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

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Source: [Dino Miniutti[12], Leif Hanlen[12], David Smith[12], Andrew Zhang[12], David Rodda[1], Ben Gilbert[1], Gengfa Fang[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: [This is a partial proposal for the IEEE 802.15.6 PHY and MAC.]

Purpose: [To provide tools for evaluating system performance. Proposing a super-beacon-based TDMA frame.]

NICTA Proposal

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

NICTA
David Rodda, Ben Gilbert, Gengfa Fang

Outline

- This is a partial proposal for IEEE 802.15.6
- Part I
  – Expected BAN performance based upon channel measurements
- Part II
  – Proposal: TDMA with CDMA super-beacons

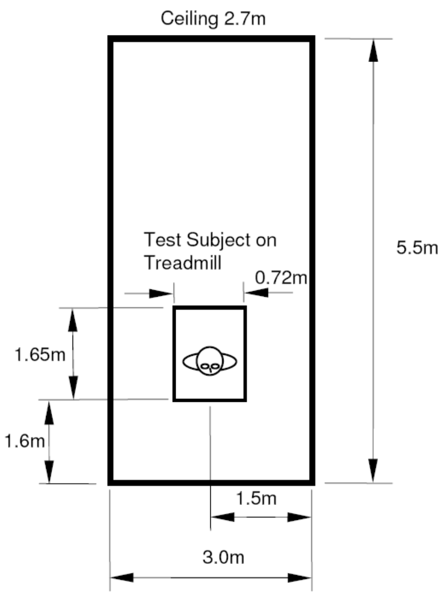
Part I

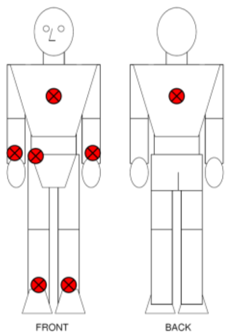
Expected BAN performance based upon channel measurements

Objective

- Provide measures of expected system performance
- Body movement or “channel dynamics” are very important to performance of BAN
  - Channels can fade over 50 dB below the mean received power (09-186)
  - Evaluating system performance at mean received power is not sufficient
    - Only describes “mean performance”
    - Need to know how system will perform most of the time
  - The following provides analysis of system performance in a dynamic channel

Measurement technique



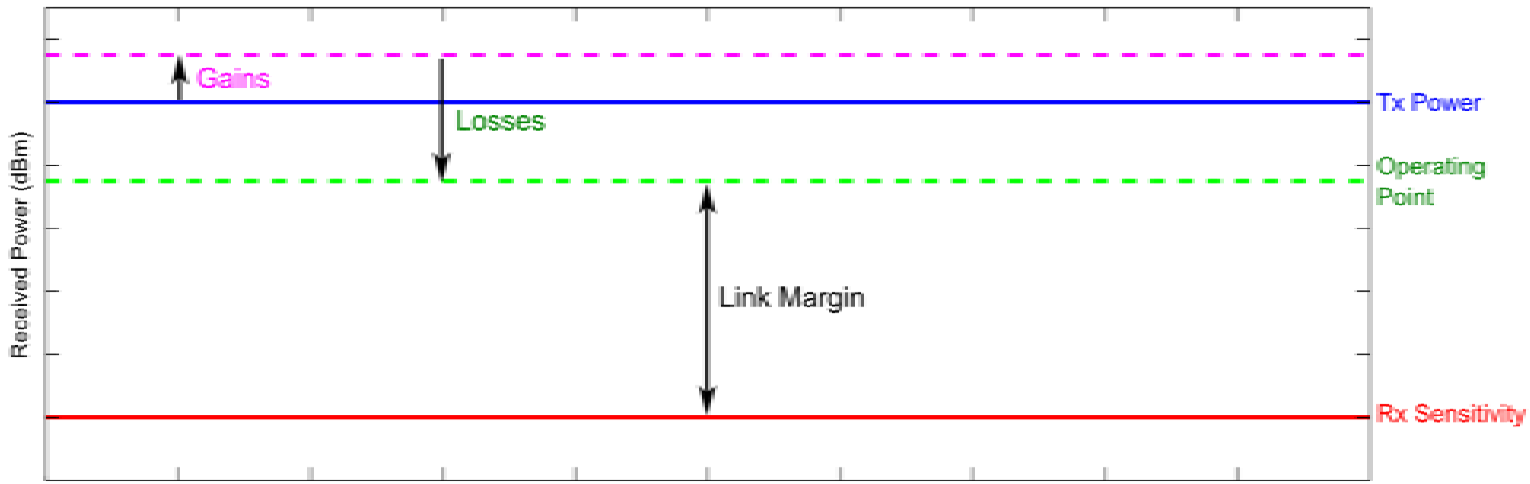


- Using NICTA's measurements from document 08-716
  - Data has already been presented; just a new way of looking at it
    - 820 MHz carrier frequency
    - 3.5 hours of data with 8 test subjects on a treadmill walking and running at different speeds: {3, 6, 9, 12} kph
    - Body surface to body surface: CM3 – Scenarios S4 & S5 in CMD
- Conjecture that shadowing is major source of attenuation
  - Actual attenuation will be different at other frequencies

Receiver location	Transmitter location					
	Chest	Right wrist	Left wrist	Right ankle	Left ankle	Back
Right hip	×	×	×	×	×	×
Chest		×		×		×

Link-margin-based performance

- Using link margin as basis of comparison
  - Each proposal states their link margin
  - Assume system does not function when Rx power drops below Rx sensitivity
    - Definition: "Outage" = Rx power < Rx sensitivity



LM = Tx power + Gains – Losses – Rx sensitivity

Link margin adjustment

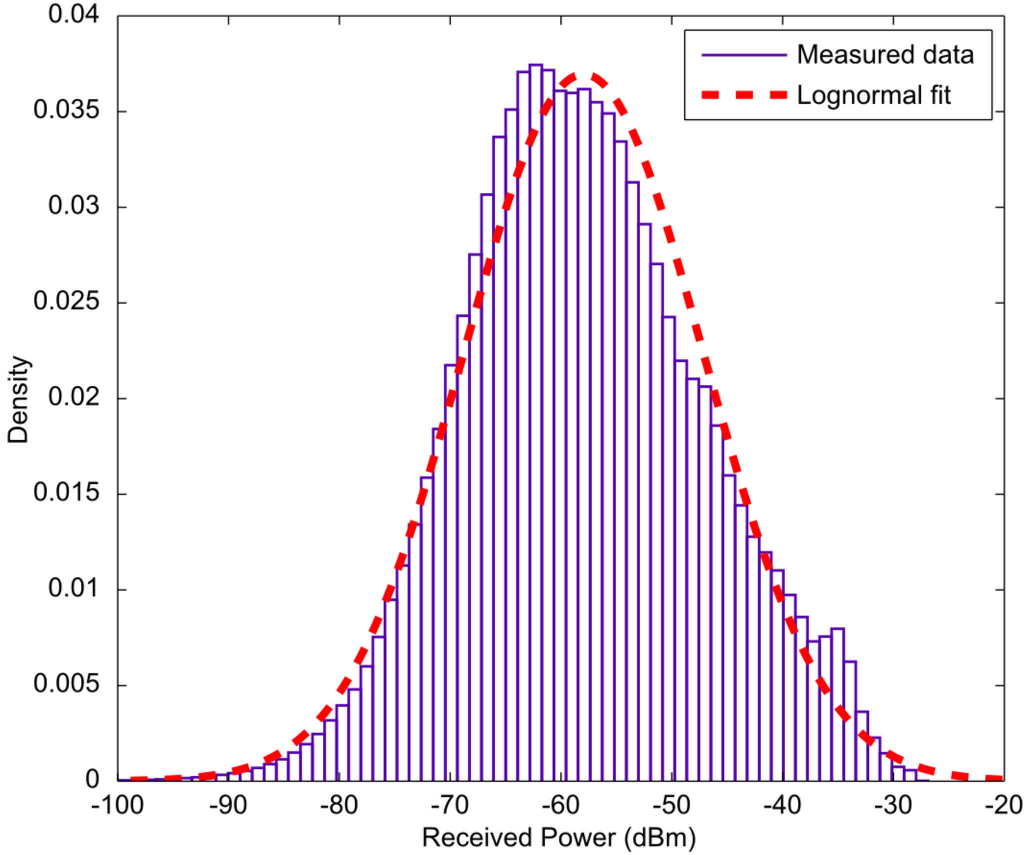
- Measurement parameters
  - Transmit power: 0 dBm
  - Median path loss: 58.5 dB (operating point)
- The graphs on the following slides are based on the above parameters
  - Proposals do not necessarily use NICTA's channel measurements to calculate their link margin, hence, in order to read off the graphs you need to modify a proposal's link margin figure by:

LM = Proposal LM + (Proposal operating point – NICTA operating point)

Example

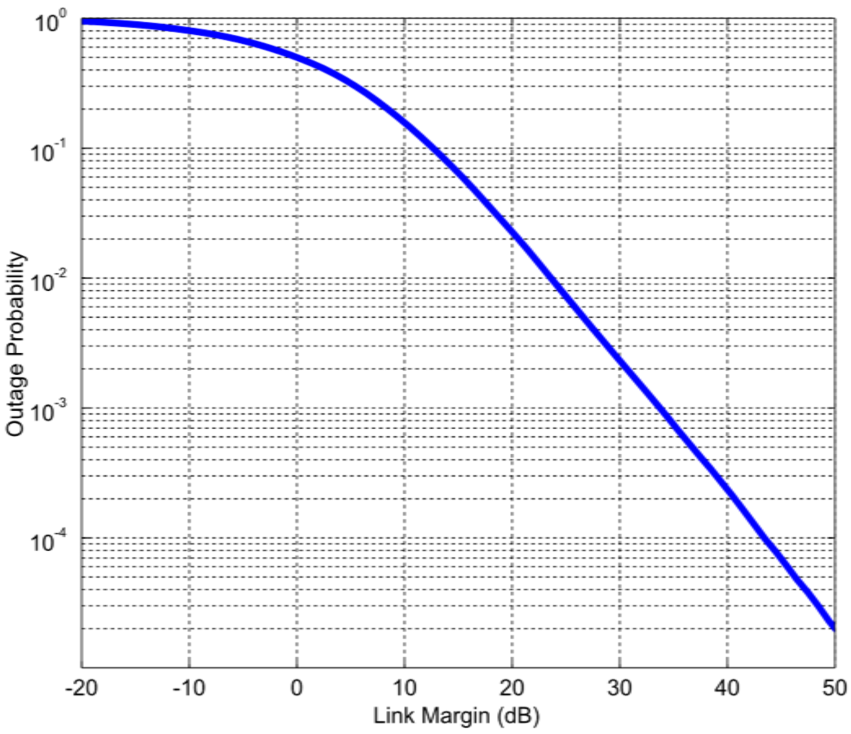
A proposal has a link margin of 15 dB that is based upon an operating point of 65 dB. To read values off the following graphs, the proposer would use a link margin of 21.5 dB (= 15 + 65 – 58.5). For example, their outage probability will be approximately 1.5%.

PDF of received power



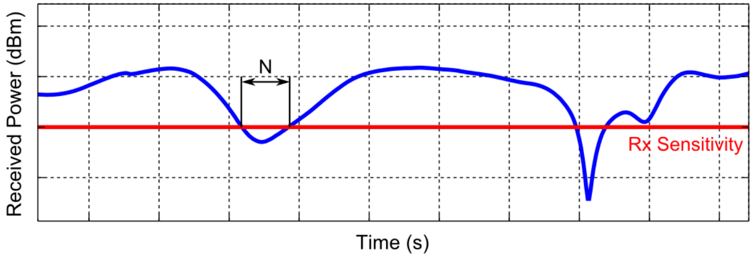
Outage probability

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



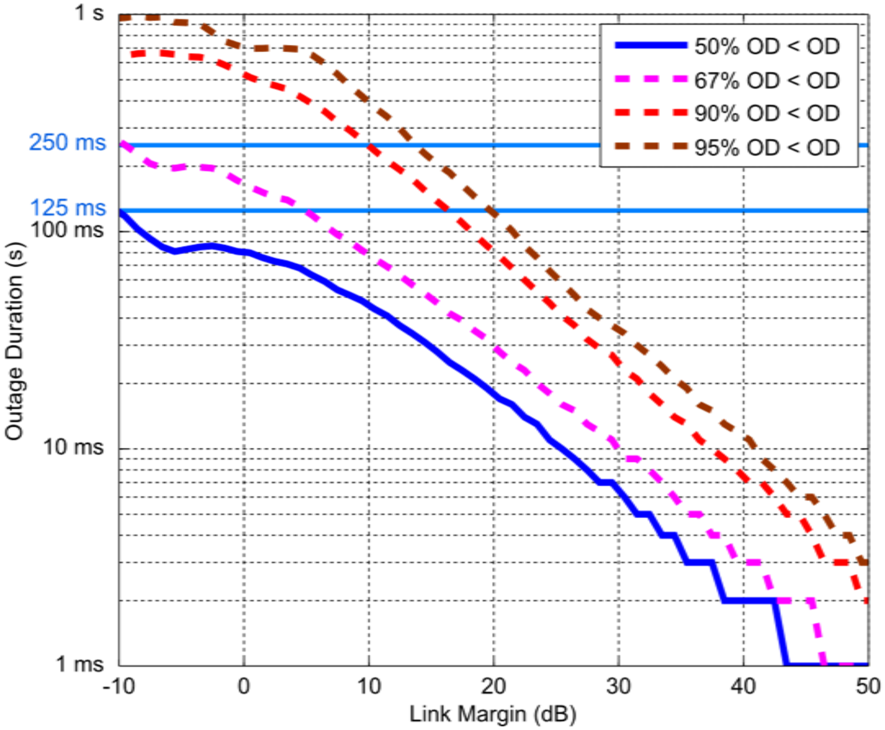
LM = Proposal LM + (Proposal operating point – NICTA operating point)

Outage duration



X% of outages last less than N seconds

- Systems must cope with losing N seconds of data X% of the time
- Latency requirements from TRD (08-644):
  - Medical < 125 ms
  - Non-medical < 250 ms
- What does this mean for interleavers?



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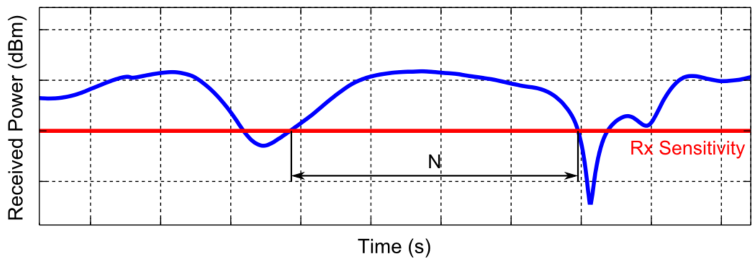
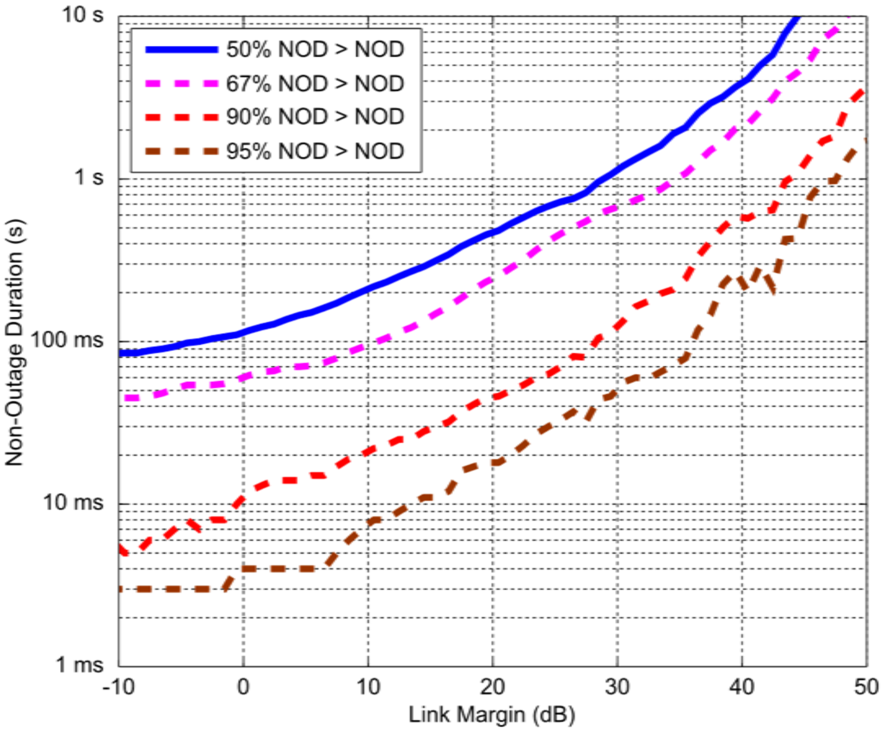
Non-outage duration



X% of non-outages last more than N seconds

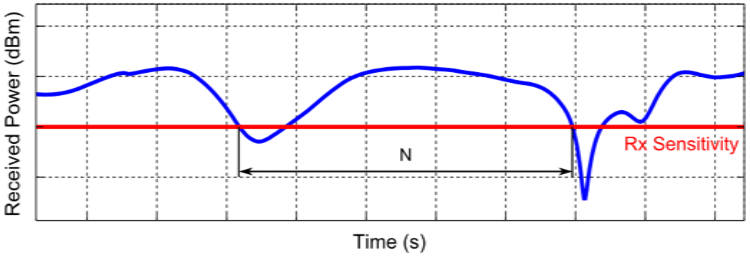
- Defines the non-interrupted period between outages with X% confidence
- Using large X, packet error rate can be approximated by:

PER = Packet duration / N



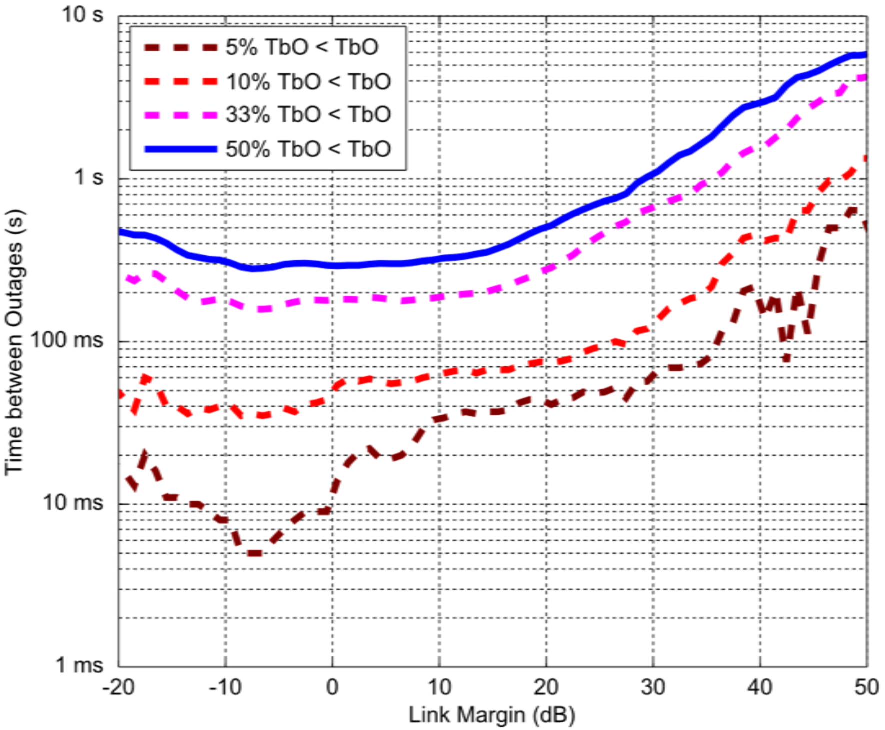
LM = Proposal LM + (Proposal operating point – NICTA operating point)

Time between outages



X% of outages are separated by less than N seconds

- Defines how often outages occur (inverse is outage rate)



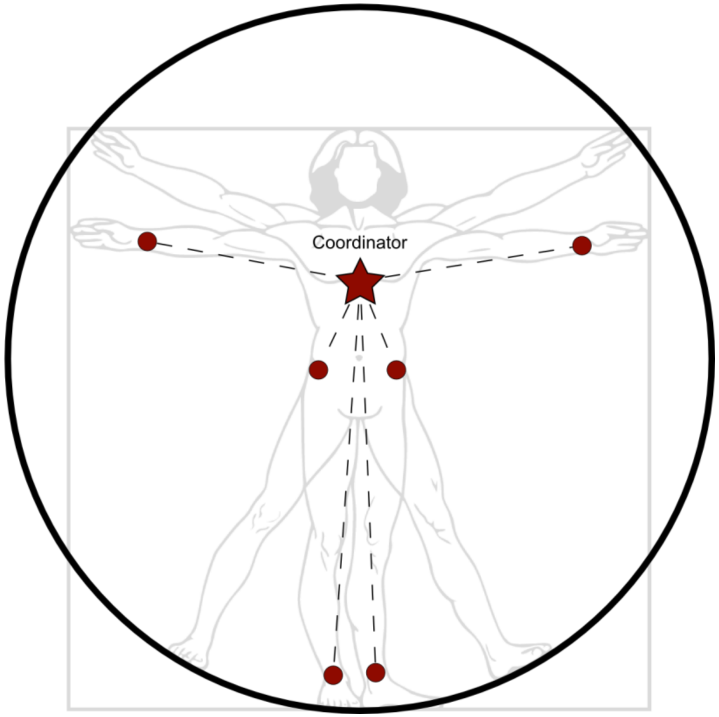
LM = Proposal LM + (Proposal operating point – NICTA operating point)

Part II

Proposal: TDMA with CDMA super-beacons

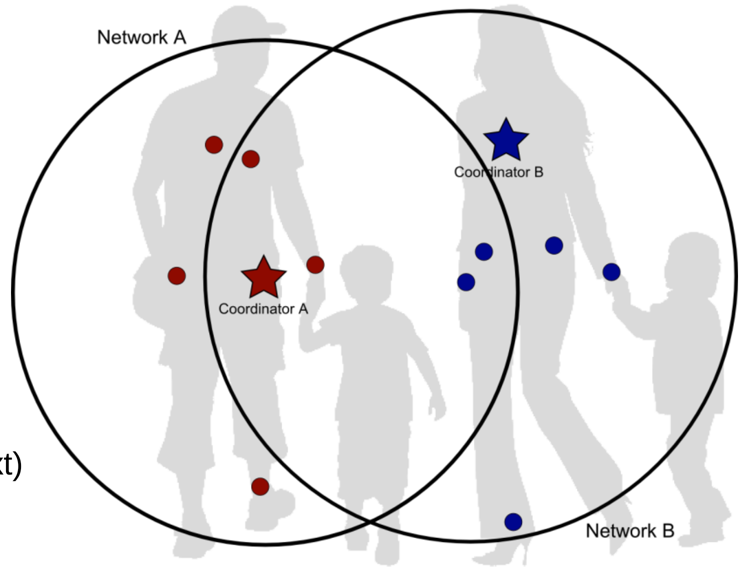
(Assumptions about) BAN Systems

- Star topology
  - No multi-hop
    - Idle listening is expensive
  - Coordinator/Gateway at centre and nodes surrounding
    - Nodes are low power (long life)
    - Coordinator can use more power (larger battery, more frequent recharging)



The Problem: Coexistence & Interference

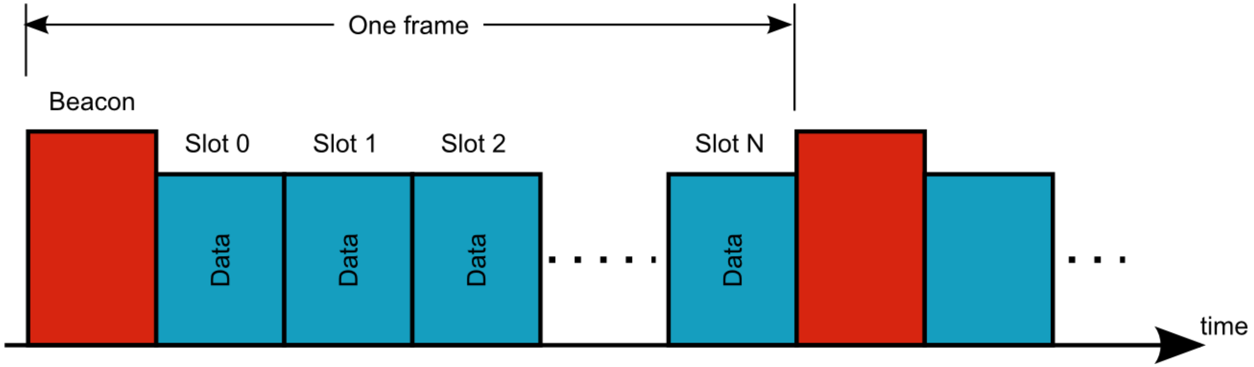
- Technical requirements document (08-644)
  - 10 co-located BANs in a volume of 6 x 6 x 6 m
  - Networks should be scalable up to 256 nodes
- BANs are located on people
  - People can move around a lot
  - BANs may move in/out of range of each other
    - May cause interference if no multiple access technique is used
    - Unpredictable (BAN can not know what person will do next)
    - May be in range of another BAN for a short or long time (again, unpredictable)
- Treat other BANs as interference
  - Coordination is very difficult to do between BANs
    - No master clock
    - No natural choice of global coordinator
  - Minimal coordination is preferred
    - Each BAN acts in such a way as to protect itself from outside interference (and does little harm to others)
- Also want protection from non-BAN interference
  - Particularly important if using ISM bands



Interference mitigation

- Must introduce measures to:
  - Allow for multiple co-located networks
  - Allow for multiple nodes within network
  - Protect networks from interference
- We believe that a combination of CDMA and TDMA is a good choice
  - CDMA
    - Allow for multiple co-located networks
    - Protection from non-BAN interference
    - "Soft fail" – extra nodes degrade performance gradually
  - TDMA
    - Allow for multiple nodes in network (can be extended by use of CDMA on data)
    - Pure contention MAC is unsuitable when there is a lot of traffic (collisions)
      - Require some form of resource allocation for QoS requirements
  - Dynamic intra-network FDMA is hard to do with sensors that can sleep for a long time
    - i.e., changing frequency when interferers are present
    - Wake up: where did the coordinator go?
    - Note: This does not preclude using multiple channels for separate BANs

TDMA & CDMA



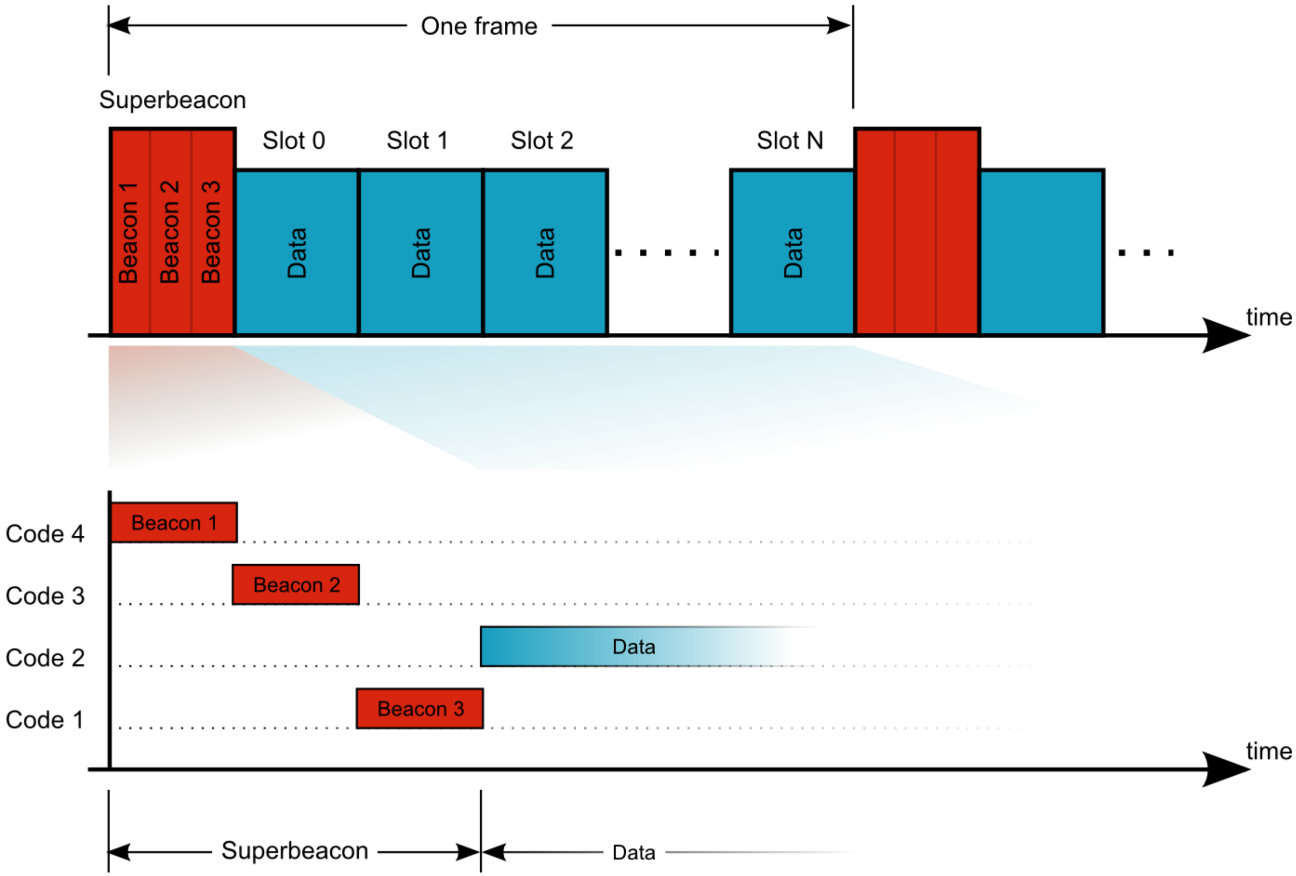
- Coordinator transmits beacons
  - Beacons give nodes a way to correct their clock drift
    - Option: Beacon contains common network information
- Beacons are very important
  - Network performance will suffer if beacons are not received successfully
    - Nodes can not transmit until a beacon is received
    - Missing a beacon can cause large delays
    - Nodes will be idle until a beacon is received (waste of energy)
  - Need to protect beacons from interference

Beacon protection

- Beacons are CDMA coded
  - Reduces likelihood of interference from neighbouring networks
- Use **extra** coding to protect beacons from interference
  - One code isn’t enough; can run into a network with the same code
  - Multiple codes make interference less likely
  - Option: Extension to variable codes (described later)

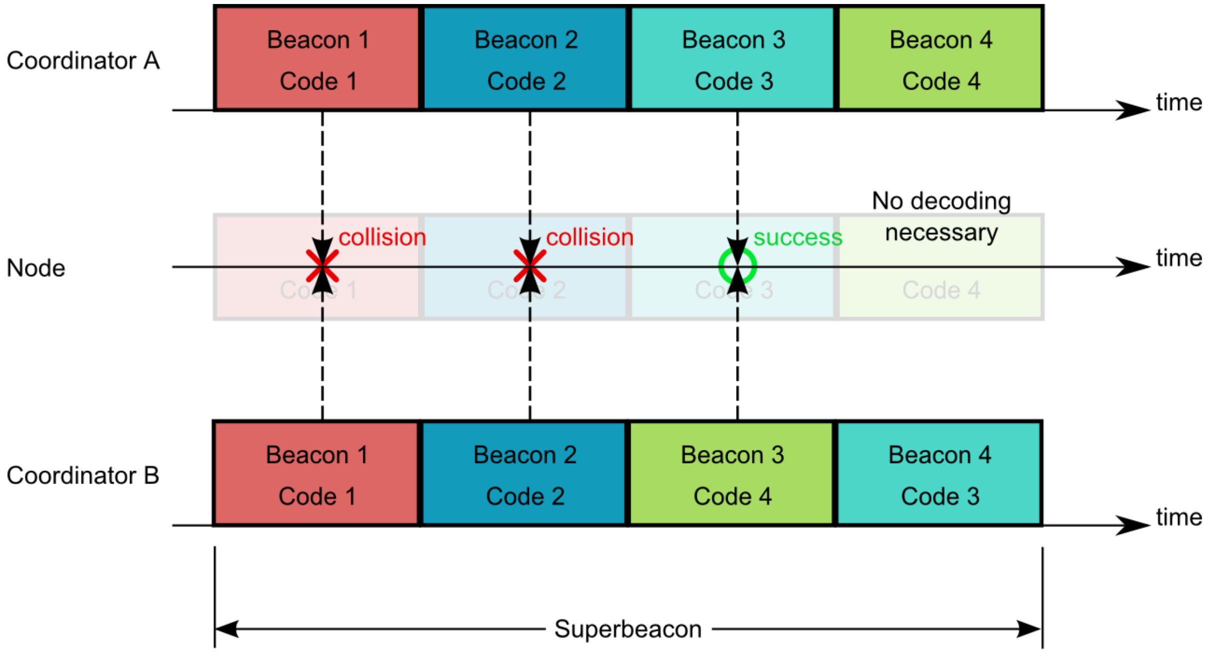
Super-beacons

- Transmit N concatenated identical beacons, each one coded by a different code
- Less likely to come across networks using the same N codes → less beacon collisions
  - Trading some efficiency (extra beaconing time) for network reliability



Super-beacon example

- Two networks (A&B)
  - Network A: Coordinator sending beacons with codes {1,2,3,4}
  - Network B: Coordinator sending beacons with codes {1,2,4,3}
  - Node belongs to network A, decoding with codes {1,2,3,4}
- First two beacons have the same code and collide, can not be resolved by node
- Third beacon code differs, node can separate beacons and receive beacon from coordinator of network A
- Node stops listening for beacons after successful decode



Why multiple codes?

- Why are multiple short codes better than a single long code?
  - Less (faster) decoding saves power
    - Can stop listening as soon as one beacon is decoded successfully
    - In most cases only one (short) beacon will need to be decoded
  - More flexible receiver implementation
    - Don’t need to decode all codes
      - Can trade reliability against receiver complexity (power consumption)
  - A subset of codes can be made variable
  - Individual decoders are shorter

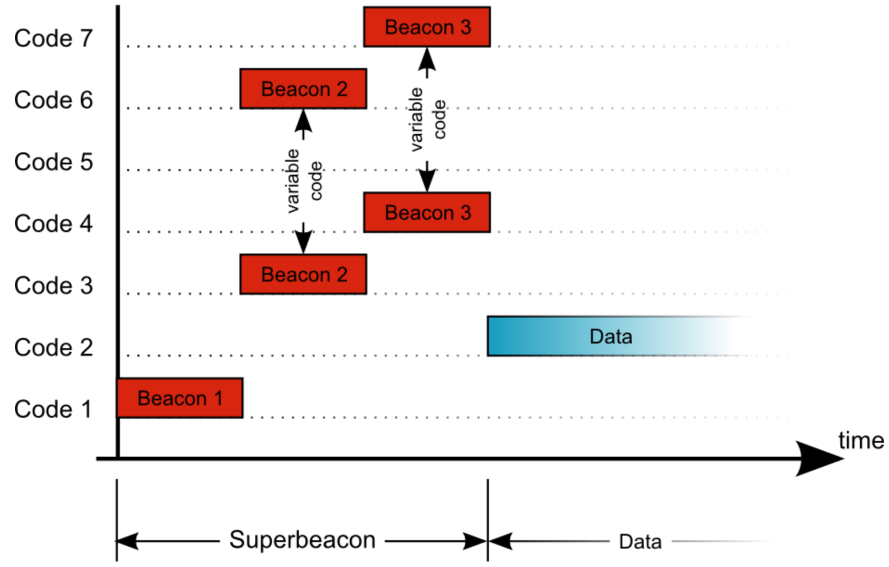
Beacon data

- Beacons may contain the following data
  - Beacon number, Network ID, Coordinator ID, etc...
  - CDMA code used for data
    - Allows data code to be changed for each frame
- Try to keep beacons short for efficiency
- Try to keep number of beacons low for efficiency

Option: Variable codes

- Use one or more variable code slots within super-beacon
- This allows the coordinator to vary a beacon code if it detects an interfering system
  - Beacon collisions avoided for any practical scenario
- Vary over a small number of codes
  - Reduces search space / receiver complexity

Example



Beacon 1: Code 1 (fixed)

Beacon 2: Codes 3 ←→ 6

Beacon 3: Codes 4 ←→ 7

Network creation

- When a node joins the network, the coordinator tells the node:
  - Number of beacons that will be sent
  - Static codes for each beacon
  - Variable codes for each beacon

Possible extensions

- Beacons
  - Beacons can be used to measure channel attenuation
    - Node measures received beacon power
    - Selects transmit power level accordingly
  - Energy sensing is also possible
    - Do not decode beacon data, just detect beacon energy
- CDMA
  - Can use variable data spreading factors to change data rate (OVSF-CDMA)
- TDMA
  - Dynamic TDMA with a scheduling algorithm
  - Hybrid TDMA scheme with contention and contention-free slots
  - Time slots can be shared by multiple low duty cycle nodes

- Many more (can use with any CDMA/TDMA/Beacon technique)

Summary of super-beacons

- Works with narrowband and DS-UWB systems
- Better interference rejection (practically zero chance with variable codes)
- Minimal overhead
- Flexible receiver operation can save power in low-power nodes

- May require multiple de-spreading paths (one for each beacon code receiver wants to decode)
- Lower channel efficiency (slight)
- More complex receivers required for full advantage of super-beacons

Collaboration

- Have presented a flexible architecture; seeking partner organisations
- NICTA has a MAC simulator (Castalia)
  - Open source
  - http://castalia.npc.nicta.com.au
- NICTA has over 100 hours of additional channel data
  - More detailed modelling of BAN radio channel for everyday activities (e.g., office, driving car, etc...)
  - Interference between people
  - More detailed BAN plugins for Castalia