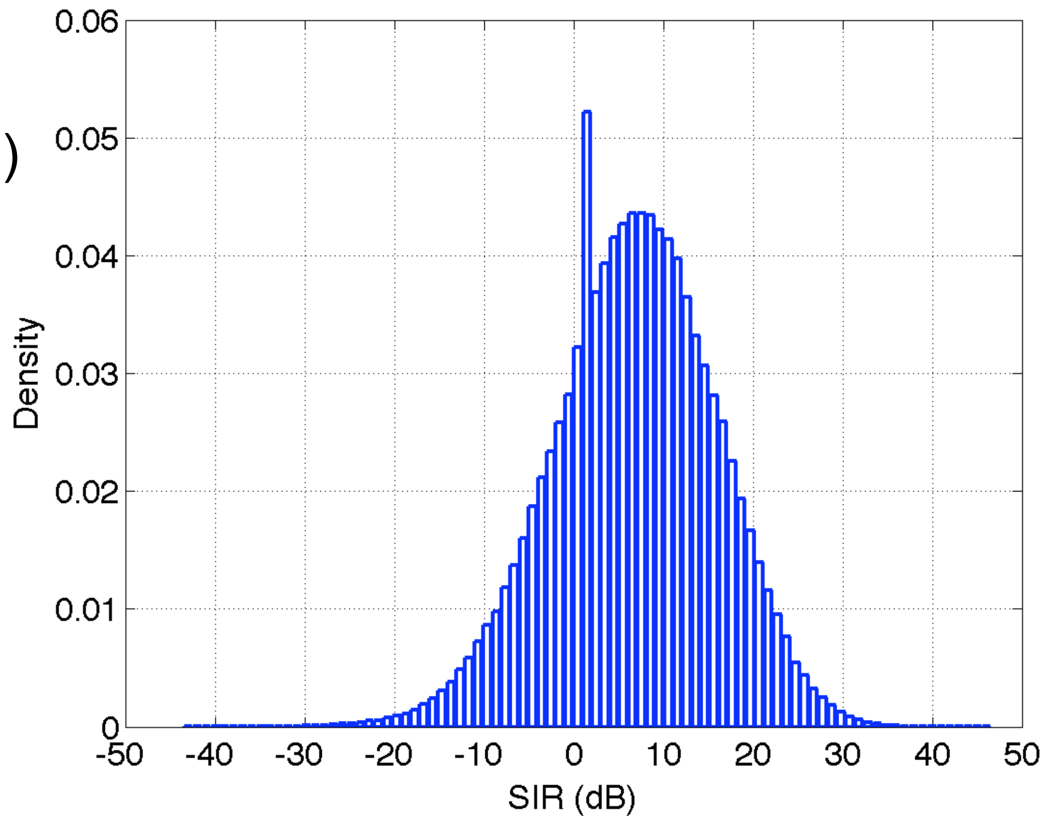
Median trend line given by:

$$-2.1D_{\text{meters}} - 67.7 \text{ dB}$$

Interference in Body Area Networks: Distance does not dominate, Hanlen, Miniutti, Rodda, Gilbert, *NICTA tech-report CRL-2175*

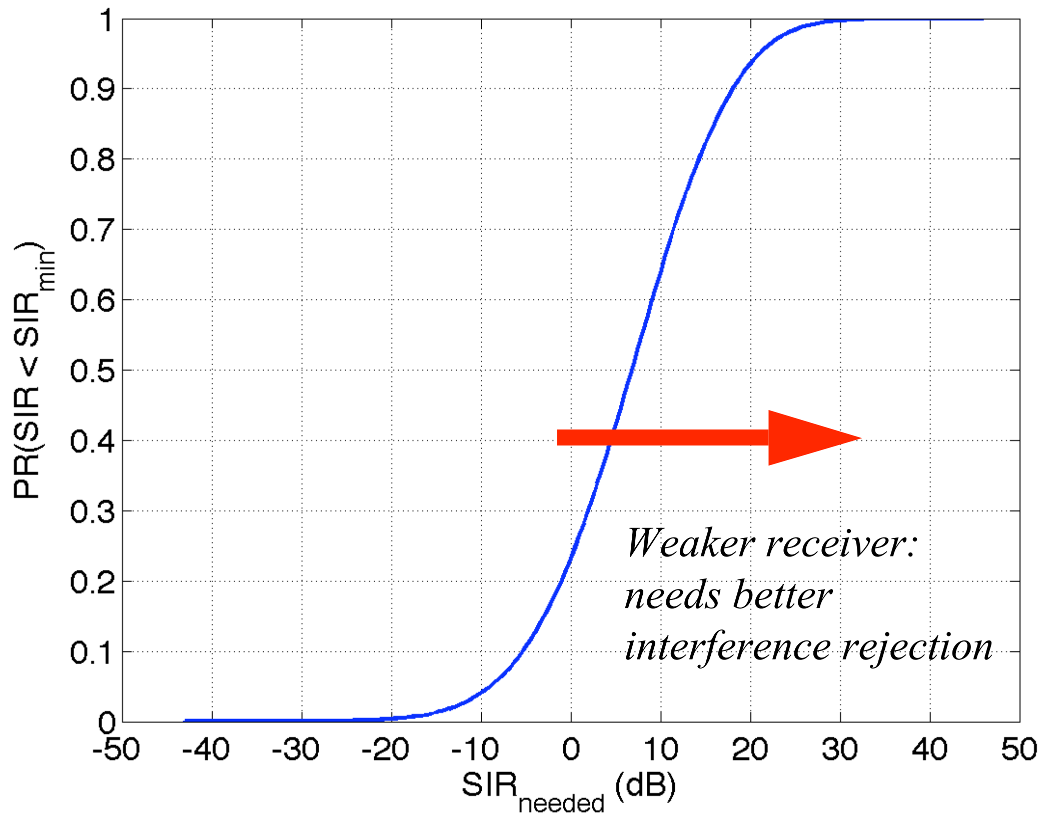
PDF of Signal-to-Interference Ratio

- Assumes all users on same channel
- Gives SIR for single (typical) interferer
- Median single-interferer SIR: +7dB



Outage probability

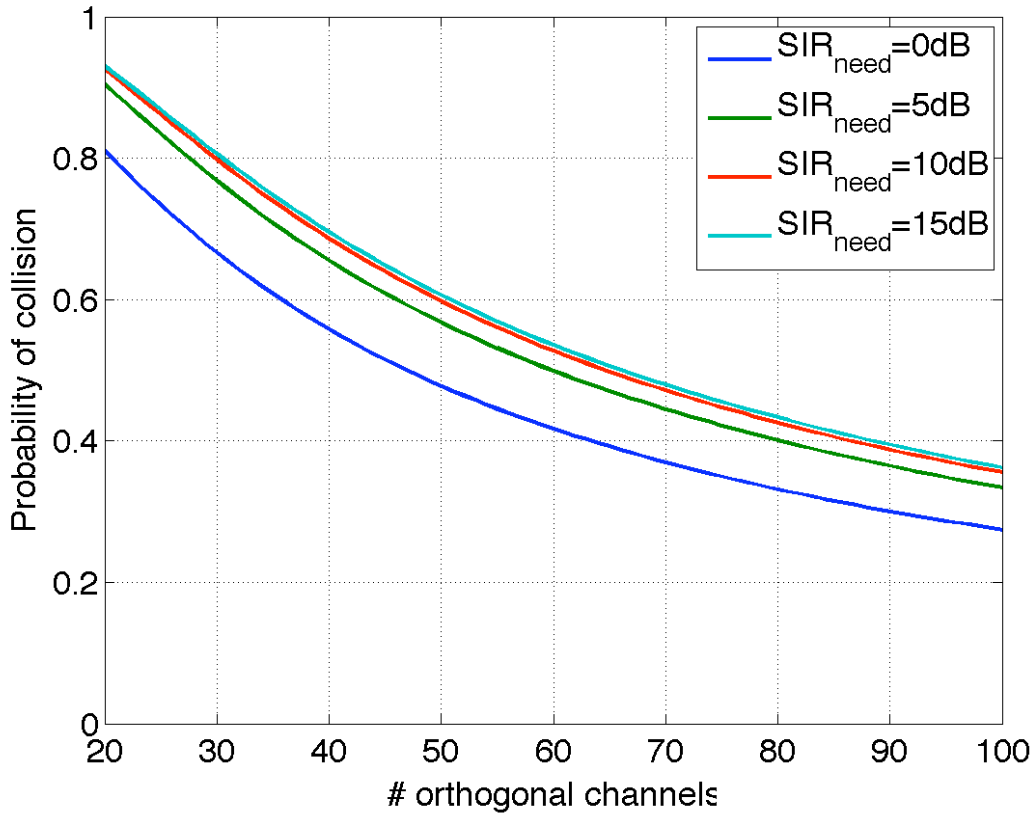
- SIR for a single user, and a single typical interference
- SIR_{NEEDED} gives minimum SIR receiver can tolerate
  - When sample SIR is below SIR_{NEEDED} the receiver is in outage



Collision probability

Assume: each BAN occupies a (whole) channel; each BAN is assigned a channel at random (from all possible)

- Given n channels and q users, the probability of at least 2 BANs in same channel (overlap) may be found numerically
  - Solution to "birthday paradox"
- AND If any overlapping user has SIR below SIR_{NEEDED}, a collision occurs (data loss due to interference)

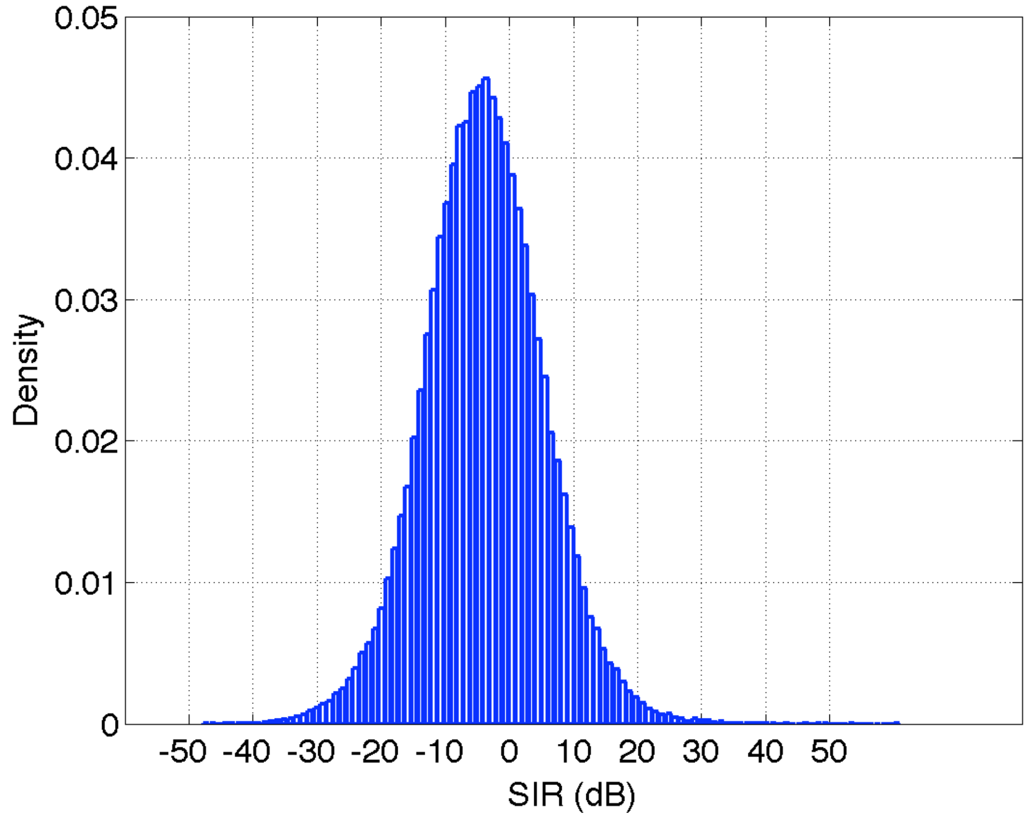


Model for multiple users

- Measured RSSI is a power measurement
  - Convert to signal amplitude
- Apply random phase (uniform between 0 and 2pi) to 10 randomly selected RSSI signals
  - Had 5 interferers in experimental results
  - Take 9 (random) samples of these measurements to generate 9 virtual interferers
- Sum to give total interference
- All calculations in linear domain (convert to dB only at the end)

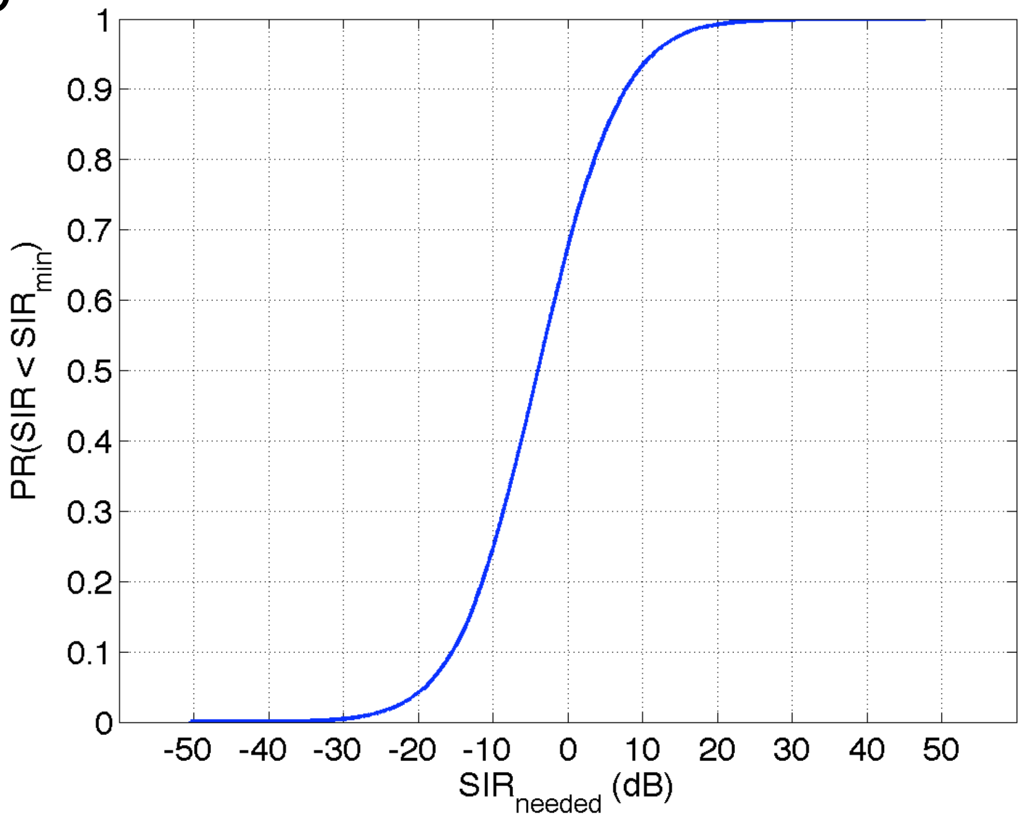
10 users modeled SIR

- Assuming 10 users in same channel
- Non-coherent (random phase) signal addition
- Median operating point:
  - 9-interferer SIR, -4dB
  - Log-normal profile



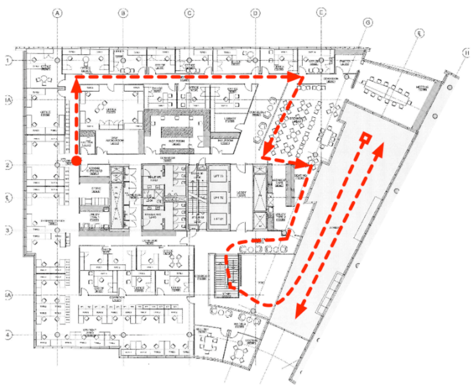
10 user model CDF

- SIR for a 1 user, and 9 co-channel interferers
- SIR_{NEEDED} gives minimum SIR receiver can tolerate
  - When sample SIR is below SIR_{NEEDED} the receiver is in outage



Measurement Technique
Scenario 2: walking in office area

- 5 male subjects walking in office
  - Movement constrained by corridors, doorways & stairs.
- Transceivers worn on wrists, in hip pockets, jacket and shirt (check) pockets
  - 2 subjects with on-body links
  - Channel sampled every 10ms

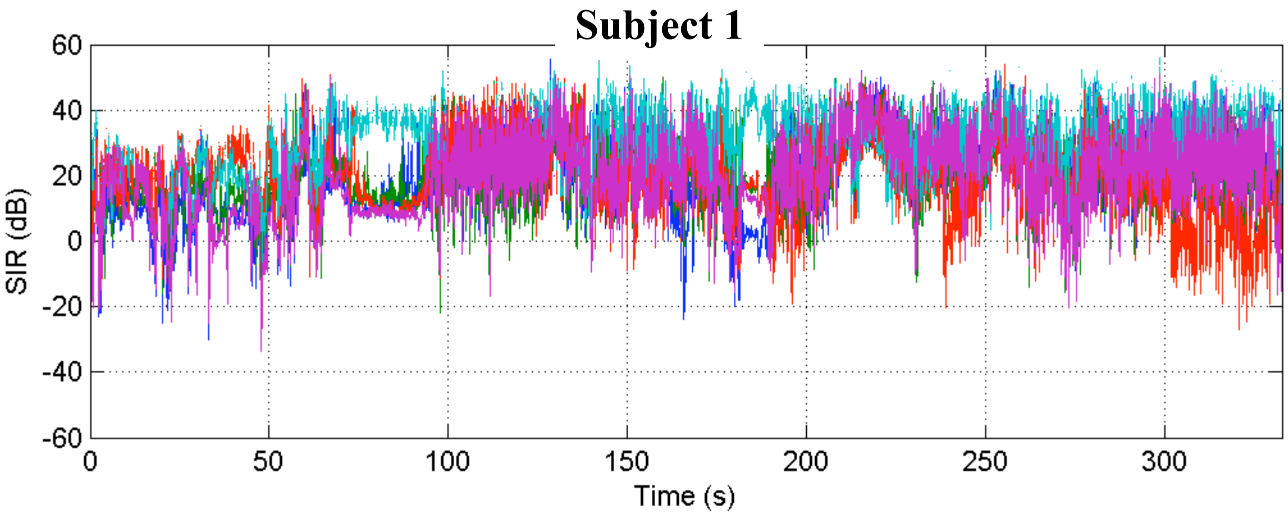


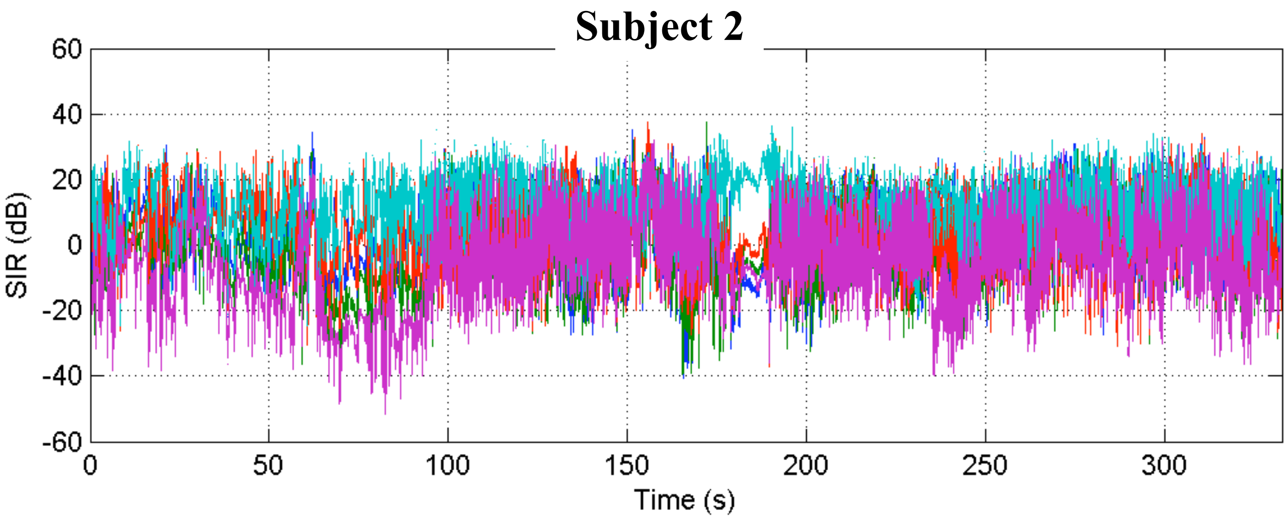
Signal strength and interference strength are time-independent over timeframes of more than a few seconds

Person	1	2	3	4	5
Tx	left wrist	left wrist			
Rx	left hip pocket	Right Hip Pocket	Jacket Pocket	Jacket Pocket	Check Pocket

Interference in Body Area Networks: Are signal-links and interference-links independent?, Zhang, Hanlen, Miniutti, Rodda, Gilbert, *NICTA tech-report CRL-2177*

SIR over time





Implications for Direct Sequence Spread Spectrum

- Difficult for networks to collaborate, cannot do conventional power-control
- Near-far issue a known problem for DS-SS
  - Also: Asynchronous nature of networks
  - Combined interference vs probability of intercept

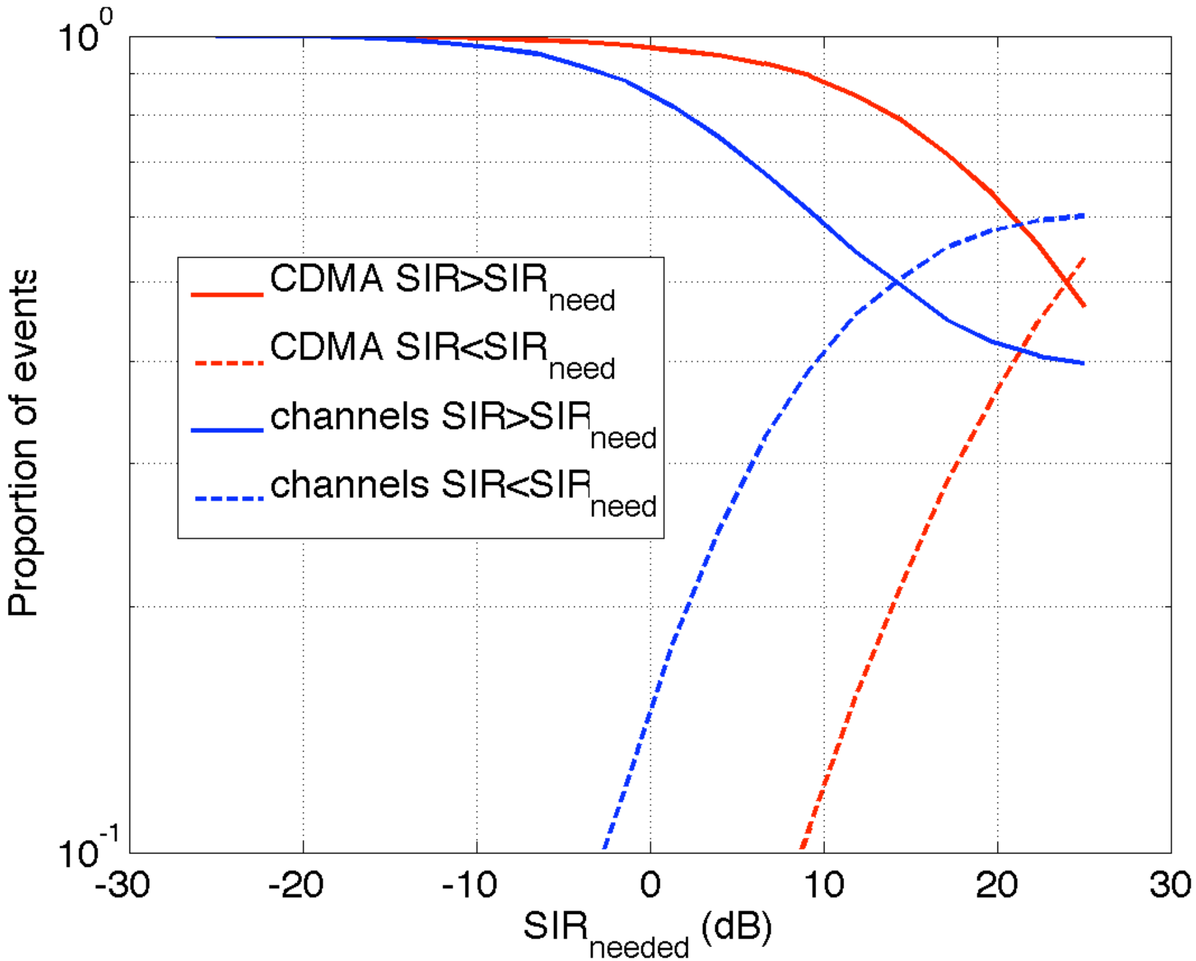
Simulation for SIR and DS-SS

- Compared SIR receiver capability with fixed channelisation vs DS-SS
- Channel uses Scenario 1, with 10 BANs (9 interferers)

- DS-SS
- Optimized length 7 codes
- Codes assigned at random to each BAN
- Asynch arrival
- Interference power adds (random phase) for 9 interferers
- IF SIR < SIR_{needed} THEN record outage.

- M-fixed channels
- BAN assigned at random to a channel
- Interference in each channel adds (random phase) for K interferers
- IF SIR < SIR_{needed} AND channel equals user's channel THEN record outage.

Simulation result



Summary

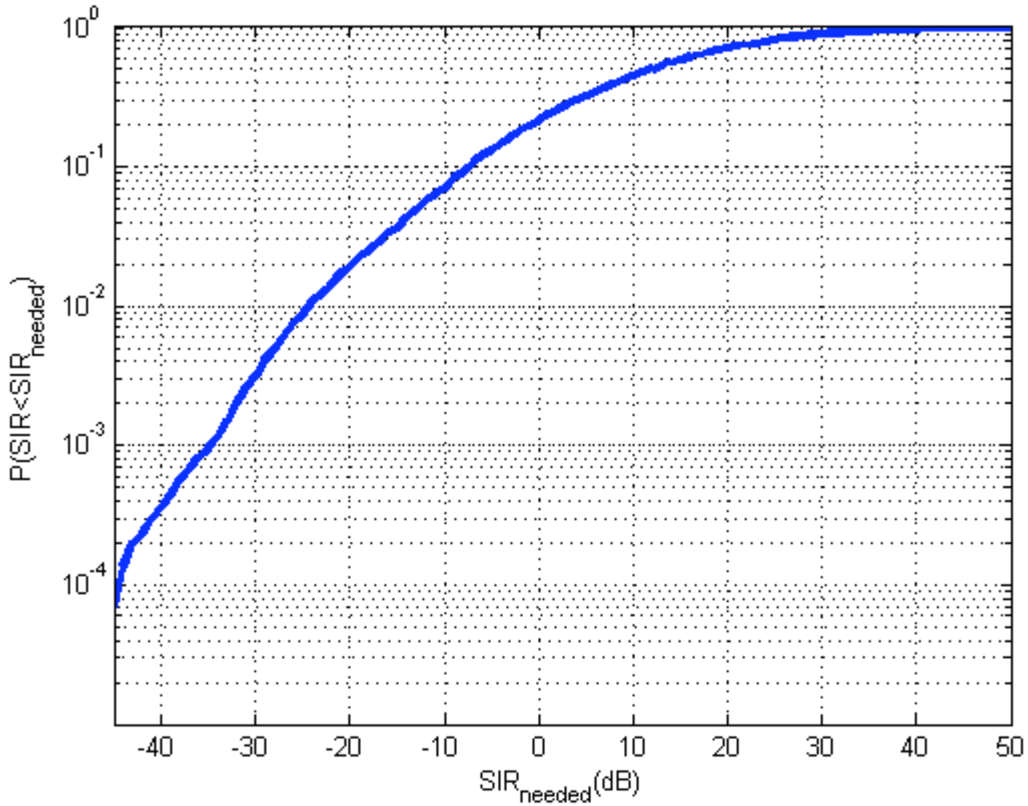
- We have measured co-channel interference in office environments
- Interferer power: Path-loss due to distance is overwhelmed by SIR variability
- Signals and Interferences are independent in macro-scale (1 to 10's of seconds)
- SIR variability causes substantial near-far issues
- Interference mitigation via DS-SS compared with fixed orthogonal random channels
  - appears robust when tested on measured and simulated multi-user interference.

Appendix 1:
Time-effects of “office traffic”

Single-user SIR outage probability [Scenario 2]

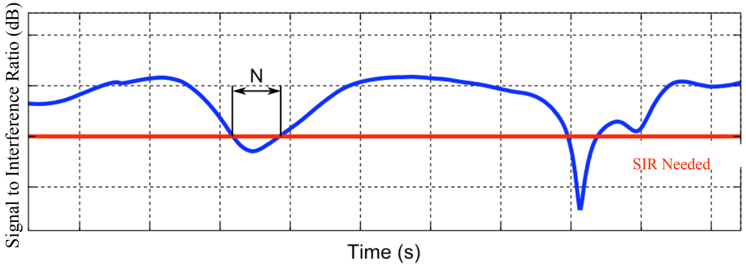
- Probability of a **sample's** power being below Rx sensitivity

- SIR for a 1 user, and 1 co-channel interferer
- SIR_{NEEDED} gives minimum SIR receiver can tolerate
  - When sample SIR is below SIR_{NEEDED} the receiver is in outage



Median SIR point is 12dB

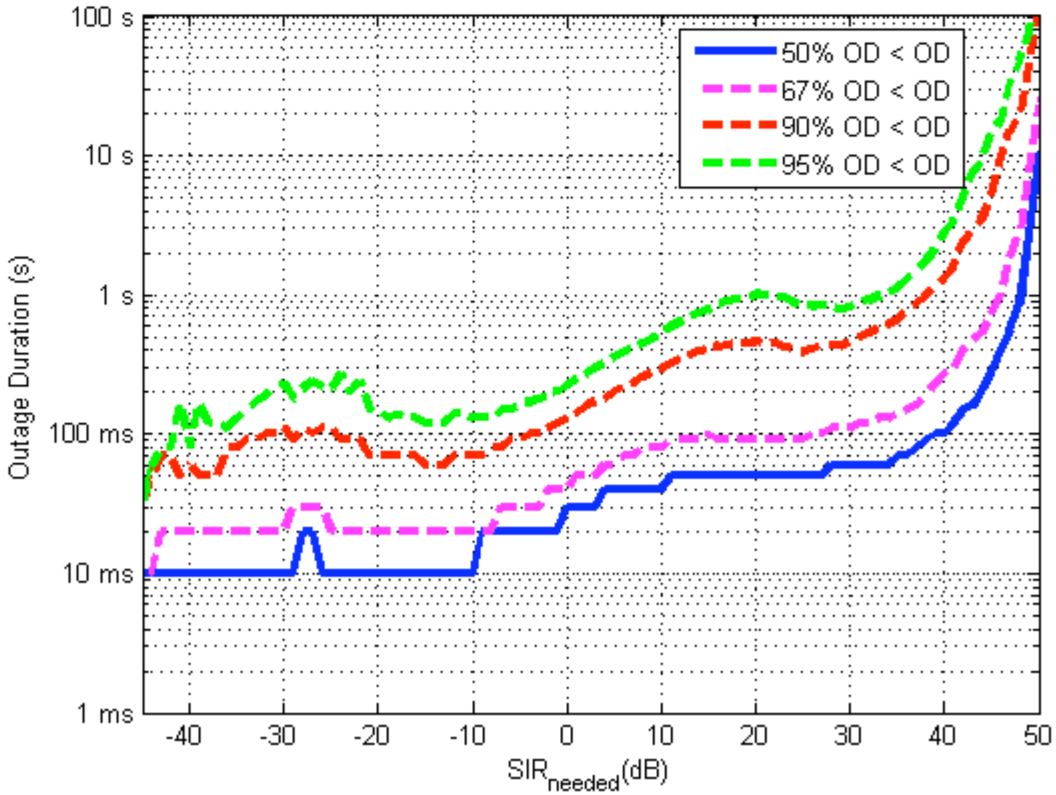
Outage duration



- Systems must cope with losing N seconds of data, X% of the time due to co-channel interference

SIR$_{NEEDED}$ gives minimum SIR receiver can tolerate

X% of outages last less than N seconds



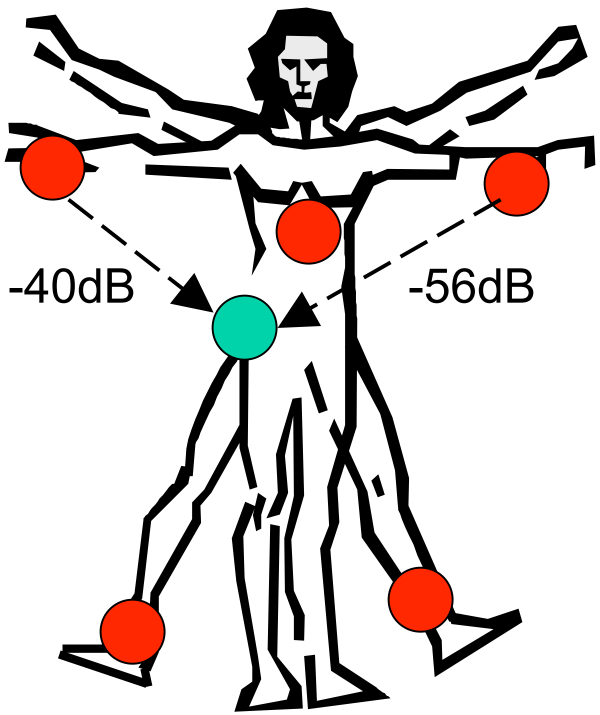
Castalia BAN examples

Results from the complex channel modelling with some simple traffic scenarios.

Castalia software V2.1

Scenarios setup

Six nodes: 1 sink (right hip), 5 transmitters (around the body)



Wireless channel: Average path losses measured in testbed + temporal variation (parameters extracted from real testbed)

Radio: 1Mbps, PSK, -95dBm sensitivity, -20dBm TX power

Scenarios run for 100sec, packets 140bytes

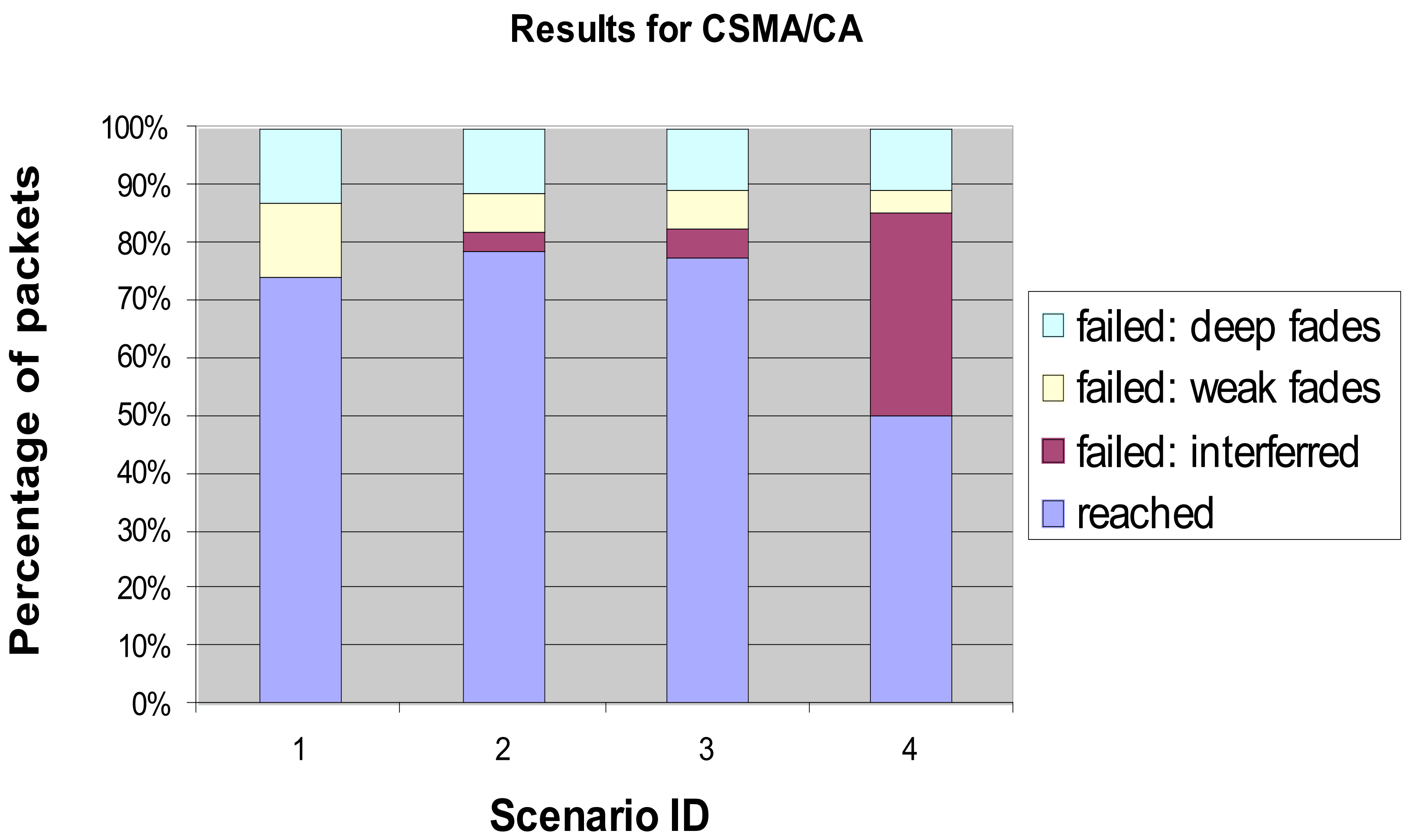
1) Only node 3 sending at 10 packets/sec
2) All nodes sending at 2 packets/sec
3) All nodes sending at 20 packets/sec
4) All nodes sending at 200 packets/sec *

* requires 1.1Mbps total throughput

Questions to answer

- How many packets get lost due to temporal fading?
- How many failed due to deep fades and how many failed with a probability of reception > 5% (weak fades)?
- Is there significant interference (despite CSMA) due to temporal hidden terminal problems?

Results for CSMA/CA

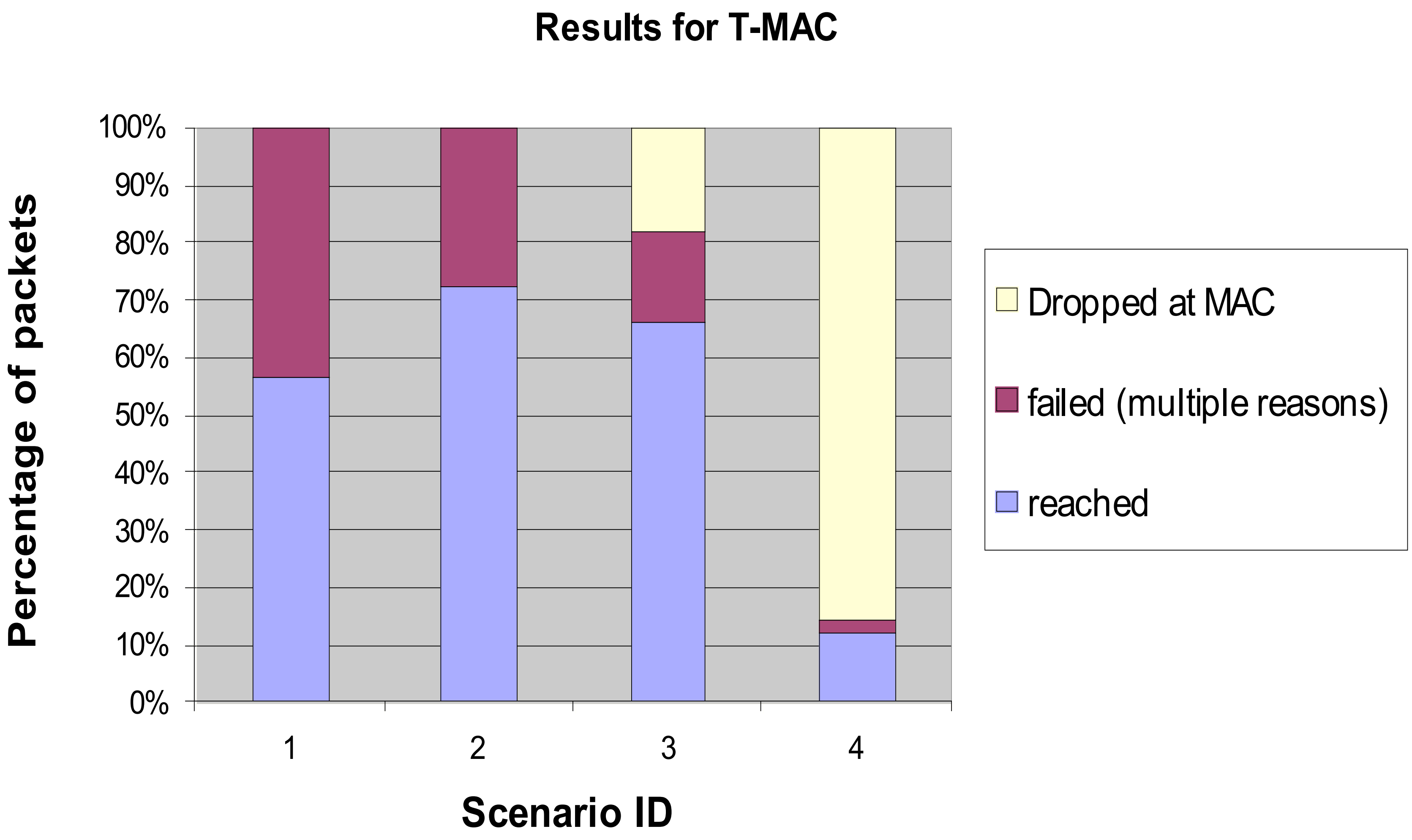


More questions

- Would a ACK-retransmission scheme (max 2 times) fight temporal fading?
- Would an RTS-CTS scheme solve the problem of interference and temporal hidden terminal problems?
- Would it efficiently handle high loads?
- Could an adaptive duty cycling scheme with time-sync be able to cope with high loads?

For all the above try T-MAC

Results for T-MAC



Appendix 2 summary

- Simpler MAC’s may be more robust under high channel variability
  - Non-intuitive results for highly variable channels.
- In high-data rate, and high channel-variability, RTS-CTS-data-ACK system may be detrimental.