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

Submission Title: [BAN superframe for TG6]
Date Submitted: [March, 2009]
Source: [Bin Zhen, Changle Li, Huan-Bang Li and Ryuji Kohno] Company [National Institute of Information and Communications Technology (NICT)]
Address [3-4 Hikarino-oka, Yokosuka, 239-0847, Kanagawa, Japan]
Voice:[+81-46-847-5445], FAX: [+81-46-847-5431], E-Mail:[zhen.bin@nict.go.jp]

Abstract: [part 1 of NICT's MAC proposal to TG6]

Purpose: [part 1 of NICT's MAC proposal to TG6]

NICT’s MAC proposal

----part 1: hybrid MAC for medical and non-medical applications

Bin Zhen, Changle Li, Huan-bang Li and Ryuji Kohno

National Institute of Information and Communications Technology (NICT)

Outline

- TG6 requirement and overview
- TDMA based BAN superframe
  - Slot design
  - CAP and CFP
  - ACK
- Priority access
  - Priority access period
  - Non-beacon mode
- Simulation
- Self-evaluation

§1. TG6 requirement and MAC protocol

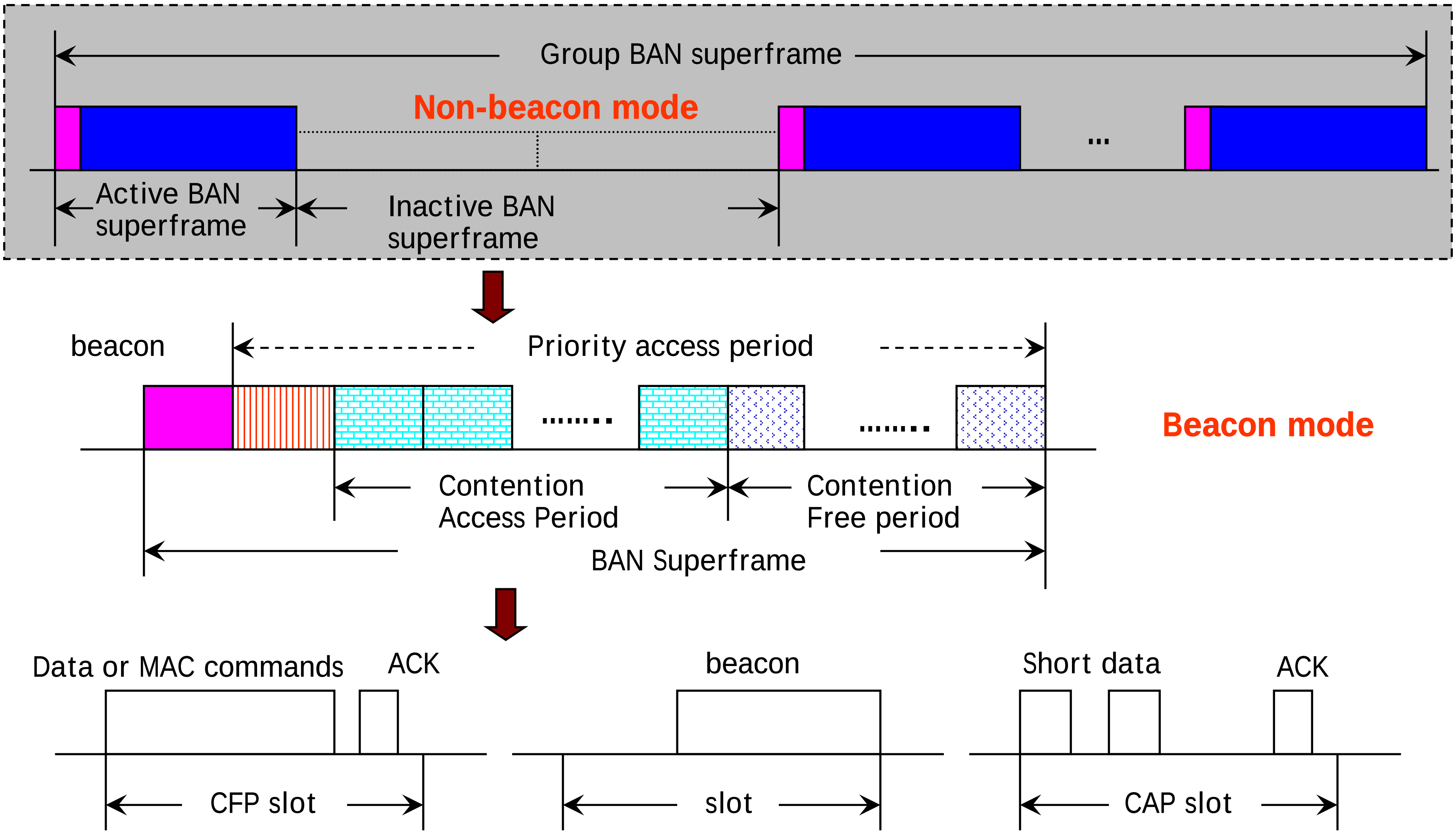
Usage scenarios

- Medical and multi-media applications on/in the same person or near space
  - Periodical vital information collection or diagnosis command from doctor
  - Video and audio for entertainment
- Operation environment includes home, hospital, small clinic, fitness center, etc
- Up to 256 sensors/actuators or device in a piconet
  - Devices can be on the surface of body, under the skin or in the deep tissue

MAC requirements

- Dependability and QoS guarantee
  - Real time and life-critical message → Priority access and CFP
- Scalability
  - Possible multiple PHYs → TDMA based BAN superframe
  - data rate
  - duty cycle and network size → (group) BAN superframe
- Power efficiency
  - → Power efficient beacon, non-beacon mode

Overview of MAC proposal



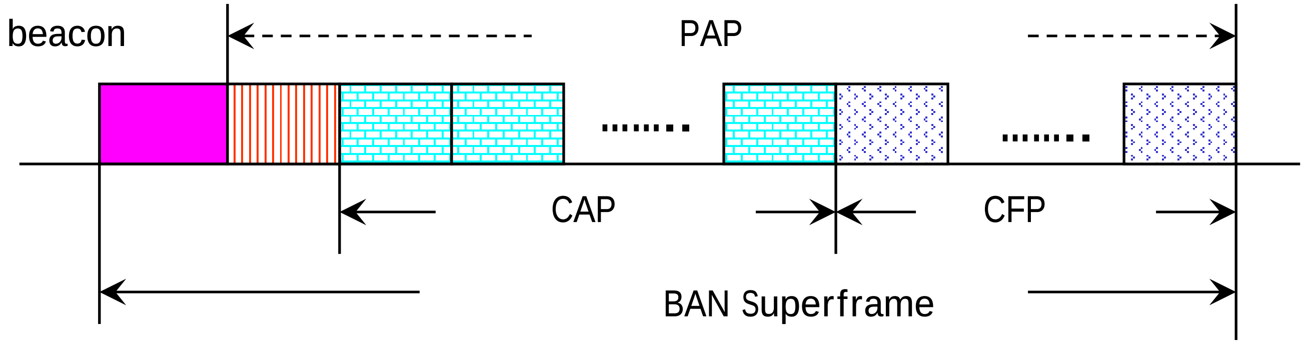
- Beacon mode: TDMA based BAN superframe
  - Contention access period (CAP)
    - Minislots in CAP and group ACK → to increase contention efficiency
  - Contention free period (CFP) → to guarantee QoS
  - Priority access period (PAP)
    - Priority slot and embedded priority period → for life-critical traffic
  - All slots in BAN superframe are equal duration → easy implementation
  - Mandatory ACK except beacon
- Group BAN superframe
  - Power efficient beacon
- Non-beacon mode
  - → for very low duty cycle traffic and uplink medical event

§2. TDMA-based BAN superframe

Motivations

- A unified MAC to meet BAN requirements
  - QoS, network scalability, different PHYs
- Easy to be implemented by chip maker

TDMA-based BAN superframe



- A BAN superframe consists of constant number of equal duration slot
  - Even number of slots in a superframe, e.g. 16 or 32.
- Priority access period (PAP) is partially overlapped with CAP and CFP
  - One fixed priority slots is optional
- A BAN superframe has *1+1+Na+Nf* slots

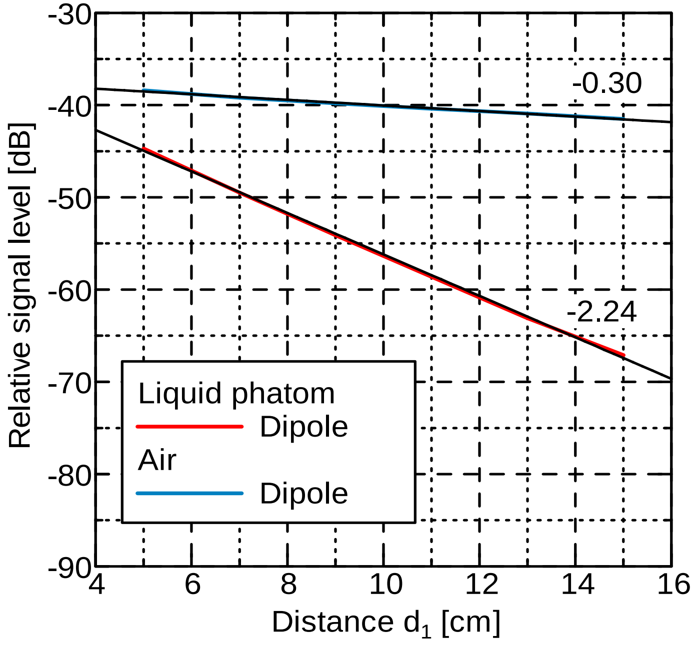
- CAP
  - Mainly for uplink GTS request and short data packet
    - Asynchronous short data packet, link management
  - Contention based slotted ALOHA
- CFP
  - For both uplink and downlink communication
    - Isochronous stream and allocated burst traffic
  - Contention free slot allocation by BAN coordinator
- PAP
  - Especially for priority traffic

Why TDMA-based BAN superframe?

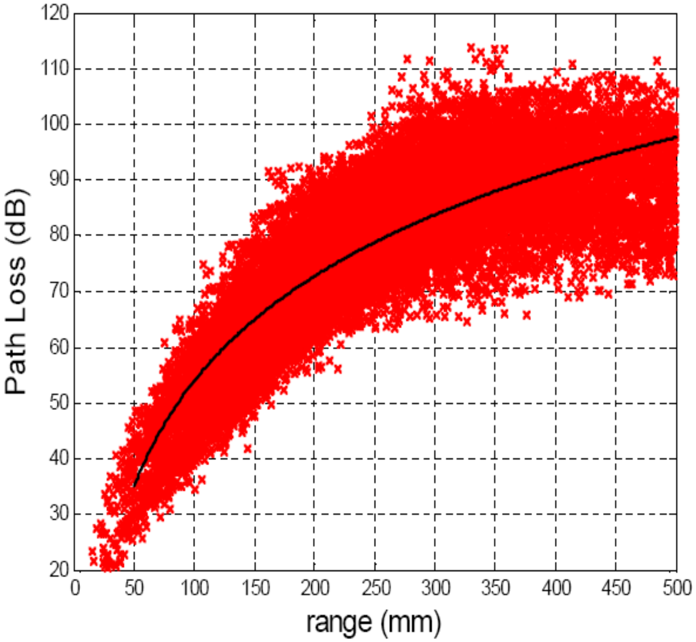
- Channel sensing cannot be guaranteed in all BAN frequency bands and scenarios
  - UWB systems
  - NLOS of on-body of narrow band systems
  - Implant systems (>300mm)
  - Dynamic environment with human movement
- Unreliable channel sensing leads to ‘hidden nodes’ in CSMA, which deteriorate system performance severely.

- MICS systems

- For both implant-implant and implant-on body, the device can conduct channel sensing within 250 mm
  - This distance is too short for most applications

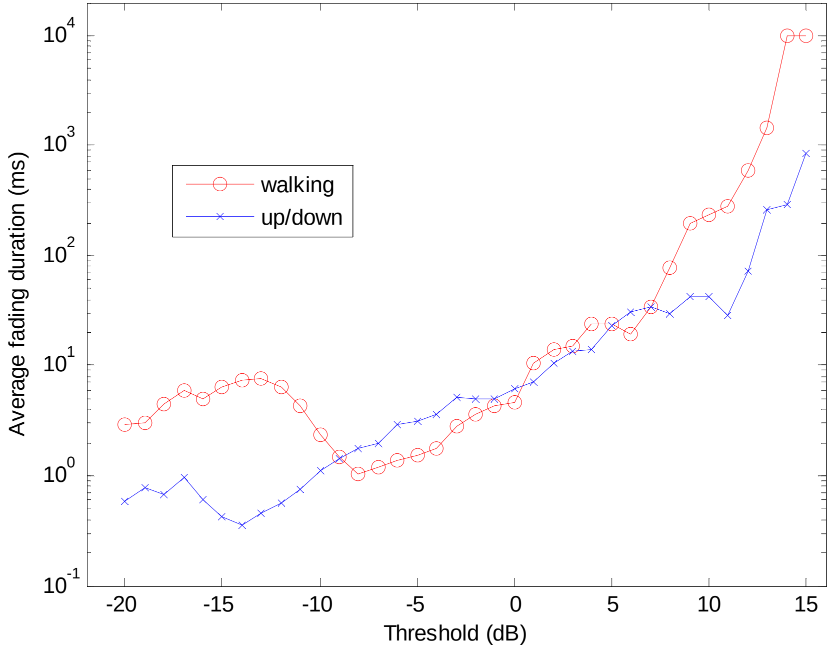


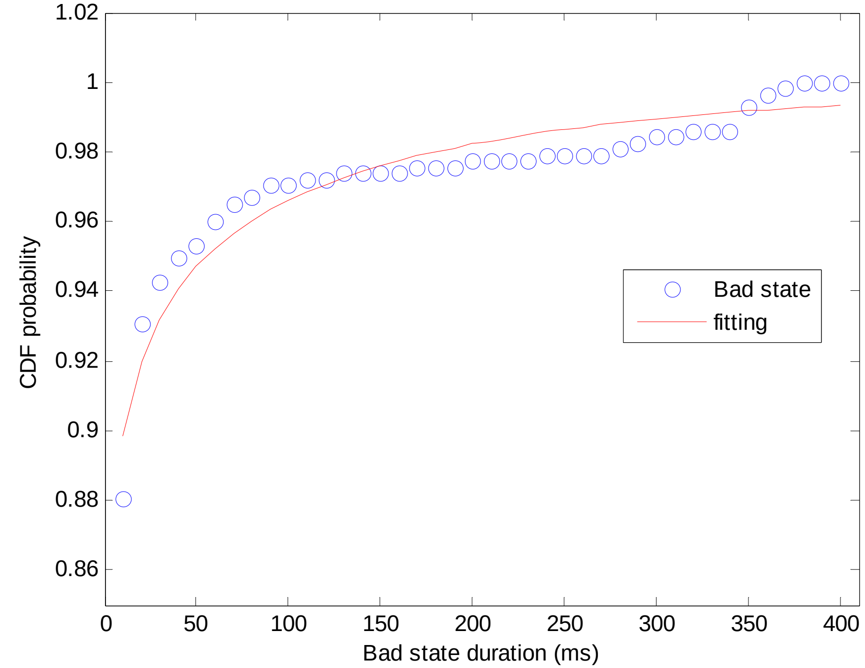
Implant-body surface (08-0416-03)



Implant-implant (08-0519-01)

-Human movements





-10 dB threshold

- Signal lower than a threshold, e.g. -10dB, usually leads to frame error or channel sensing error
- It is true even for narrow band systems

§2.1 Slot design

Motivations

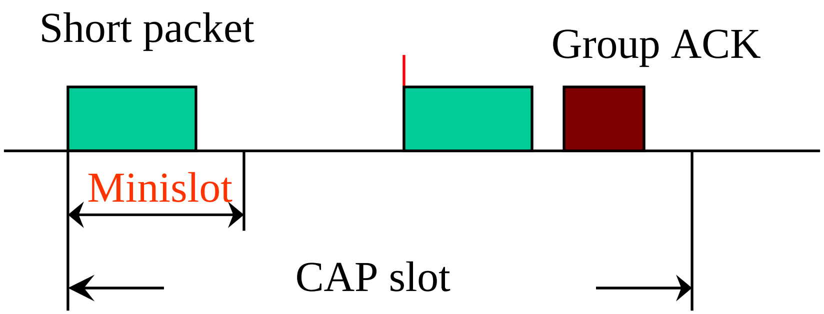
- To increase contention efficiency in CAP
- To guarantee QoS

Slot design

- Slot of BAN superframe can be
  - a beacon slot, or
  - an optional priority slot, or
  - three minislots and a group ACK in CAP, or
  - a data packet and an ACK in CFP or PAP.
- An equal slot duration for easy implementation
  - To be determined by the lowest mandatory data rate in a PHY
  - Slot duration should be optimal for most applications
    - High data rate may have more payload bytes
- Communication only occurs at the beginning of the slot

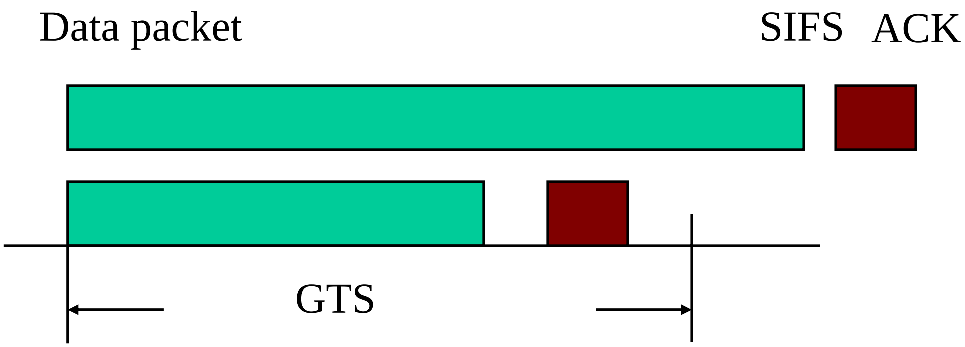
Minislots in CAP

- Slots in CAP are for channel contention
- 4 minislots in a CAP slot
  - 3 times capacity slotted ALOHA
  - The number of 4 is tradeoff
- Three minislots share a group ACK
  - The last minislot is for group ACK
- No cross-boundary communication in CAP



Guaranteed time slot in CFP

- Slots in CFP are Guaranteed time slots (GTS)
- A GTS consists of a data packet and an ACK
  - A data packet may cross two continuous GTS if they are allocated to the same link



§2.2 CAP and CFP

CAP

- CAP is mainly for channel contention
  - The number of slot in CAP is configurable
- Minislot can be used for GTS request and short uplink data packet
  - The short packet can be ID packet, link request etc.
- Limited payload for packet in a minislot
  - 1/4 of a slot

CFP

- CFP is mainly for data transmit and/or re-transmit
  - GTS can be uplink/downlink
- GTS in CFP are allocated by BAN coordinator
  - GTS allocation is of life time
    - It can be a BAN superframe, group BAN superframe or more
  - BAN coordinator can actively de-allocate the GTS allocation
- Free GTS are unallocated GTS in a BAN superframe
  - Re-transmission in case of packet error
  - Down link traffic

Medical and multi-media

- Radio resource can be measured by GTS
  - Radio resource allocation is controlled by coordinator
  - Coordinator can rejects a new association when the radio resource is insufficient
- GTS is configurable in BAN superframe
  - Duration and number of GTS
  - Scalability in QoS
- Coordinator can allocate GTS to medical links or multi-media links
  - Peaceful coexistence

§2.3 ACK

Information piggybacked ACK

- Mandatory ACK packet in CAP, CFP and PAP
  - ACK in CAP is group ACK
- To confirm packet reception
- To piggyback GTS allocation in CFP
  - ACK to packet in CAP
    - To receive downlink command or data from coordinator
  - ACK to packet in CFP and PAP
    - The second chance for corrupted packet in the same BAN superframe
- Benefits of piggybacked information
  - To increase capacity of CAP
  - To reduce latency and power consumption in CFP and PAP

§3 Priority access

§3.1 Priority access period

Motivations

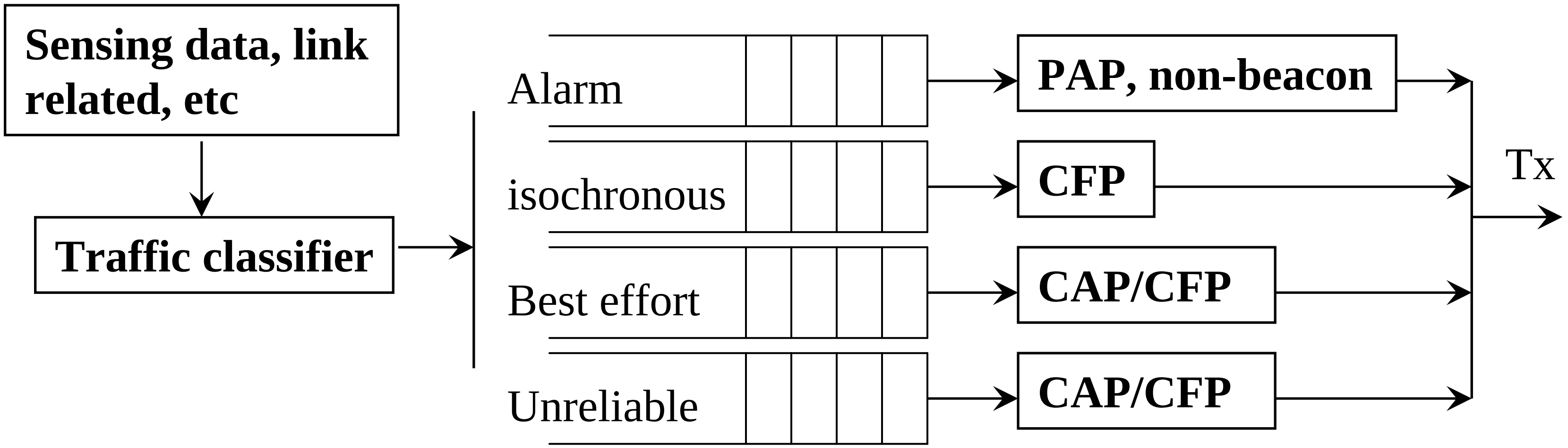
- Transmit of life-critical medical message should be guaranteed and ASAP
- FDA requires guaranteed medical communications

What is priority traffic?

- Medical event that is life-critical
  - Abnormal vital information or state
    - Body temperature > 40ºC, fall
  - Abnormal sensor state
- Characteristic of priority traffic
  - Priority traffic can be uplink or downlink after the link have been established
  - Very low duty cycle (e.g. <0.001%)
  - Limited payload

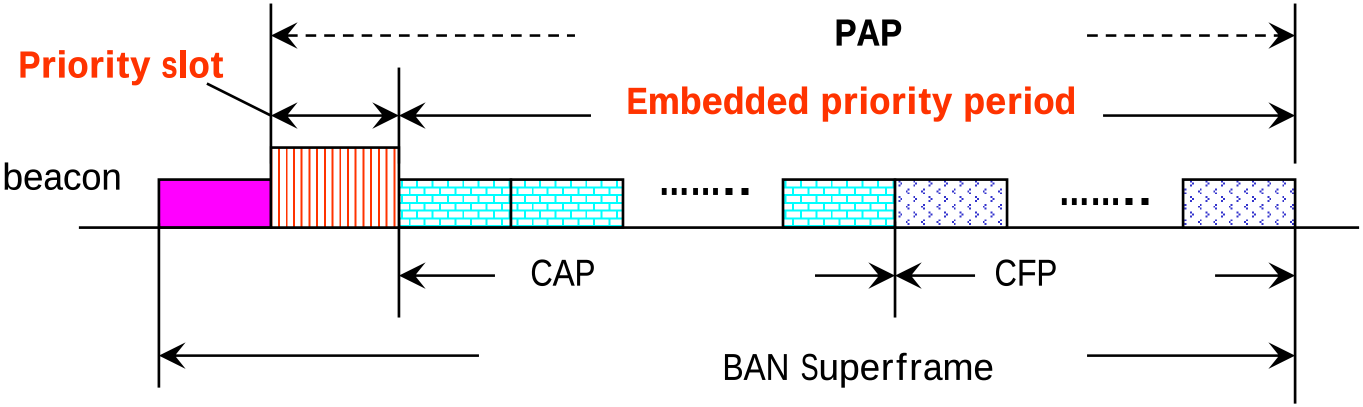
Priority traffic

- Traffic must be classified and buffered in queues
  - Different traffic categories should be buffered in different queues
- Priority traffic go first in a BAN superframe



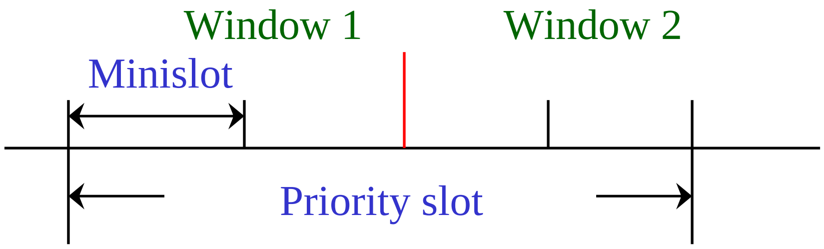
Priority access period

- Only priority traffic can take PAP
- PAP can be
  - an optional priority slot, and
  - embedded priority period: the free period in CAP and CFP

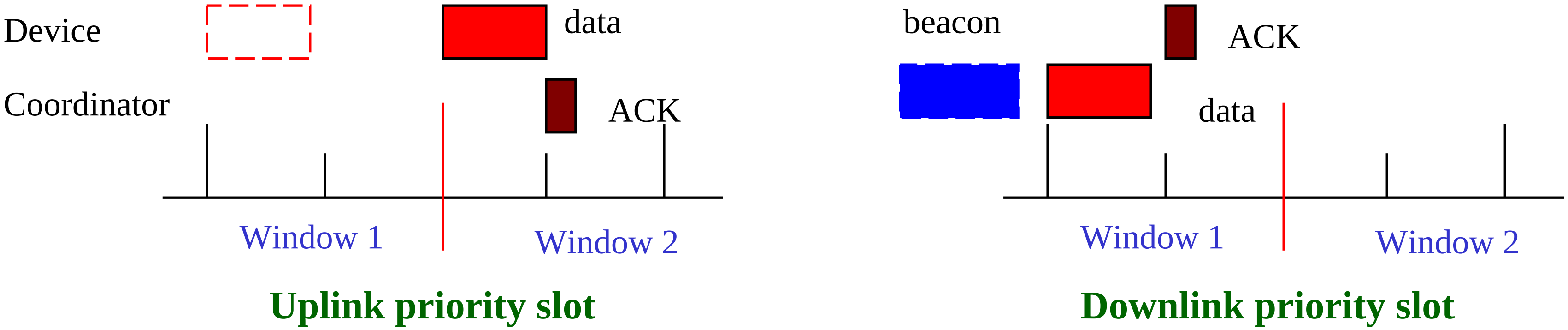


Priority slot

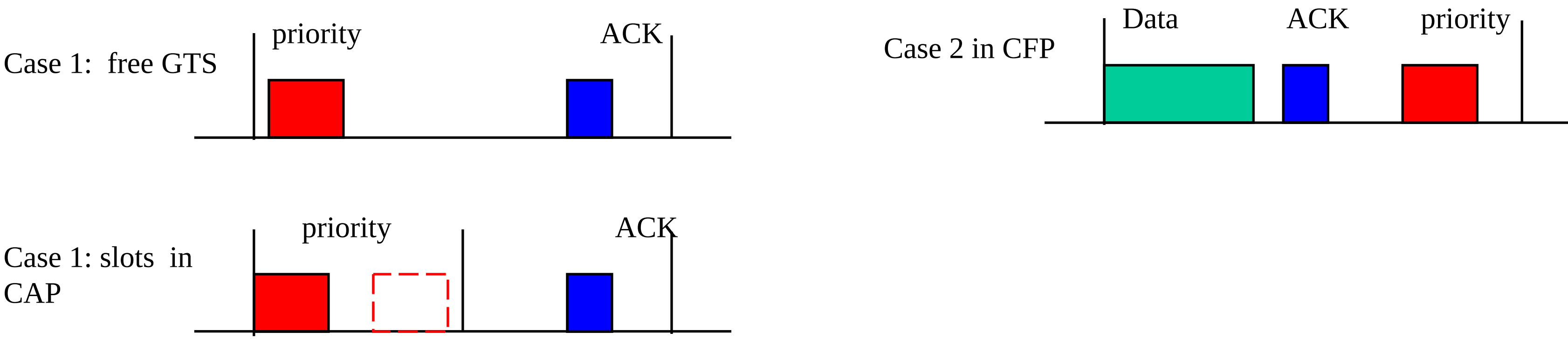
- Priority slot is the slot immediately after beacon in the BAN superframe
  - Two communication windows in 4 minislots
  - Priority slot is allocated by beacon
  - Priority slot is optional
- Priority slot guarantees the upper limit of the priority traffic delay
  - Priority slot can be uplink or downlink as indicated by beacon



- Beacon broadcast direction of priority slot and pending priority traffic in beacon
- Uplink priority slot
  - Coordinator enters receiving state in if there is no pending priority traffic
  - Node can randomly select a window
- Downlink priority slot
  - Coordinator transmits pending priority traffic and wait for ACK
  - Tow priority traffics in two windows
- If priority slot fails, go to embedded priority period



Embedded priority period



- Case 1: a free slot
  - All minislots in CAP except ACK are free slots
  - Unallocated GTS
- Case 2: a busy GTS
  - the free period in GTS if it is long enough
    - Due to equal slot division, there may be some free space after ACK
    - Allocated GTS should be protected
- After transmit alarm message, the device waits for ACK
  - ACK to alarm message take the next transmission chance

Detection of channel free period in case 2

- Coordinator assisted detection
  - Coordinator broadcasts BUZZ signals once the GTS is free
  - Device with priority traffic listens the BUZZ signal in all GTS
- Device detection
  - Device actively conducts channel sensing to detect free space in a GTS
  - Hidden node issues

§3.2 Non-beacon mode

Two motivations

- Some FCC rules
  - Implanted medical device in MICS band can transmit immediately in case of some medical events
- For very low duty cycle devices, periodical listening to beacon is power consuming

Non-beacon mode communication

- In case of some medical events from device, communication can enter non-beacon mode
  - There is no need of any BAN superframe concept
  - Channel access is pure ALOHA based handshake
- Non-beacon mode can be used in inactive BAN superframe
  - Coordinator enters receiving state in inactive period periodically or upon command from application layer
  - Coordinator and nodes should have synchronized clock
- Power efficient handshake protocol is TBD

Reliable medical event communication

- MAC layer scheme
  - Multiple transmissions and smart backoff
- PHY layer scheme
  - Higher transmit power and spreading gain
- Application layer scheme
  - First try non-beacon mode.
  - If fails, go to PAP in beacon mode

§4. Performance Evaluation

Simulation assumption and definition

- A perfect physical channel
- Packet errors are due to packet collision, lifetime and buffer overflow
- Traffic
  - Periodical traffic
  - Poisson distribution of best-effort traffic
- Star topology
- Communication and power consumption includes slot request, ACK and re-transmission
- 50% BAN superframe duty cycle

Simulation parameters

Parameters	Value
Data rate	250 kbps
Slots in BAN superframe	16 , 32
Slot duration	240 symbols
Symbol time	16 µs
PHY Symbols per Octet	2
SIFS	12 symbols
LIFS	40 symbols
Turnaround time	12 symbols
CAP Retries	3
GTS Request command	11 Octets
ACK wait duration (max.)	54 symbols
ACK command	5 Octets
MAC Header	9 Octets
PHY Header	6 Octets

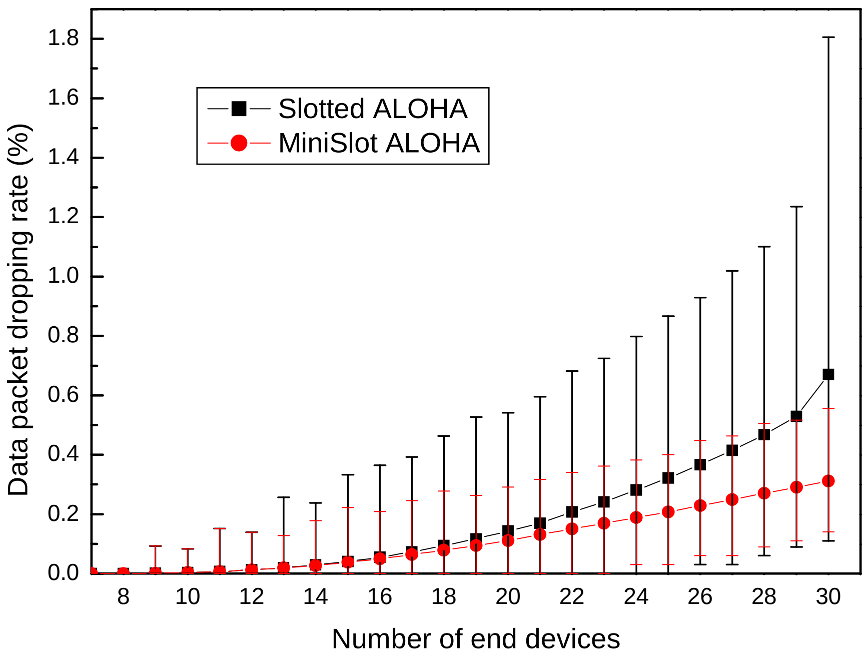
Parameters	Value
Tx power consumption	36.5 mW
Rx power consumption	41.4 mW
Sleep power consumption	42 µW

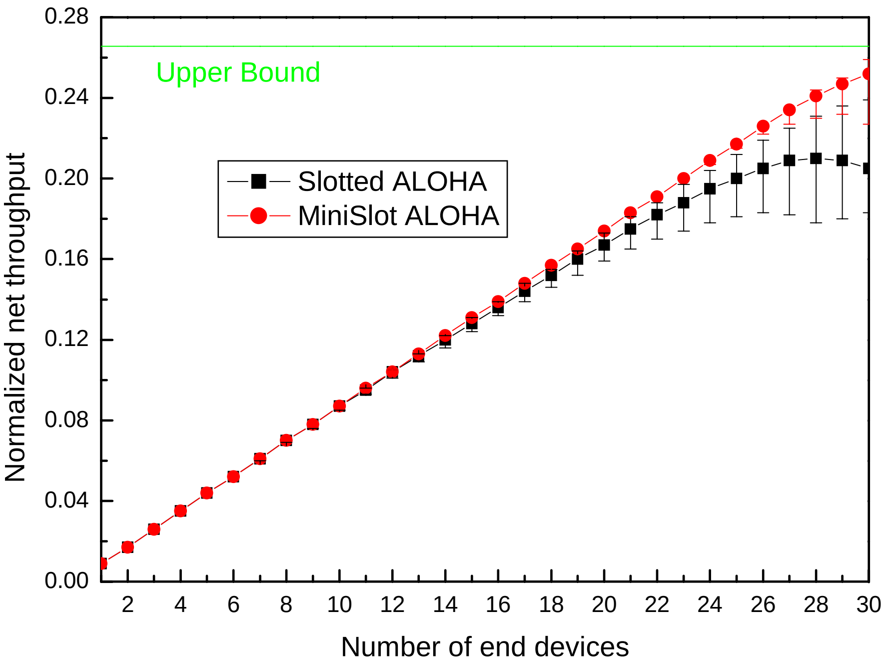
Ref. Chipcon CC2420

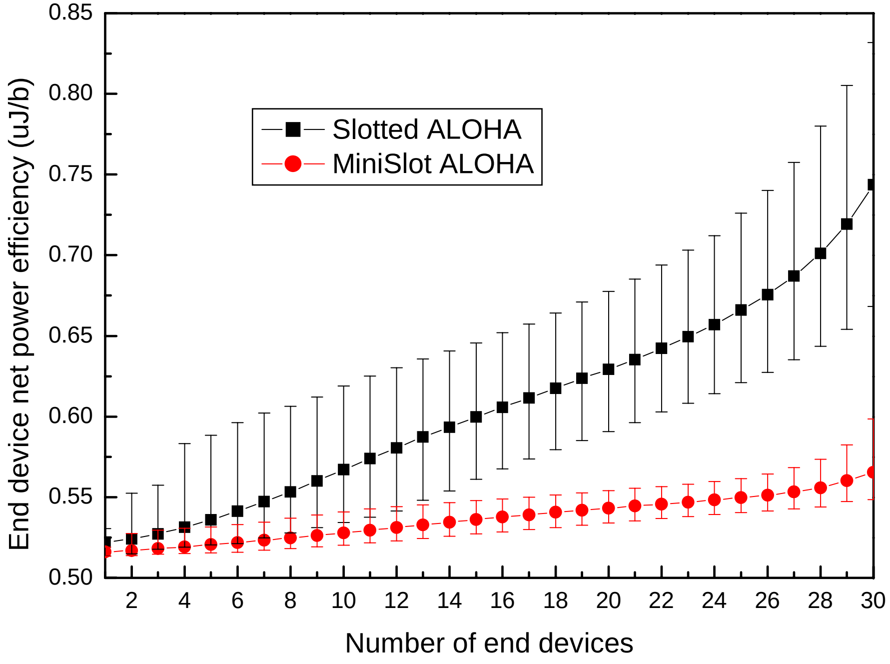
Simulation time	30 s
Simulation running	50,000 times
Confidence level	0.95

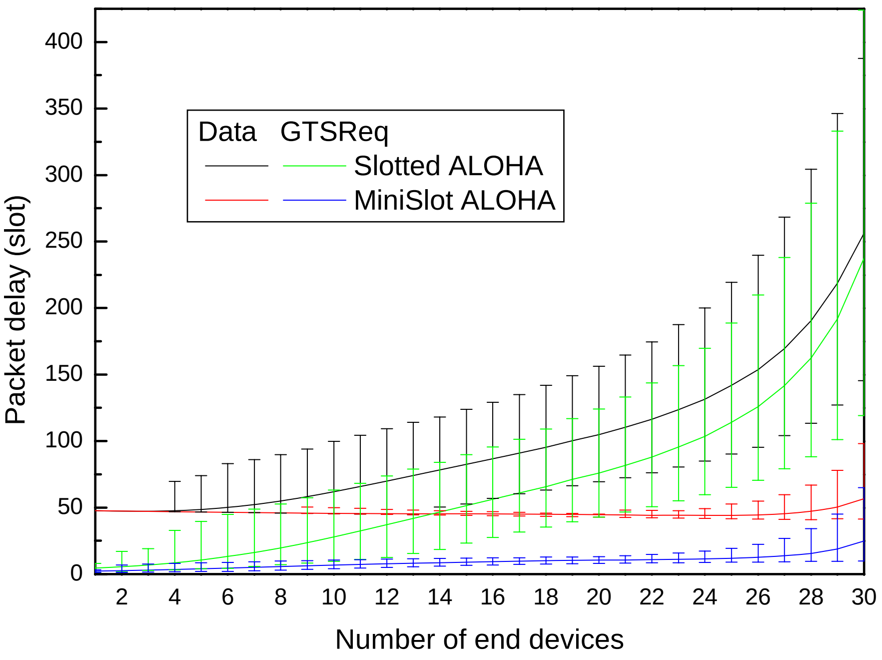
periodical traffic

- Commands contend in CAP and data transmit in GTS
- Slot request in CAP is dropped after 3 times of retransmissions
- Data rate: 2.176kbps/node









most of delay is due to GTS request.

§5. Self-evaluation

- MAC transparency
  - TDMA based BAN superframe
- Scalability
  - Group BAN superframe
  - Minislots in CAP
- QoS and dependability
  - GTS in BAN superframe
  - PAP
  - Non-beacon mode
- Power efficiency
  - Inactive BAN superframe
  - Distributed beacon listen and B-E beacon
- Topology
  - Star topology
- Interference and coexistence
  - TH and FH of BAN superframe
- Easy to implement

Conclusions

- Beacon mode
  - TDMA based BAN superframe
    - CAP, CFP and PAP
  - Equal slot duration
    - Minislots in CAP
    - Mandatory information piggybacked ACK
  - Priority access period
    - Optional priority slot and embedded priority period
- Non-beacon mode
  - For medical event or very low duty cycle traffic
  - To be used in the inactive BAN superframe
- Simulation
- Self-evaluation