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Submission Title: [BAN Sleeping Channel: Implications for Relays]
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Abstract: [Our experimental results show that the choice of relay depends on the quality of the base-relay link and the relay-sensor link. We propose giving sensor nodes more information to help them choose the best available relay.]

Purpose: [To improve the performance of relay nodes in BAN.]

BAN Sleeping Channel: Implications for Relays

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Introduction

- We consider “sleeping channels” for BAN
  - *Person sleeping or lying down for long periods of time*
- In “Sleeping channel measurements for body area networks” (Doc. 09-0778) we showed that sleeping channels experience:
  - more attenuation than non-sleeping channels
  - longer outages than non-sleeping channels (up to several minutes)
- We study the implications of sleeping channels on relays and recommend giving sensor nodes more information about the relay to hub channel

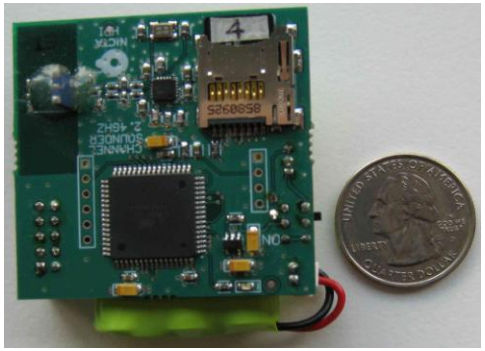
Scenario

- We consider a hospital room as an example application
  - Subject sleeping / lying down for extended periods of time
  - Loss of link is potentially life threatening

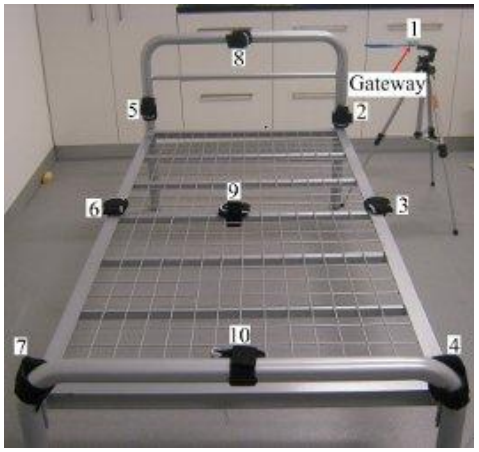
- In this scenario we have three elements:
  - A patient lying on a bed with **sensors** attached to them
  - A medical device (**hub/gateway**) at the side of the bed wirelessly receiving data from the sensors
  - **Relay** nodes placed on the bed and around the room
    - Only used when sensor to hub link is unavailable
    - No relay to relay communication

Experiment setup: Equipment

- Using NICTA's body-worn "channel sounder" (same one used in previous measurements)
  - 0 dBm transmit power
  - -95 dBm receiver sensitivity
  - Just outside 2.4 GHz ISM band to avoid interference



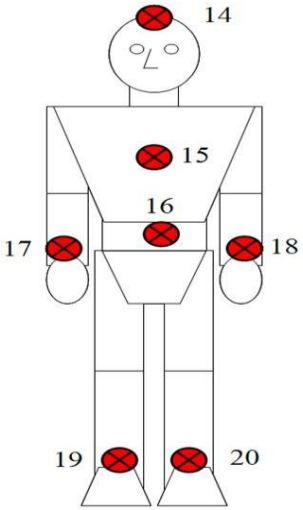
- 6 human test subjects
  - 5 male, 1 female (aged 22--35 years)
- Metal-frame bed
  - 95 cm (W) x 195 cm (L) x 45 cm (H)
  - Top-rail at head of bed 90 cm from the ground

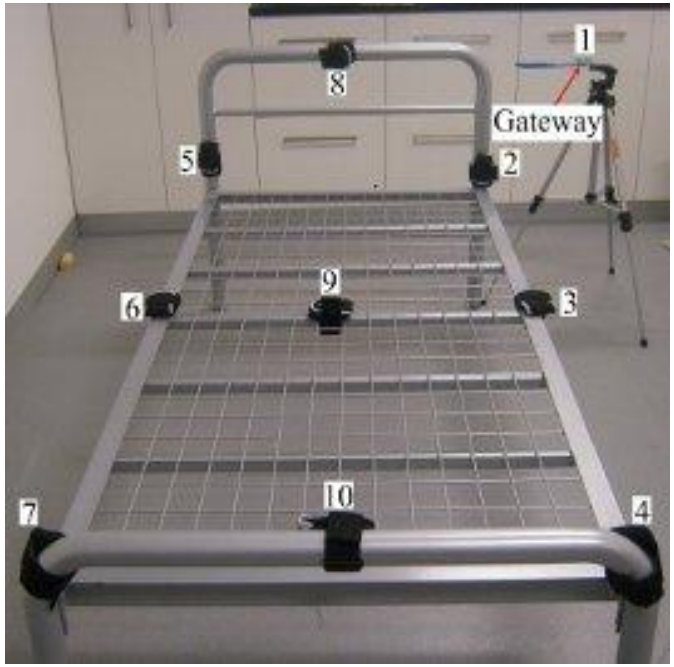


- Experiment carried out in a closed room at NICTA Canberra Research Lab
  - 295 cm(W) x 500 cm (L) x 270 cm (H)
  - All smooth and hard surfaces on floor and walls (much reflected energy)

Experiment setup: Node placement

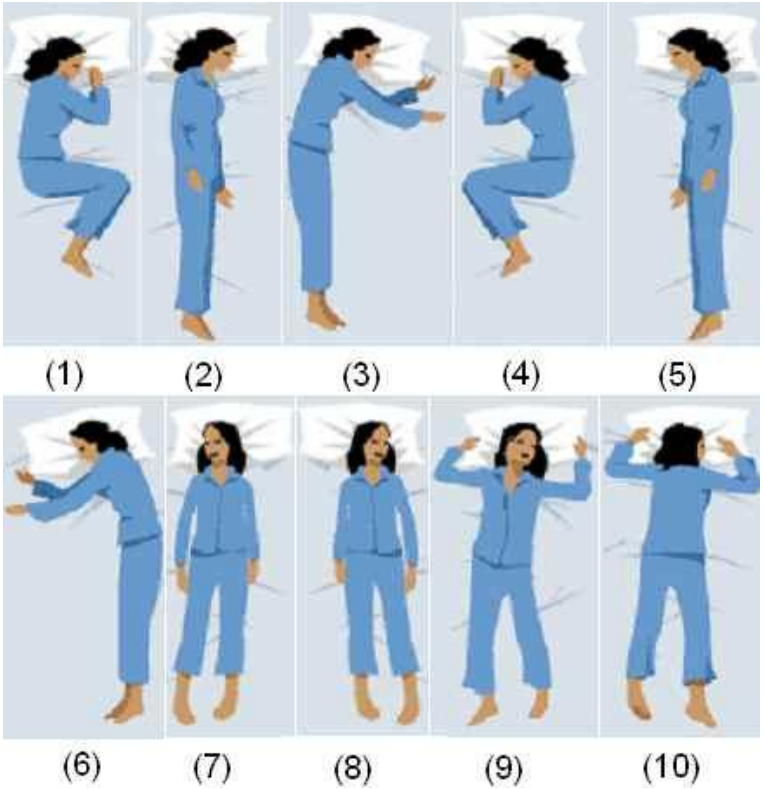
- Node 1: **Hub/gateway** at head of bed
  - 40 cm from bed at a height of 80 cm
- 12 nodes, 2—13: **Relays**
  - 9 on bed frame
  - 3 on ceiling above middle of bed (50 cm apart)
- 7 nodes, 14—20: On-body **sensors**
- All nodes have the same sensitivity





Distances
- Hub to node 7: 230 cm
- Hub to node 4: 200 cm
- Hub to node 5: 150 cm
- Hub to node 2: 55 cm

Experiment setup: Sleeping positions

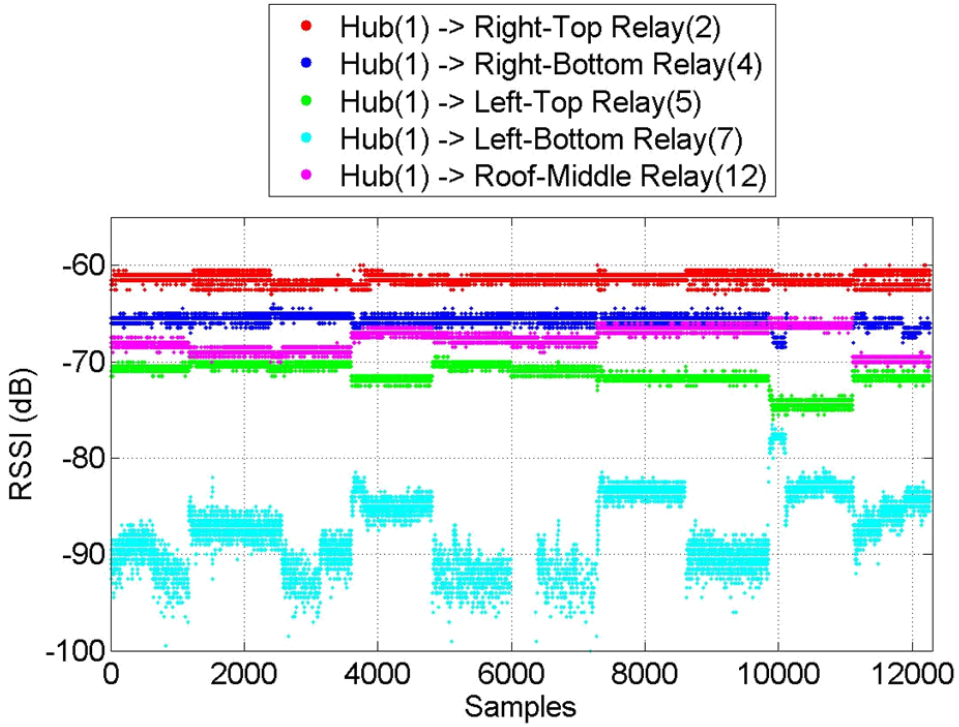


- 10 most common sleeping positions
  - Source: http://news.bbc.co.uk/2/hi/health/3112170.stm
  - Included reversed positions (left/right, up/down)

Experiment Setup: Channel measurements

- Test subject told to lie still in bed in each position for 2 minutes at a time
- Round-robin transmission from each sensor node
  - Each device transmits a packet every 100 ms
  - Measured the channel gain of each link in the system
- Link is considered in outage if it drops below receiver sensitivity
  - Using -90 dBm receiver sensitivity for the following analysis
- When the direct link (sensor to hub) is in outage we attempt to complete the link with a relay node
  - Only consider sensor to relay to hub; no relay to relay links

Example: Relay to hub channels



- Choice of relay depends on the sensor to relay link **and** relay to hub link
- Sensor to relay link gains vary slowly in time
  - Step changes, due to different sleeping positions, in channel gain followed by slowly changing periods of time

Relay usage results

Test Subject	Direct link available	Relay Usage % (Max usage duration)				No link % (Max outage (no link) duration)			
		Relay 2	Relay 4	Relay 7	Relay 12	Relay 2	Relay 4	Relay 7	Relay 12
A	98.55%	1.45% (3.5 sec)	0.46% (1.3 sec)	1.37% (3.3 sec)	1.45% (3.5 sec)	0.001% (0.1 sec)	0.99% (3.5 sec)	0.08% (0.2 sec)	0% (0 sec)
B	97.58%	2.42% (22.5 sec)	1.15% (4.6 sec)	2.14% (18.9 sec)	2.39% (22.5 sec)	0% (0 sec)	1.27% (22.5 sec)	0.28% (0.7 sec)	0.02% (0.8 sec)
C	99.83%	0.17% (0.4 sec)	0.17% (0.4 sec)	0.16% (0.4 sec)	0.17% (0.4 sec)	0% (0 sec)	0% (0 sec)	0.01% (0.2 sec)	0% (0 sec)
D	98.72%	1.28% (3.8 sec)	1.28% (3.8 sec)	1.28% (3.8 sec)	1.27% (3.7 sec)	0.001% (0.1 sec)	0% (0 sec)	0% (0 sec)	0.01% (0.1 sec)
E	98.54%	1.46% (86.8 sec)	1.46% (86.8 sec)	1.46% (86.8 sec)	0.09% (2.2 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	1.37% (32.3 sec)
F	98.32%	1.68% (19.4 sec)	1.68% (19.4 sec)	1.68% (19.4 sec)	1.68% (19.4 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)
Max	99.83%	2.42% (86.8 sec)	1.68% (86.8 sec)	2.14% (86.8 sec)	2.39% (22.5 sec)	0.001% (0.1 sec)	1.27% (3.5 sec)	0.28% (0.7 sec)	1.37% (32.3 sec)
Min	97.58%	0.17% (0.4 sec)	0.17% (0.4 sec)	0.16% (0.4 sec)	0.09% (0.4 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)
Mean	98.59%	1.41%	1.034%	1.35%	1.176%	0.0004%	0.377%	0.061%	0.23%

- Some relays are better than others
- Only 2 minutes of data collected in each position, longer periods of time could have longer outages
- Based on -90 dBm Rx sensitivity; see appendix for -85 dBm and -95 dBm figures

Choosing a relay

Dest. Node	Direct link	Relay node	Relay usage	No link
Head (14)	100.0%	-	0.00%	0.00%
Chest (15)	100.0%	-	0.00%	0.00%
Hip (16)	99.37%	2	0.63%	0.00%
		3	0.63%	0.00%
		4	0.63%	0.00%
		5	0.62%	**0.01%**
		7	0.60%	**0.03%**
		12	0.63%	0.00%
Right Wrist (17)	90.50%	2	9.49%	**0.01%**
		3	9.50%	0.00%
		4	2.59%	**6.91%**
		5	9.47%	**0.03%**
		7	8.97%	**0.53%**
		12	9.49%	**0.01%**
Left Wrist (18)	100.0%	-	0.00%	0.00%
Right Ankle (19)	100.0%	-	0.00%	0.00%
Left Ankle (20)	100.0%	-	0.00%	0.00%

- Body shape, sleeping position and sensor location can affect:
  - sensor to hub connectivity
  - sensor to relay connectivity
- Sensor needs to choose which relay to use
  - No way to know which relay will have a reliable link to the sensor and the hub at the same time
  - Links that are near reception threshold are relatively more likely to go into outage in the (near) future

The current MAC

- The current MAC allows sensors to discover and associate with relays. There are two mechanisms:
  - Connected nodes listen for ACKs sent from the relay to the hub
  - Unconnected nodes listen for broadcast messages sent by the relay
- Sensor is responsible for choosing relay to connect to; want to pick the most reliable relay
- Where multiple relays exist, there is currently no way to differentiate between them
  - Sensor can assess link to relay, but it can not assess the link between the relay and the hub
  - Proper communication relies on both of these links being reliable (takes time to associate, etc…)

Recommended change to MAC

- (For unconnected nodes only)
- Optional “relay to hub” link quality value sent by relay broadcast message
  - Relay can choose value according to internal mechanism; e.g., (but not limited to) channel gain between relay and hub
  - Allow sensor to evaluate “reliability” of a given relay option
    - Can choose between relays

Appendix

Relay usage: -85 dBm Rx sensitivity

Test Subject	Direct link usage	Relay Node Usage (Max usage duration)				No link (Max outage (no link) duration)			
		Relay 2	Relay 4	Relay 7	Relay 12	Relay 2	Relay 4	Relay 7	Relay 12
A	95.40%	4.59% (124 sec)	0.80% (3.1 sec)	2.80% (116.9sec)	4.59% (124.1sec)	0.01% (0.1 sec)	3.80% (124.1sec)	1.80%% (124.1sec)	0.01% (0.1 sec)
B	95.80%	4.16% (127.1sec)	2.13% (122.5sec)	0.03% (1 sec)	3.68% (127 sec)	0.04% (0.2 sec)	2.07% (120.8sec)	4.17% (120.8sec)	0.52% (3.9 sec)
C	96.78%	2.9% (59.1 sec)	2.71% (59.1 sec)	0.73% (13 sec)	2.83% (59.1 sec)	0.32% (0.7 sec)	0.51% (1.3 sec)	2.49% (48.3sec)	0.39% (13 sec)
D	93.44%	5.54% (114.1sec)	6.49% (114.1sec)	6.56% (114.1sec)	4.64% (46.1 sec)	1.03% (3.6 sec)	0.07% (0.5 sec)	0% (0 sec)	1.92% (8.3 sec)
E	94.70%	5.3% (116.3sec)	4.36% (116.3sec)	5.30% (116.3sec)	3.54% (21.5 sec)	0% (0 sec)	0.94% (20.3 sec)	0% (0 sec)	1.76% (116.3sec)
F	96.08%	3.92% (113.6sec)	3.09% (113.6sec)	3.92% (113.6sec)	2.92% (113.6sec)	0% (0 sec)	0.83% (5 sec)	0% (0 sec)	1% (5 sec)
Max	96.78%	5.54% (127.1sec)	6.49% (122.5sec)	6.56% (116.9sec)	4.64% (127 sec)	1.03% (3.6 sec)	3.80% (124.1sec)	4.17% (124.1sec)	1.92% (116.3sec)
Min	93.44%	2.90% (59.1 sec)	0.80% (3.1sec)	0.03% (1 sec)	2.83% (21.5 sec)	0% (0 sec)	0.07% (0.5 sec)	0% (0 sec)	0.01% (0.1 sec)
Mean	95.37%	4.40%	3.26%	3.22%	3.70%	0.23%	1.37%	1.41%	0.93%

Relay usage: -95 dBm Rx sensitivity

Test Subject	Direct link usage	Relay Node Usage (Max usage duration)				No link (Max outage (no link) duration)			
		Relay 2	Relay 4	Relay 7	Relay 12	Relay 2	Relay 4	Relay 7	Relay 12
A	99.52%	0.47% (1.7 sec)	0.10% (0.4 sec)	0.46% (1.7 sec)	0.47% (1.7 sec)	0% (0 sec)	0.38% (1.7 sec)	0.02% (0.1 sec)	0% (0 sec)
B	98.63%	1.34% (6.1 sec)	0.40% (0.8 sec)	1.33% (6 sec)	1.36% (6.1 sec)	0% (0 sec)	0.97% (6.1 sec)	0.04% (0.2 sec)	0.01% (0.1 sec)
C	99.95%	0.05% (0.2 sec)	0.05% (0.2 sec)	0.05% (0.1 sec)	0.05% (0.2 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)
D	99.42%	0.57% (0.7 sec)	0.58% (0.7 sec)	0.58% (0.7 sec)	0.58% (0.7 sec)	0.01% (0.1 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)
E	98.63%	1.37% (31.3 sec)	1.37% (31.3 sec)	1.37% (31.3 sec)	0.63% (14.4 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	0.74% (1.2 sec)
F	99.14%	0.85% (4.9 sec)	0.85% (4.9 sec)	0.85% (4.9 sec)	0.85% (4.9 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)
Max	99.95%	1.37% (31.3 sec)	1.37% (31.3 sec)	1.37% (31.3 sec)	1.36% (6.1 sec)	0.01% (0.1 sec)	0.96% (6.1 sec)	0.04% (0.2 sec)	0.74% (1.2 sec)
Min	99.63%	0.05% (0.2 sec)	0.05% (0.2 sec)	0.05% (0.1 sec)	0.05% (0.2 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)	0% (0 sec)
Mean	99.22%	0.78%	0.56%	0.77%	0.66%	0.002%	0.223%	0.007%	0.124%