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Submission Title: [PHY Interference Statistics and MAC Simulations]
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Source: [Dino Miniutti[12], David Smith[12], Leif Hanlen[12], Andrew Zhang[12], Athanassios Boulis[1], David Rodda[1], Ben Gilbert[1]] Company [NICTA[1], The Australian National University[2]]
Address [7 London Circuit, Canberra, ACT, 2600, Australia]
Voice:[+61-2-6267-6256], FAX: [+61-2-6267-6220], E-Mail:[dino.miniutti@nicta.com.au]

Abstract: [First order statistics of BAN signal and interference links. Castalia MAC simulations.]

Purpose: [To help design and evaluate BAN systems.]

PHY Interference Statistics and MAC Simulations

NICTA & The Australian National University
Dino Miniutti, David Smith, Leif Hanlen, Andrew Zhang

NICTA
Athanassios Boulis, David Rodda, Ben Gilbert

Outline

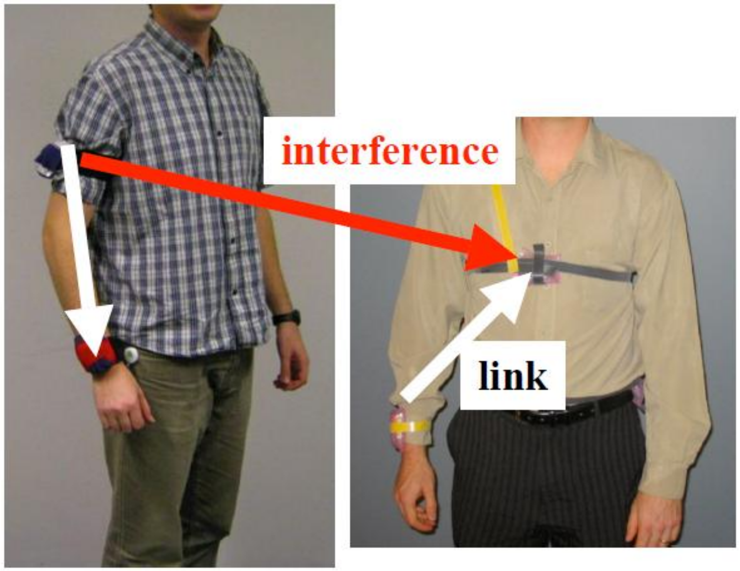
- Part I
  - PHY interference measurements
  - First order statistics of signal and interference strength
- Part II
  - MAC simulation results

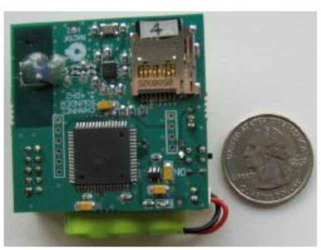
Part I
PHY Interference Measurements

Objective

- Characterise signal and interference links
  - Interference from other BANs (networks on other people)
  - More detailed models than previously published by NICTA
  - Intent is to allow groups to simulate their own systems
- We will show how severe interference can be if nothing is done to avoid it
  - i.e., we are showing how important it is to avoid interference

Measurement technique





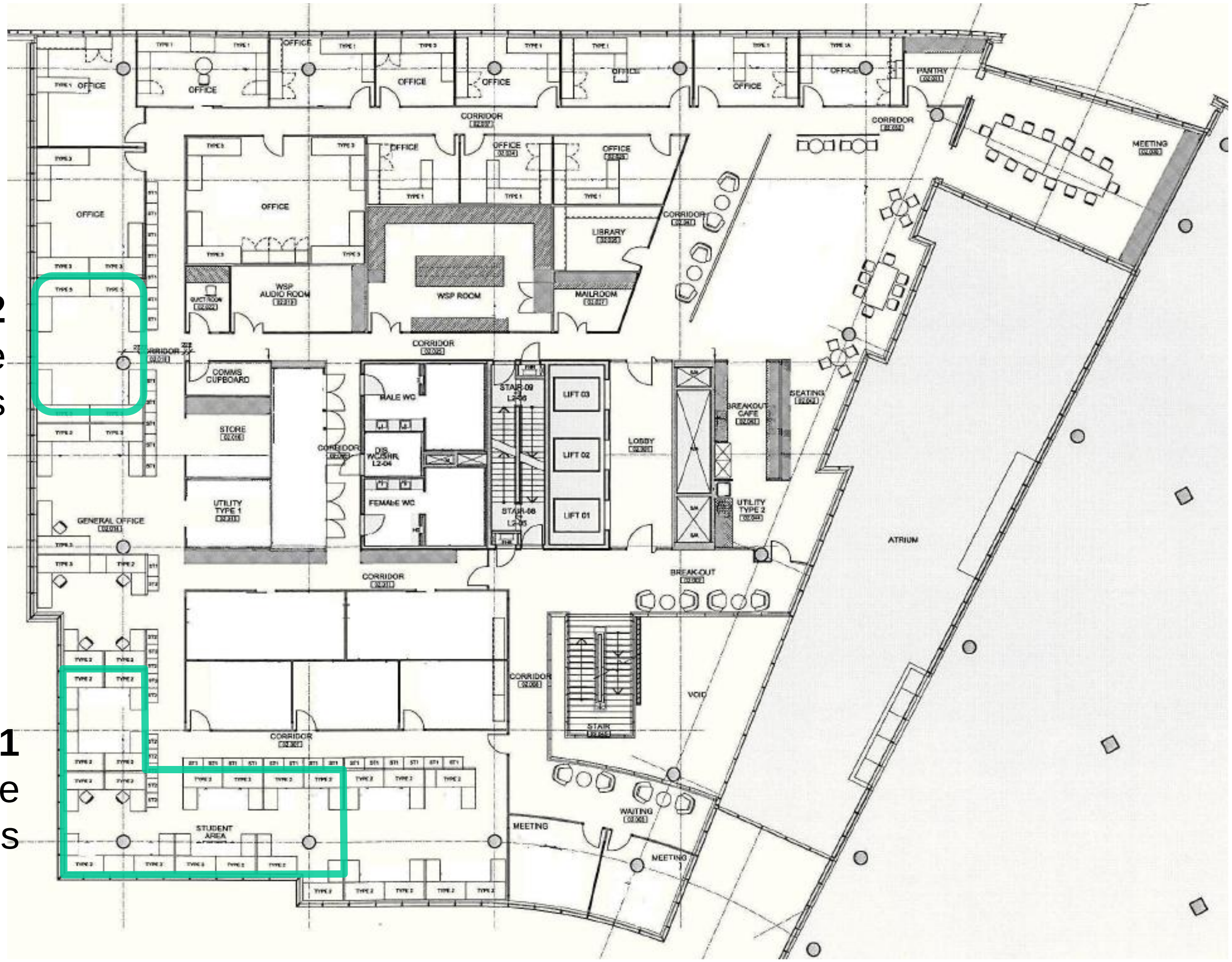
- Each person wears one Tx and multiple Rx devices (pictured)

- 2.4 GHz signal sent from Tx
- RSSI logged at each Rx
  - Signal = On-body links
  - Interference = Off-body links
  - Antennas are considered part of channel

Experimental Environment

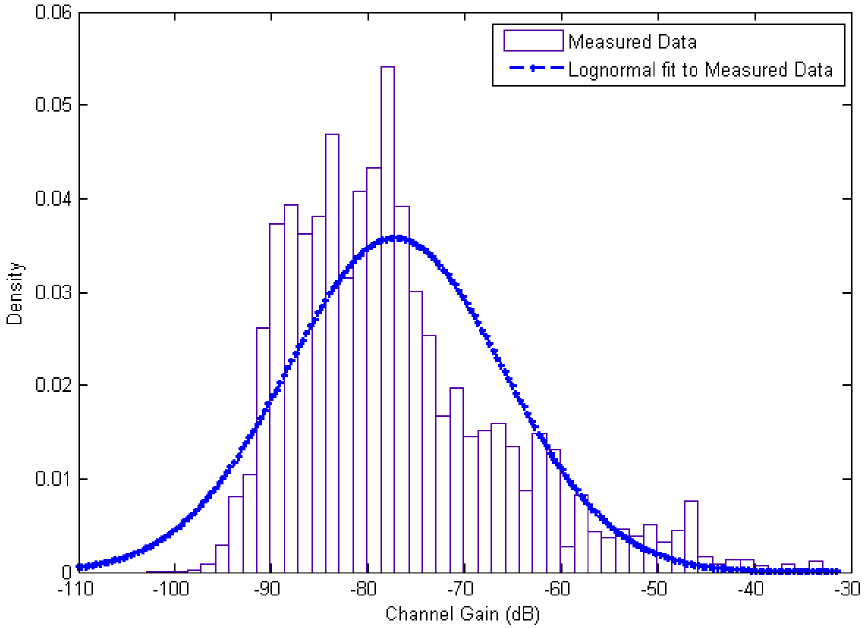
Experiment 2
3 people
~1.5 hours

Experiment 1
7—9 people
~8 hours



Channel Gain Power Distribution: Signal

- Experiment 1
  - The Lognormal distribution is the best fit to the received signal power



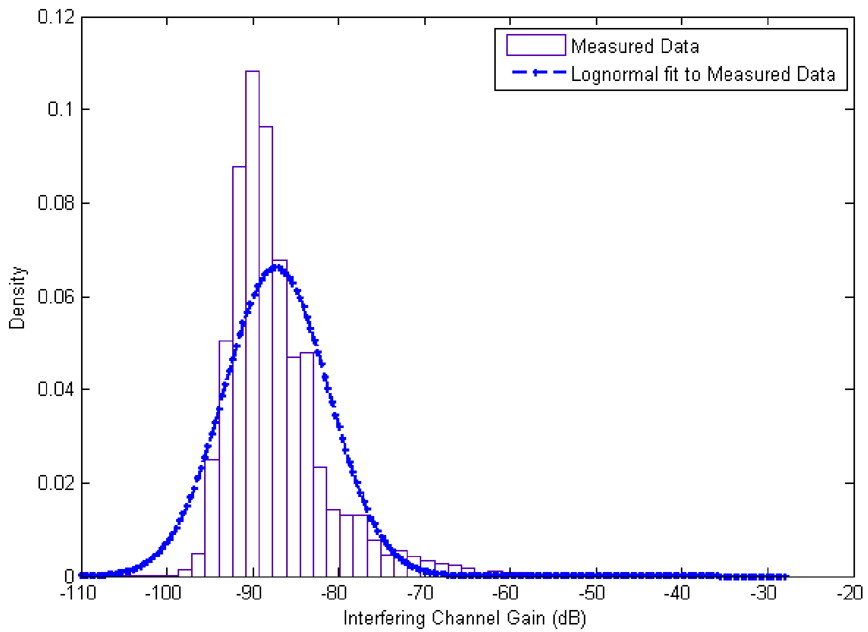
Lognormal:

$$f(x|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{\frac{-(\ln(x)-\mu)^2}{2\sigma^2}\right\}$$

- Best ML estimates:
  - Log mean, μ = -17.8
  - Log standard-dev, σ = 2.57
- Median Channel Gain -79 dB

Channel Gain Power Distribution: Interference

- Experiment 1
  - The Lognormal distribution is the best fit to the relative interference power



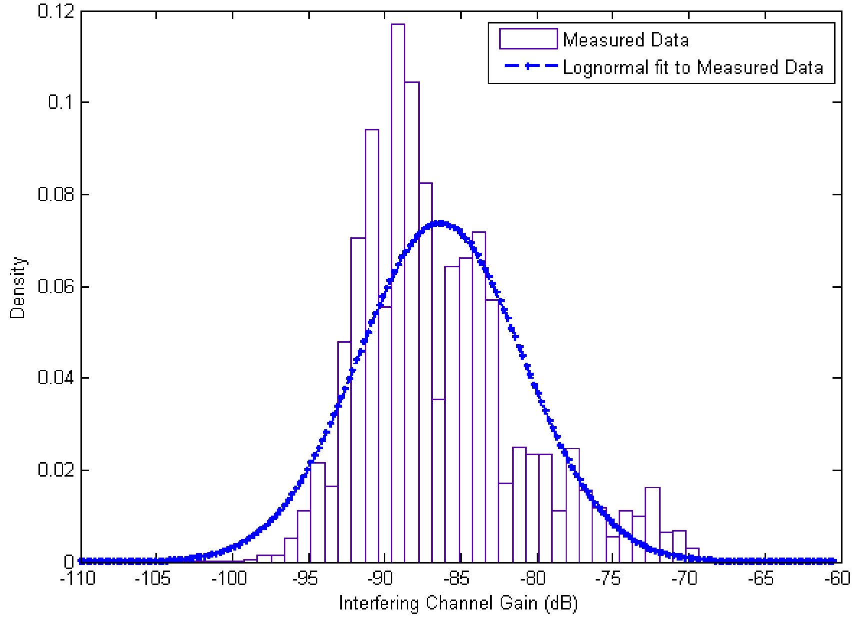
Lognormal:

$$f(x|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{ \frac{-(\ln(x)-\mu)^2}{2\sigma^2} \right\}$$

- Best ML estimates:
  - Log mean, μ = -20.1
  - Log standard-dev, σ = 1.39
- Median measured interfering channel gain -88.5 dB
  - Hence reasonable median SIR is 9.5 dB
- Percentage time of measured interference (i.e. > -100dB)
  - 6.3%

Channel Gain Power Distribution: Interference 2

- Experiment 2
  - The Lognormal distribution is the best fit to the relative interference power



Lognormal:

$$f(x|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{\frac{-(\ln(x)-\mu)^2}{2\sigma^2}\right\}$$

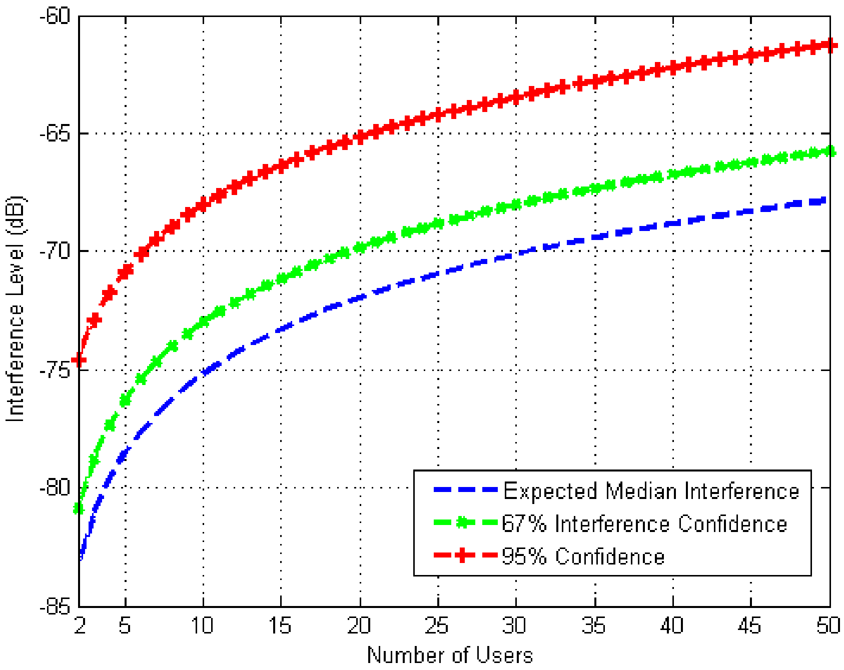
- Best ML estimates:
  - Log mean, μ = -19.9
  - Log standard-dev, σ = 1.25
- Median measured interfering channel gain -87.5 dB
- Percentage time of measured interference (i.e. > -100dB)
  - 26.7%

Combining Interference

- Experiment 1 had up to 9 people. What happens when you add more interferers?

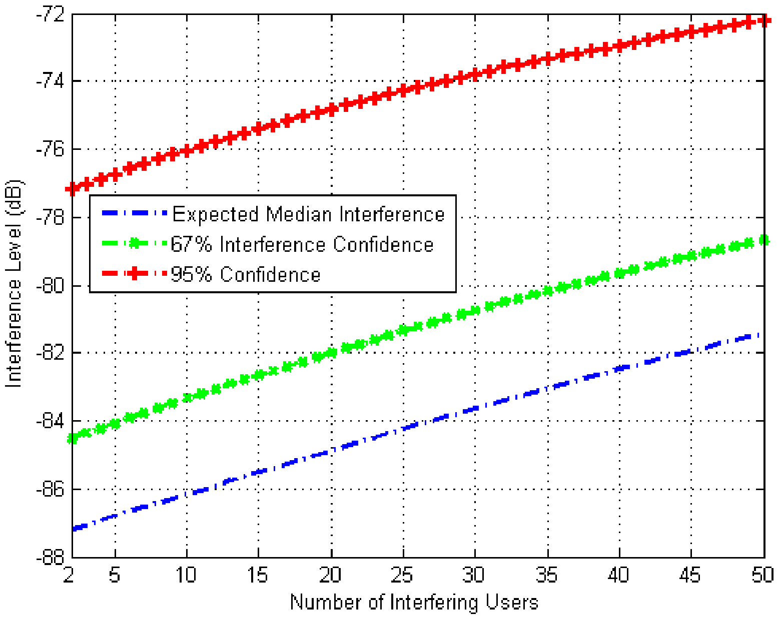
- To find interference level: Sample from distribution, apply random phase, combine.

- No interference avoidance (e.g., FDMA, frequency hopping...)
- Interferers always present
    - Read lower number off graph if interferer not present



Assuming Fixed Chance of Interference

- Now assuming that interferers have a fixed chance of being present
  - 6.3% chance of interference (obtained from experiment 1)
  - Chance of interference is scenario specific (does not generalise)
- Interference level increases at a lower rate, as expected

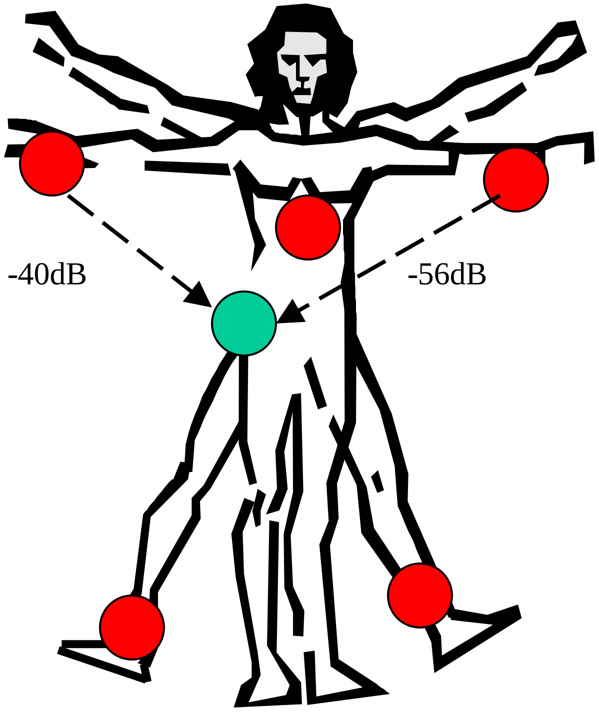


Part II
MAC Simulation Results

Objective

- Using Castalia to simulate an example MAC
  - Unexpected behavior can be observed in seemingly simple conditions
  - Showing effect of channel dynamics
- Using a modified version of the IEEE 802.15.4 MAC as an example
  - Modified to use BAN-appropriate parameters where possible
- Not trying to propose a MAC
- Not trying to improve 15.4 MAC

Simulation Setup: Wireless Channel



- Star topology
  - 1 sink/hub (right hip)
  - 5 transmitters
- Wireless channel based on NICTA's measurements
  - Includes temporal variation

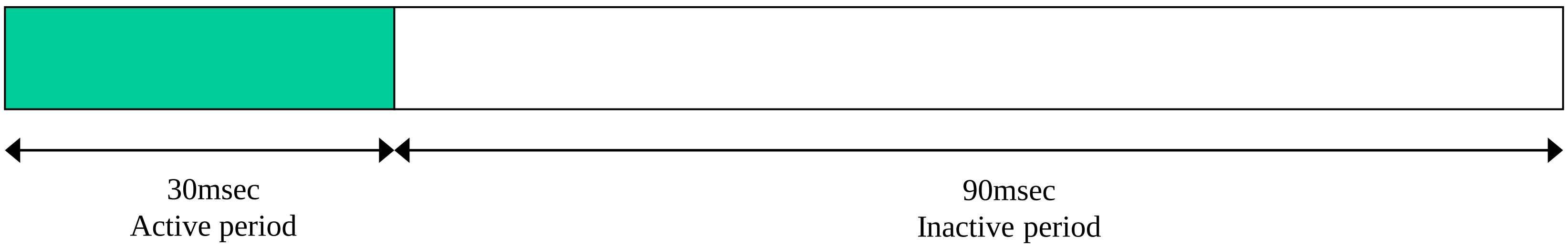
Simulation Setup: Radios

Data rate	1024 kbps	512 kbps
Modulation	D-QPSK	D-BPSK
Rx sensitivity	-87 dBm	-91 dBm
Noise BW	1 MHz	
Noise Floor	-104 dBm	
Tx power	{-10, -12, -15, -20, -25} dBm	
CCA time	1 ms	
Tx→Rx and Rx→Tx transition times	20 μs	

Unless specified otherwise, the 512 kbps option is used for the following analysis

Simulation Setup: MAC

- Modified version of 802.15.4 MAC
  - Using 802.15.6 parameters where appropriate

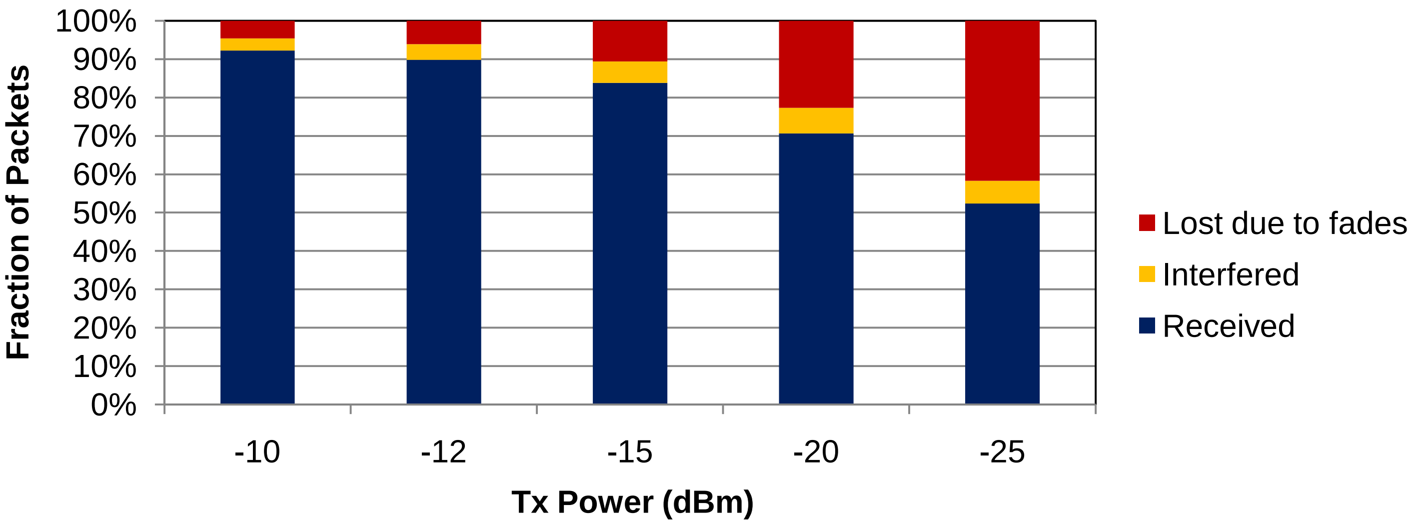


- 25% duty cycle, time synched active periods, contention based
- ACKed data packets
- 1 retransmission allowed (ACK timeout ~1.2 ms)
- Synced active periods
  - Beacon packets TXed every period
  - Two beacons lost → resync (current packet dropped)
- Application layer is providing MAC with data at constant rate
- 32 packet Tx buffer

Measuring Performance

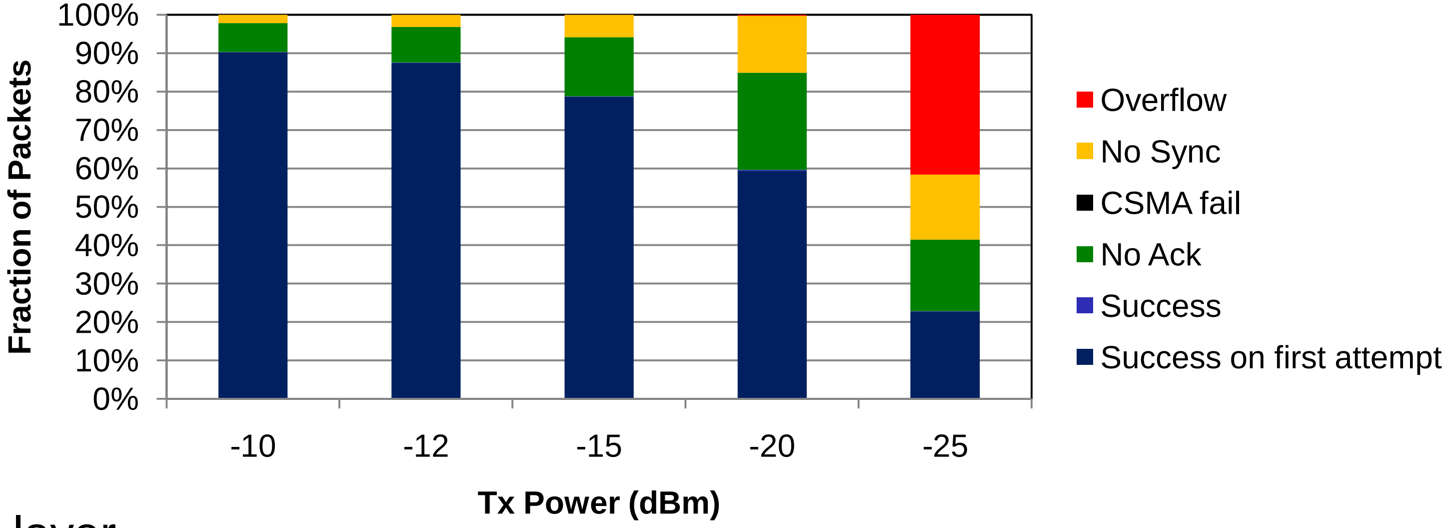
- At the PHY layer, receiver node
  - Each data packet is counted individually
  - No differentiation between first attempt or retransmit; each packet is equal
  - E.g., if initial Tx fails, then retransmit → counted as two packets
- At the MAC layer, transmitter node(s)
  - Each data packet is counted once
  - E.g., if initial Tx fails, then retransmit → only counted as one packet

Results: Varying Tx Power



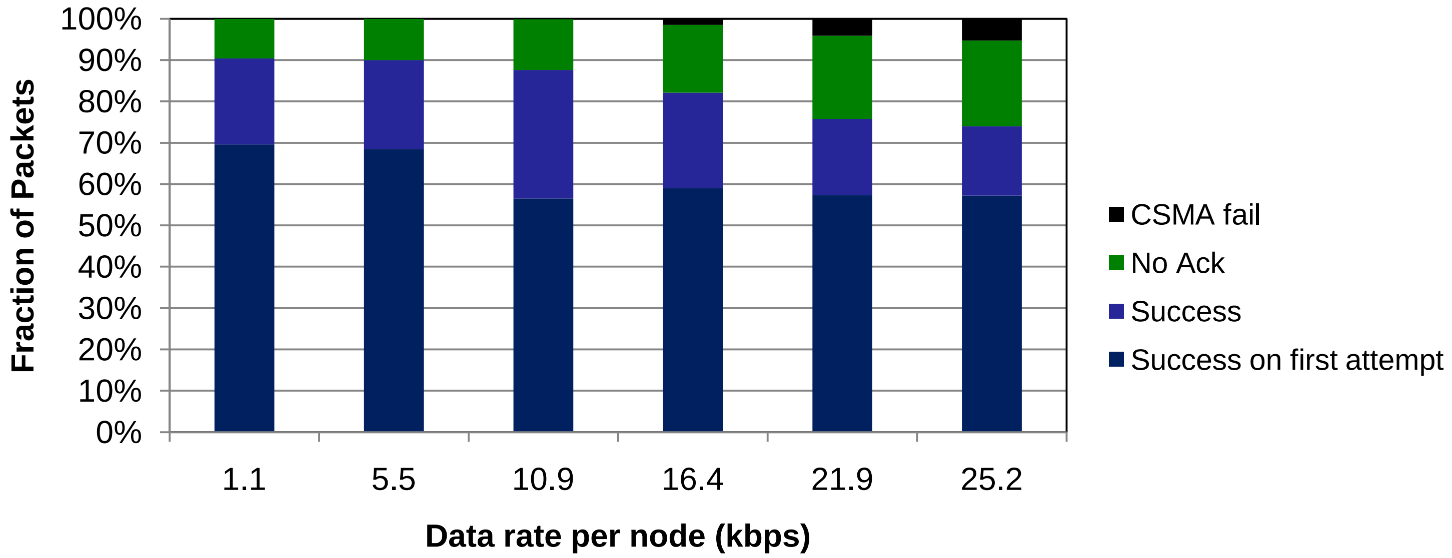
- PHY Layer
- Only one node sending data (at 10 kbps)
  - Other nodes are still active, no data, just sending control packets
- Less power → More dropped packets
- Interference is due to collision with control packets
  - Beacons, re-association requests
- Generally expected behaviour

Results: Varying Tx Power



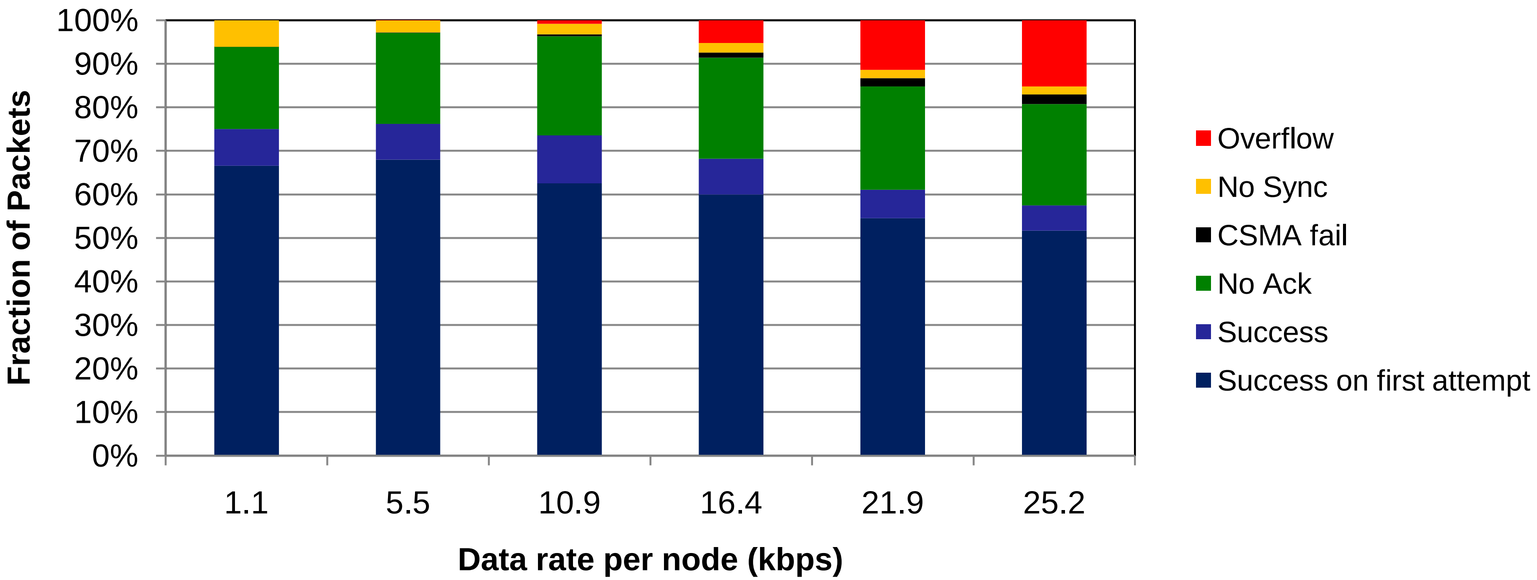
- MAC layer
- Many ways for Tx to fail; look at overflow at -25 dBm Tx power since the high number of overflown packets is a little unexpected
  - Increased delays → buffer filling up and dropping packets (overflow)
  - Due to many beacon packets lost from fades → Nodes disassociated for longer (takes time to resync)
    - Attempting to resync 25% of time → Mean packet delay =10 s
    - (compared to 8% and 170 ms at -15 dBm, respectively)
- This sort of behaviour isn't always obvious; simulation is required

Results: Varying Traffic



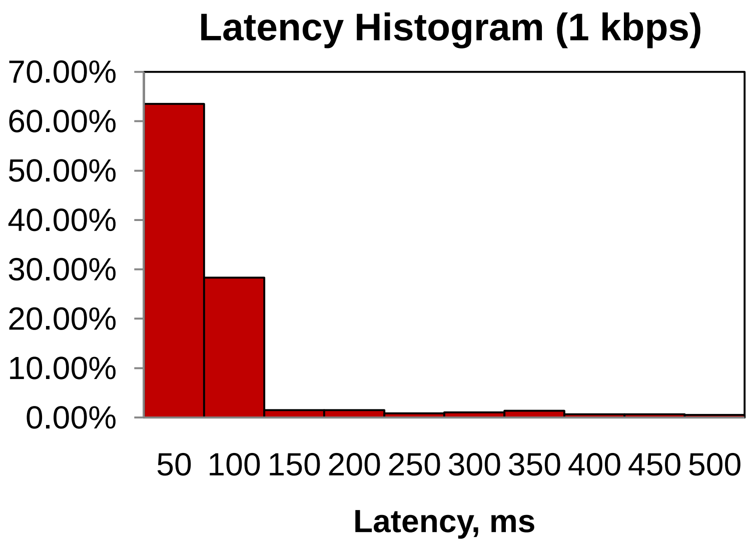
- MAC layer, now all 5 nodes transmitting, Tx power = -10 dBm
- No temporal fading in channel model
  - All failures are due to collisions with packets from other nodes
- Notice that a large portion of packets are successful on 2^{nd} attempt
- Generally expected results

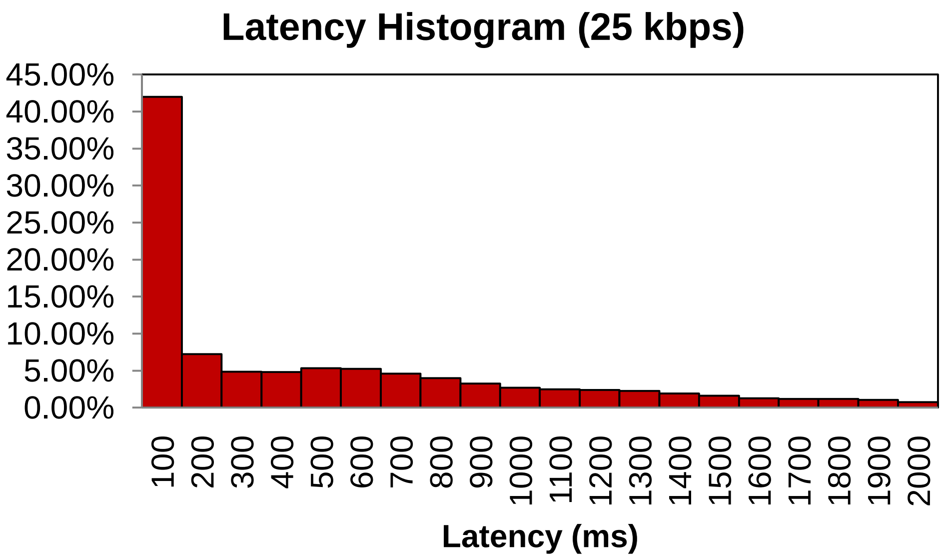
Results: Varying Traffic



- Introduce temporal fading in channel model
- Proportion of successful packet retransmissions are now a lot lower
  - When channel is bad it stays bad for a while
  - Retransmission techniques less useful now.
- Also, less successful transmissions → increased delay → increased chance of overflow (as before)

Delay Profiles





- Low rate: Barely meets TRD requirements
- High rate: 50% of packets have delay > 200 ms
  - Long tail (up to 2s)

- Large size of delays is due to channel dynamics
  - Mean delay for 25 kbps case is 707 ms
  - If remove temporal variations in channel, the mean delay becomes 45 ms

MAC Conclusions

- MAC behaviour isn’t always obvious
  - Need to simulate MAC to be sure
- Channel dynamics introduce many new issues for BAN MACs
  - Larger delays, overflown packets, retransmissions not as effective
  - Can not ignore temporal variations
- Castalia and simulations are open source. May be verified by anyone

Updated Castalia License

- Now have choice of license to use
  - Old licence: Academic Public Licence (academic use only)
  - New licence: Free for development of IEEE 802.15.6

- Website: http://castalia.npc.nicta.com.au/