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

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Abstract: [Presentation slides of the MAC proposal for IEEE 802.15.6 task group.]
Purpose: [To present our MAC proposal to IEEE 802.15.6]

IMEC UWB MAC Proposal for IEEE 802.15.6

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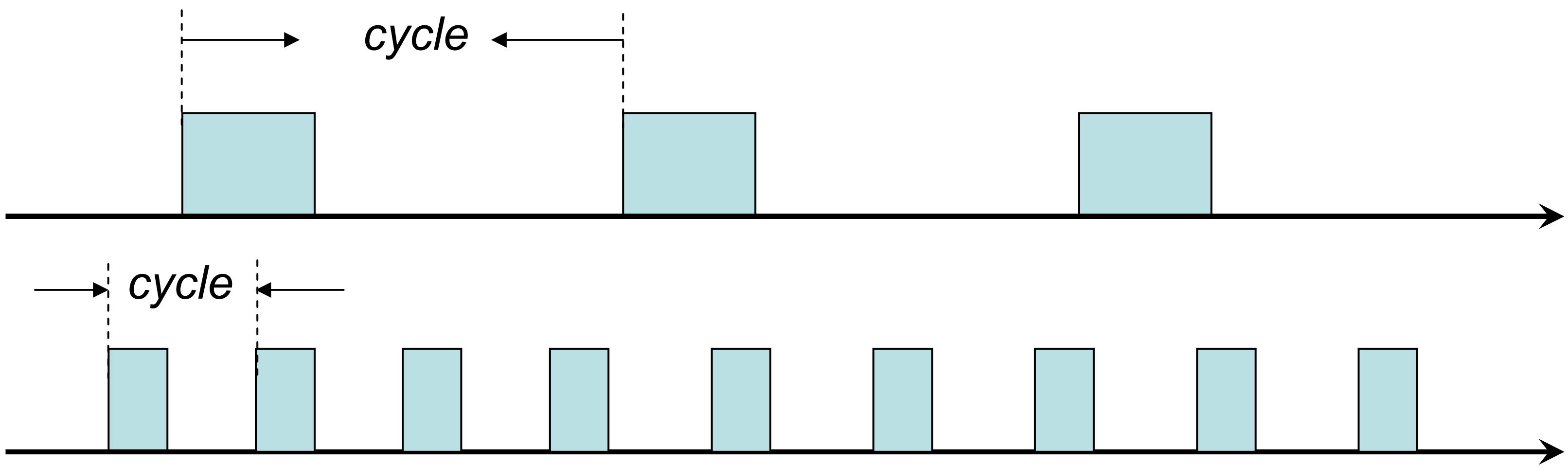
Proposal Overview

1) *Superframe structure:* dual duty-cycling (DDC)
2) *Enhanced slotted Aloha* for random access with QoS differentiation
3) Nested Access Period (NAP) for *tree topology support*

The MAC proposal outlined in this presentation is a part of IMEC's UWB PHY/MAC proposal. The complete proposal is made of this MAC used in combination with the UWB PHY presented in document 15-09-0330-00-0006

1) Superframe Structure Based on Dual Duty-Cycling (DDC)

Superframe Structure Based on Dual Duty Cycling



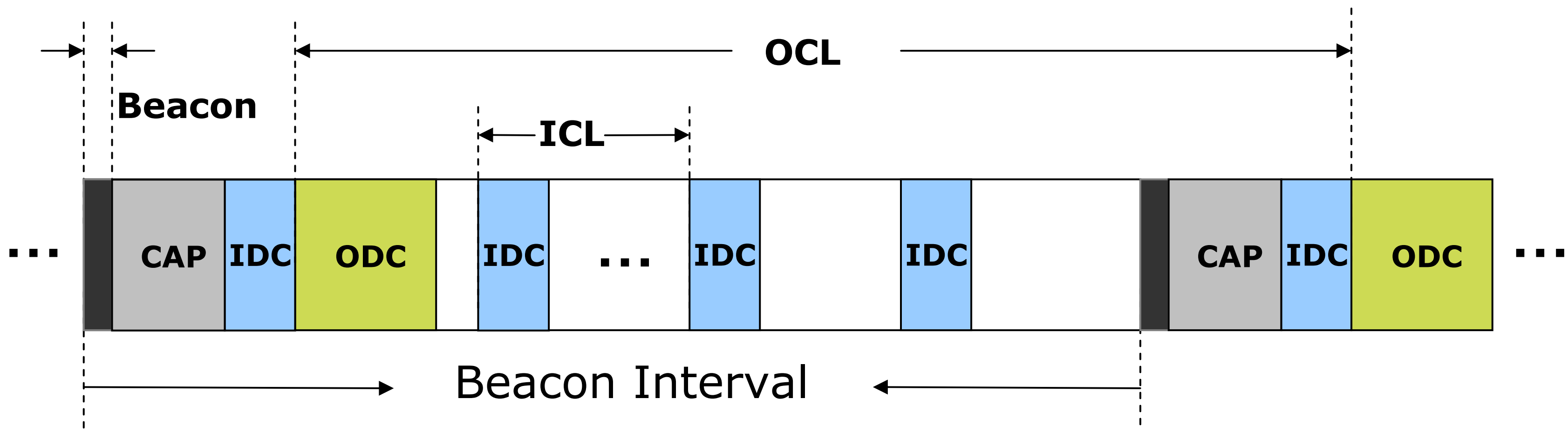
- Mixed traffic sources having different latency, reliability QoS requirements, → may result in different duty cycles

➡ *eg, heart beat can have much smaller cycle length than EEG*

How to design a duty cycling scheme which is

energy efficient & meeting various QoS parameters?

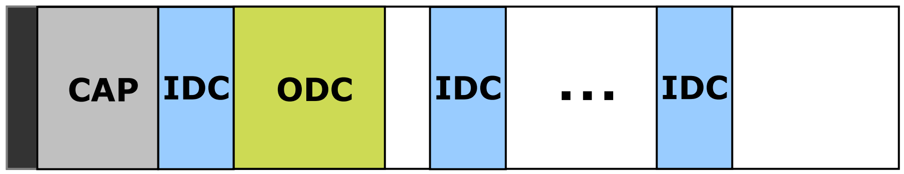
Superframe Structure Design - 1



- Interleaving *Inner Duty Cycles (**IDC**s)* and *Outer Duty Cycle (**ODC**)*
  - IDC: delay-sensitive, urgent data
  - ODC: delay-tolerable, bulky data
- CAP: contention access period for sporadic data, *enhanced slotted Aloha*

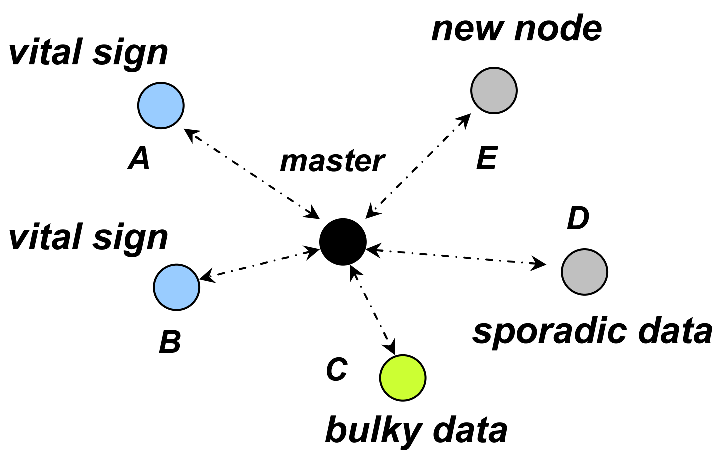
- *Inner Cycle Length (**ICL**)*
- *Outer Cycle Length (**OCL**)*
- Define *K* as ***Cycle Length Ratio*** (***CLR***): $K = ICL / OCL$, $0 \le K \le 1$

Superframe Structure Design - 2

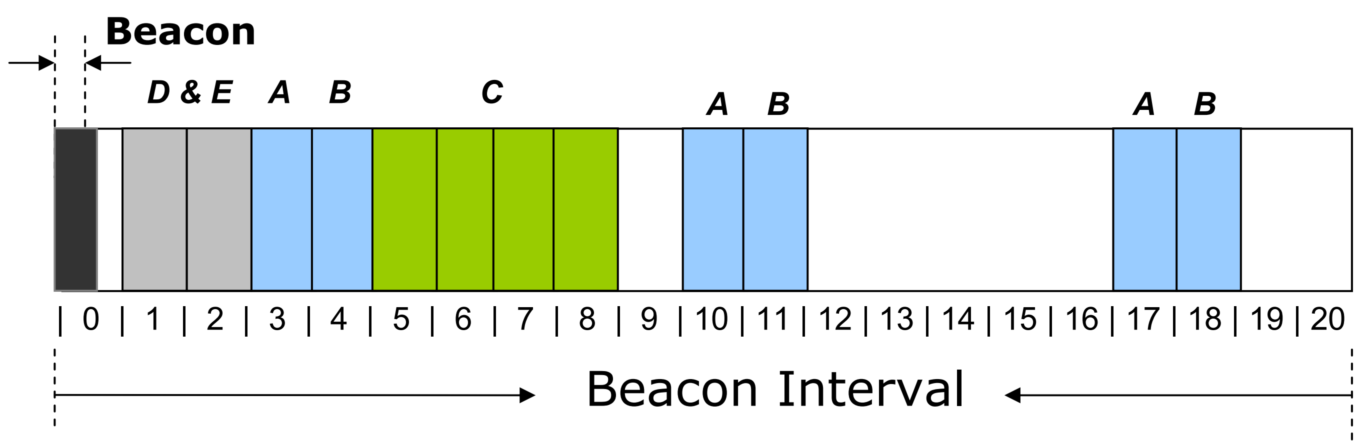


- An IDC contains a number of ***mini-slots***, each slot with length 0.2 ms
- Node is allowed to reserve mini-slots for ***life-critical*** messages in IDC's
- The CAP & ODC can be interrupted by IDC's
- CAP, ODC and IDC's can overlap with each other if receiver is capable of receiving multiple transmissions simultaneously
- Transmission strictly starts at the beginning of slots (with accuracy of 40 ppm) for time acquisition in UWB networks
- The DDC superframe is ***backward compatible*** with 802.15.4 MAC (set *BO*=*SO* and assign GTS slots as in DDC)

DDC Superframe Example



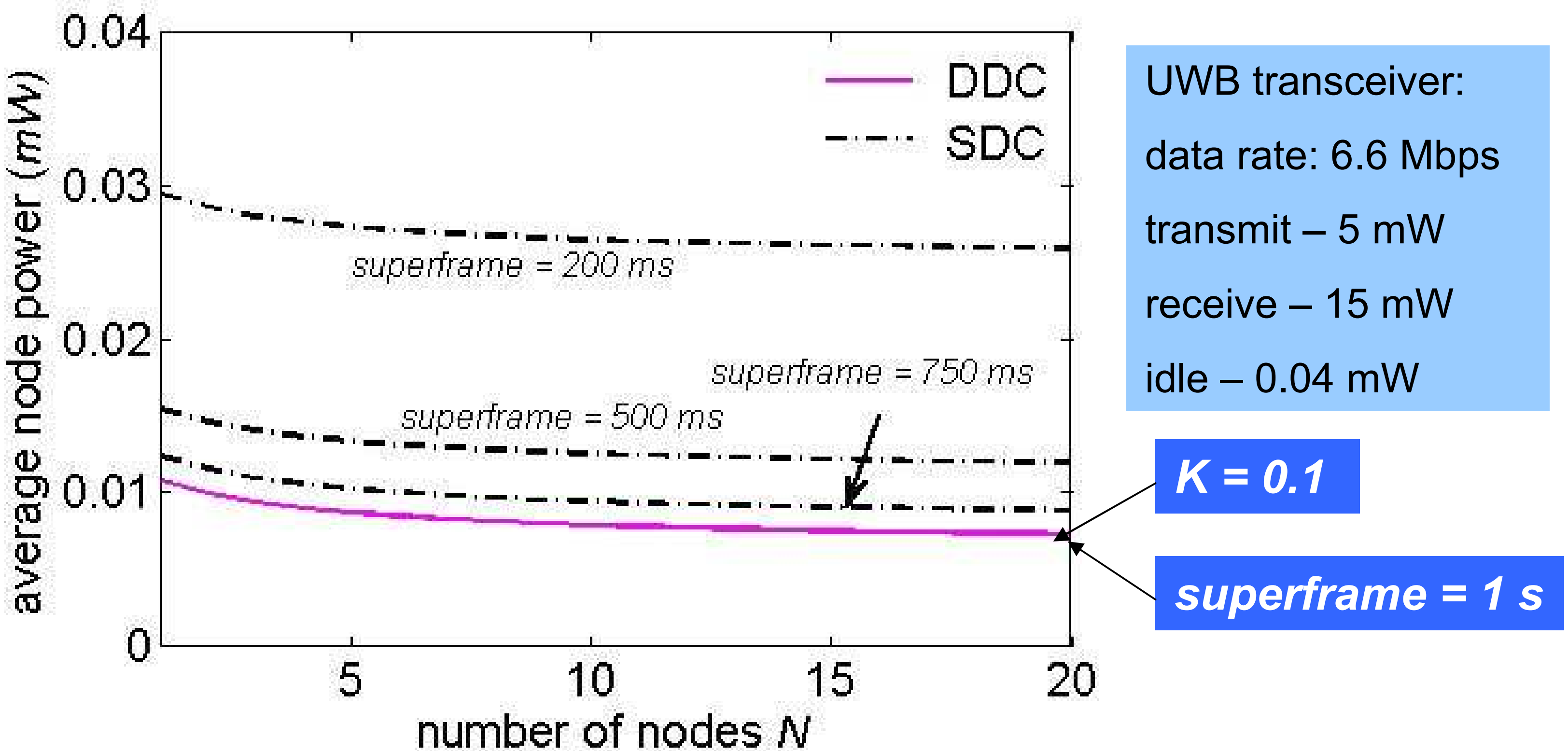
- slot 0: beacon by master
- slots 1, 2: node D & E, random access
- slots 3, 10, 17: node A
- slots 4, 11, 18: node B
- slots 5, 6, 7, 8: nodes C
- other slots: inactive



Evaluation of DDC

- Data and beacon packets are 256 bytes
- number of critical nodes: three, each with 10 kbps continuous data flow
- number of non-critical nodes: changeable, each with 5 *k* bytes data
- Power consumption evaluated between DDC and single duty cycling (SDC) schemes, such as IEEE 802.15.4 MAC

Power Consumption - UWB



UWB transceiver:

data rate: 6.6 Mbps

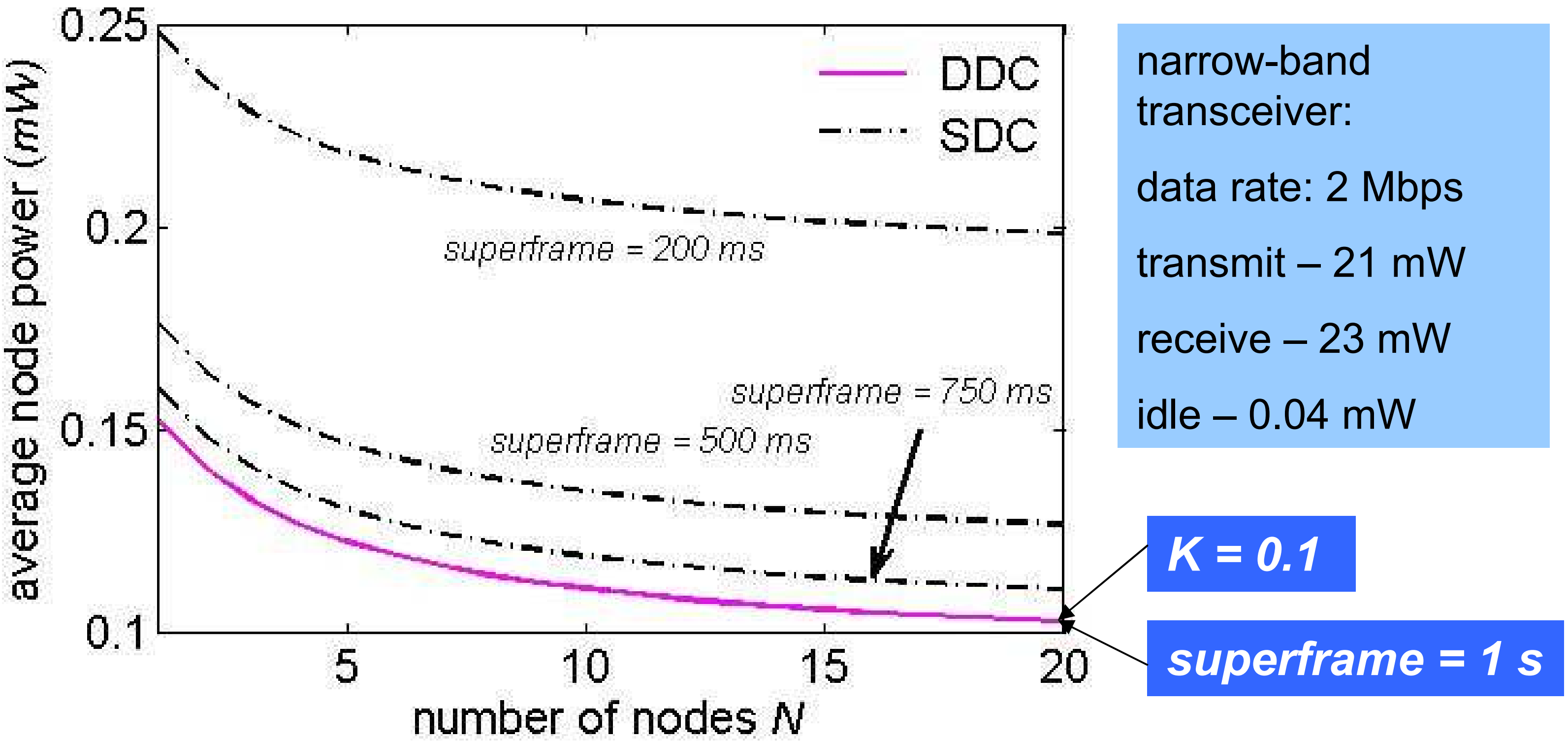
transmit – 5 mW

receive – 15 mW

idle – 0.04 mW

- Shorter cycle length reduces delay but increases power consumption
- Longer cycle length has similar power to DCC, but suffers from long delays
- DCC achieves a balance between power efficiency & delay

Power Consumption – Narrow-band



narrow-band transceiver:

data rate: 2 Mbps

transmit – 21 mW

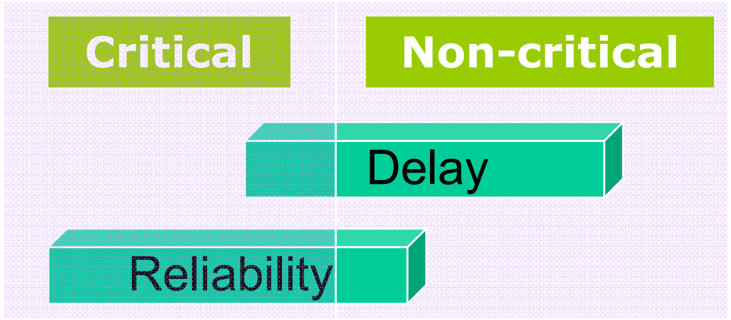
receive – 23 mW

idle – 0.04 mW

2) Enhanced Slotted Aloha for Random Access with QoS Differentiation

QoS support in wireless BANs

- As technical requirement document (TRD) specifies, major QoS for wireless BANs include
  - Latency
  - Reliability



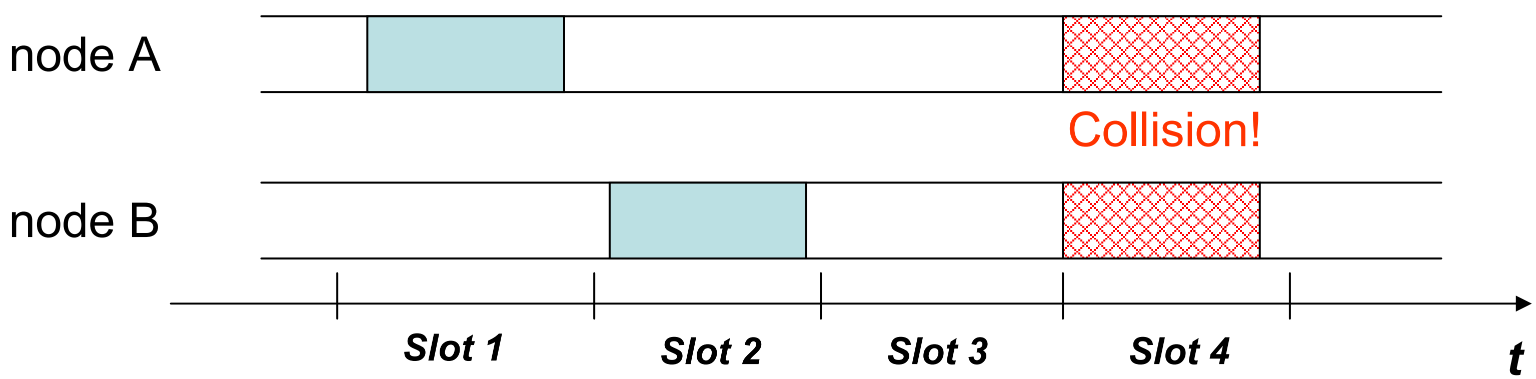
- When critical & non-critical app's co-exist, give priorities to critical ones

  ➡ ***QoS differentiation mechanisms needed***

Reliability def.: BER, packet loss, *packet success rate*

Slotted Aloha with QoS Differentiation

- The conventional ALOHA is simple
  1. If there is a packet, send it immediately;
  2. If a collision occurs, send it later.



Drawback -> Every node is treated *identically*

Include two techniques to enhance Aloha with QoS differentiation!

Technique 1: Discriminated Packet Transmission (DPT)

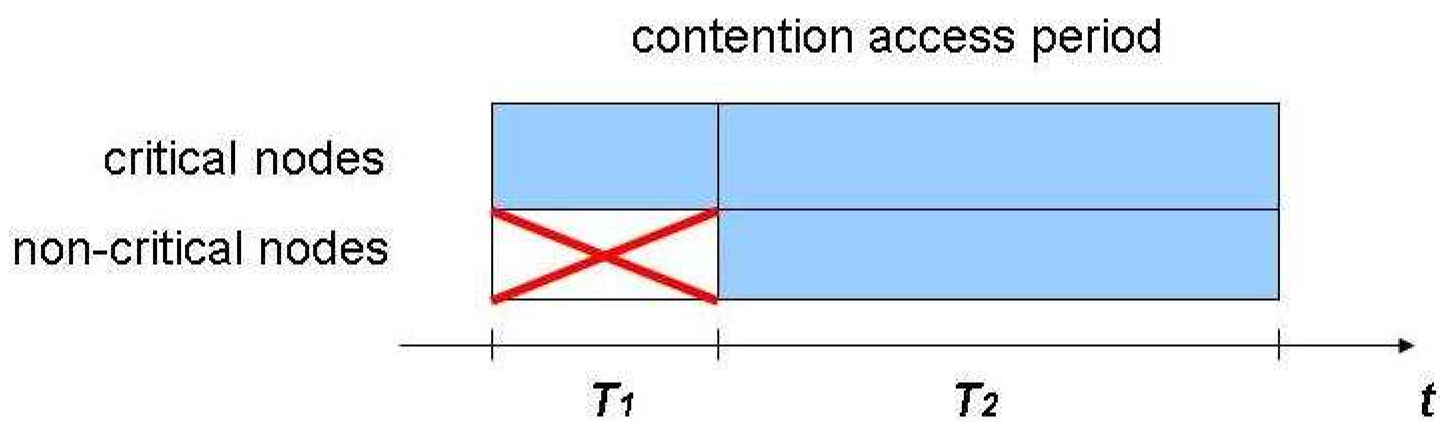
- If there is a new packet, the node sends it with probability ***p.***
- The sent packet will be immediately acknowledged
- If no ACK is received, a packet is considered to be collided. If a packet experiences *R* collisions, it will be discarded.
  - Critical node sends packet with *p1,* non-critical node with *p2*
  - If in collision, critical nodes retransmit with *p1*, and non-critical nodes with *p2*
  - A critical packet will be discarded after *R1* collisions, a non-critical packet will be discarded after *R2* collisions.

$p_1 > p_2$

$R_1 > R_2$

In this way, critical nodes get ***lower latency*** and ***higher success rate*** than non-critical nodes.

Technique 2: Hierarchical Contention Access (HCA)

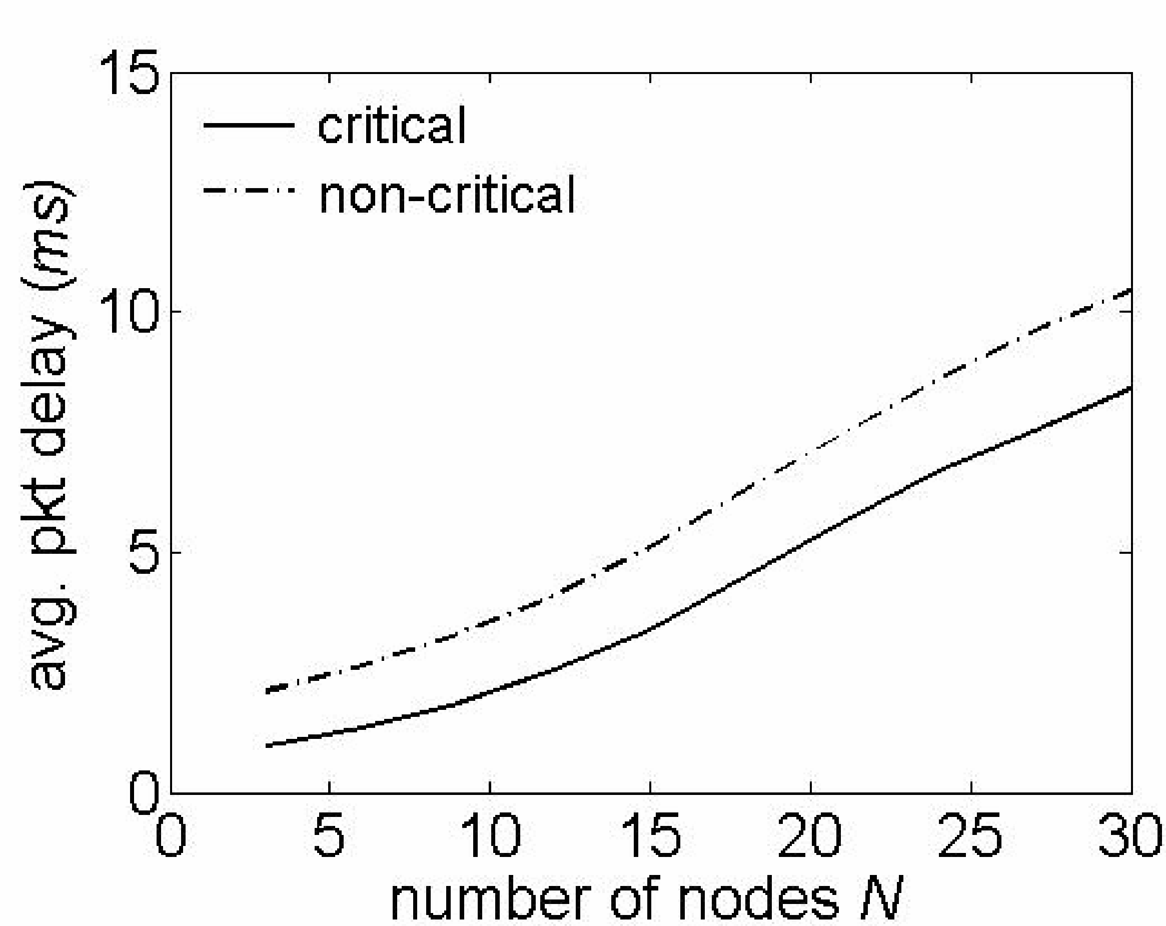


- Divide the whole CAP into two time periods
  - ***T1*** is reserved exclusively for critical nodes
  - ***T2*** can be used by all nodes

Performance Evaluation

- Implemented a C++ simulator
- CAP is fixed to 100 time slots
  - Each slot is 0.2 ms
  - ***T1*** = 30, ***T1*** = 70, in HCA
- Number of nodes, *N*, *33%* are critical nodes
- Assume each node has a packet to transmit at the beginning of the CAP
- Each point is obtained by averaging 1000 independent simulation runs

Average Access Delay - DPT



p1 = 0.2

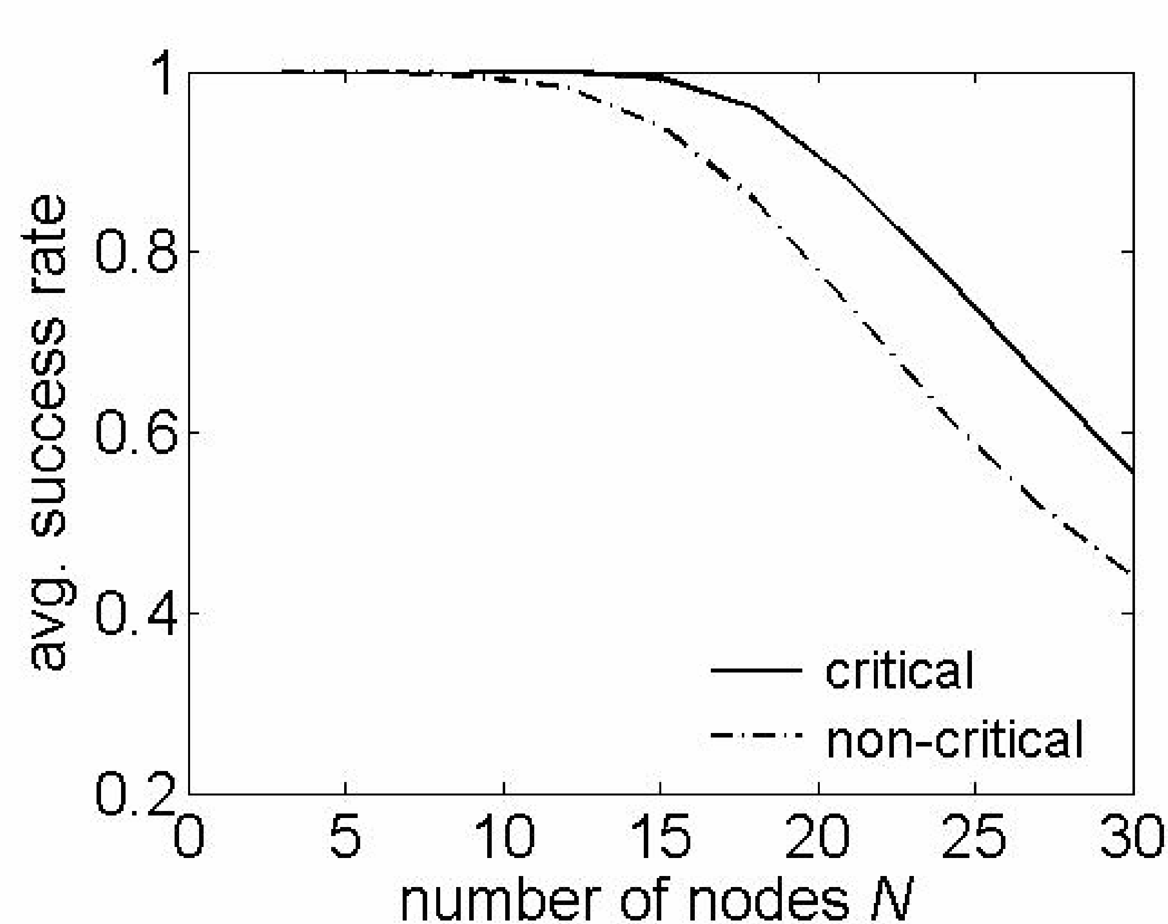
p2 = 0.1

R1 = 10

R2 = 5

- DPT gives more priority to critical nodes for delay

Packet Success Rate - DPT



p1 = 0.2

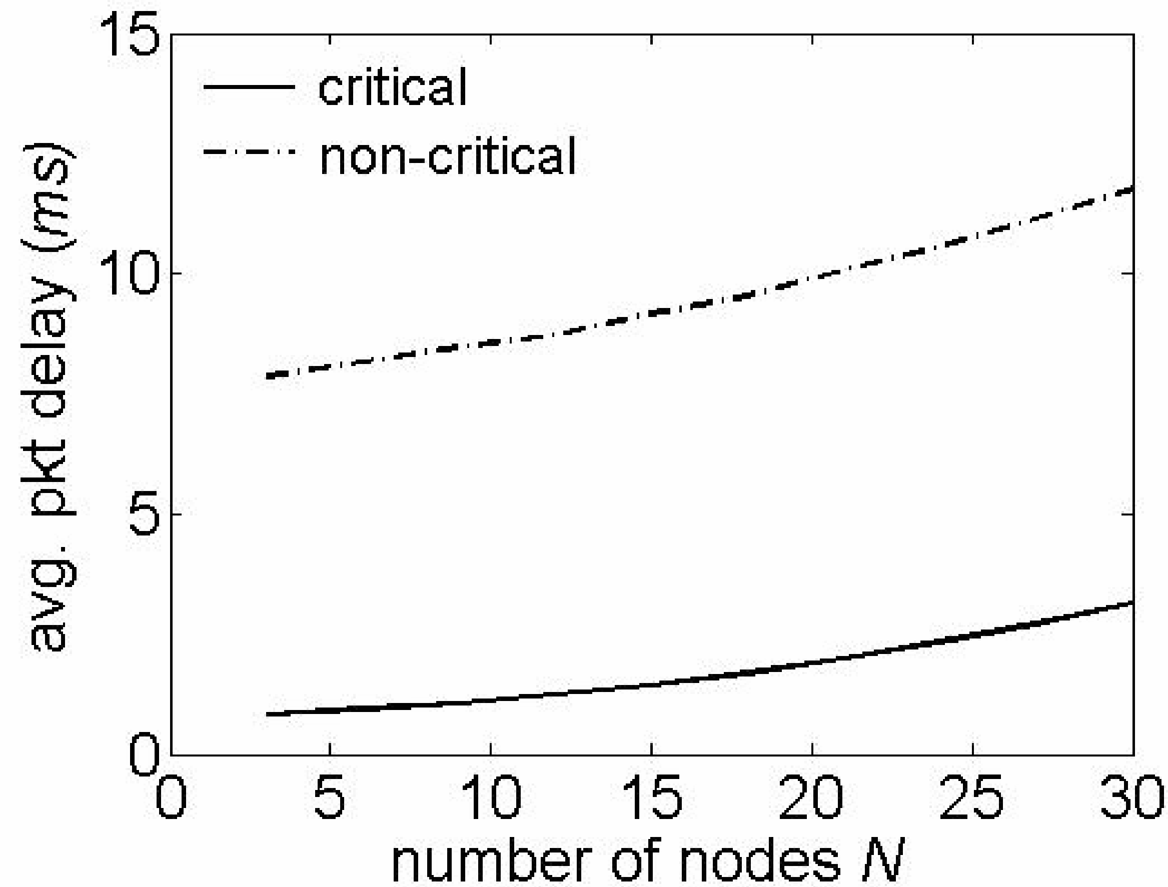
p2 = 0.1

R1 = 10

R2 = 5

- DPT also gives priority to critical nodes for packet success rate

Average Access Delay – DPT&HCA



p1 = 0.2

p2 = 0.1

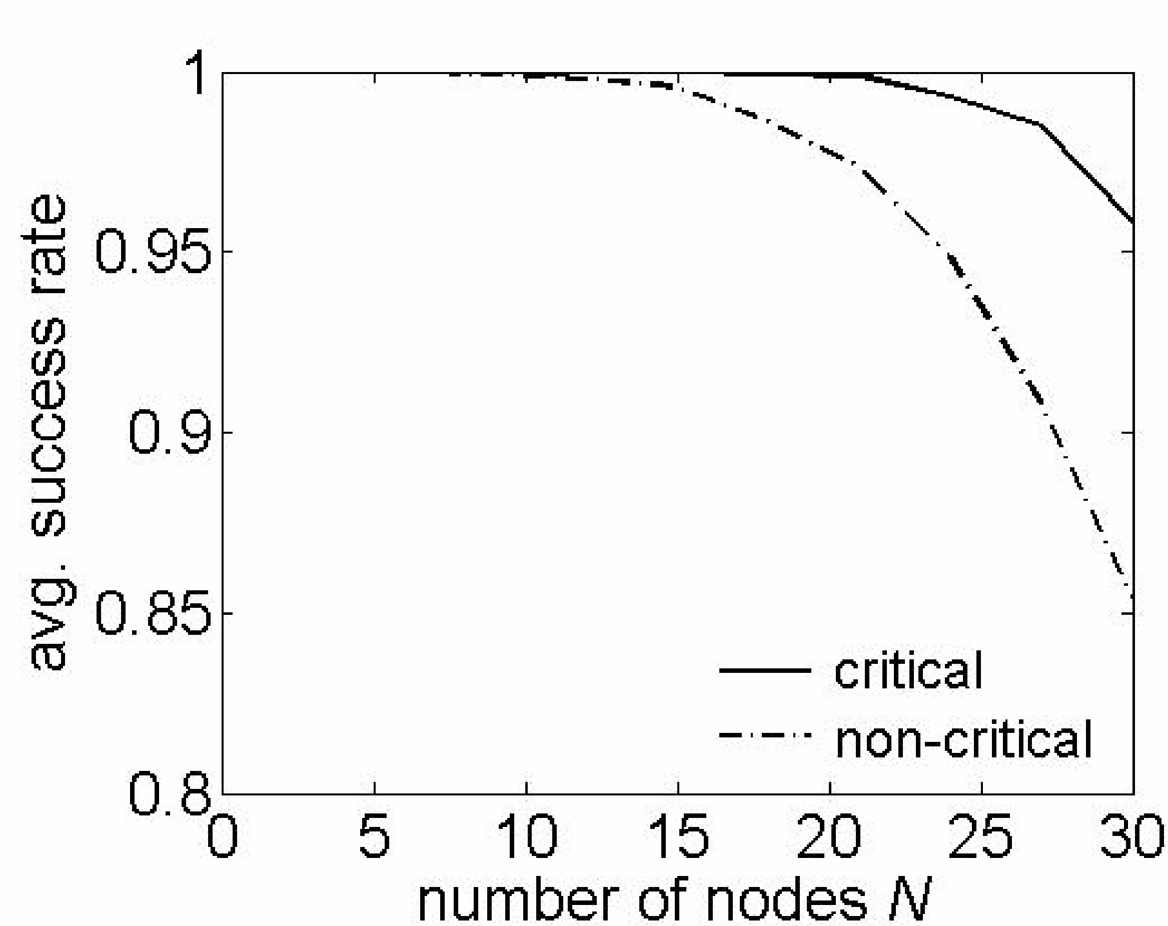
R1 = 10

R2 = 5

T1 = 30

- Combining DPT and HCA, critical nodes have much lower delay

Packet Success Rate – DPT&HCA

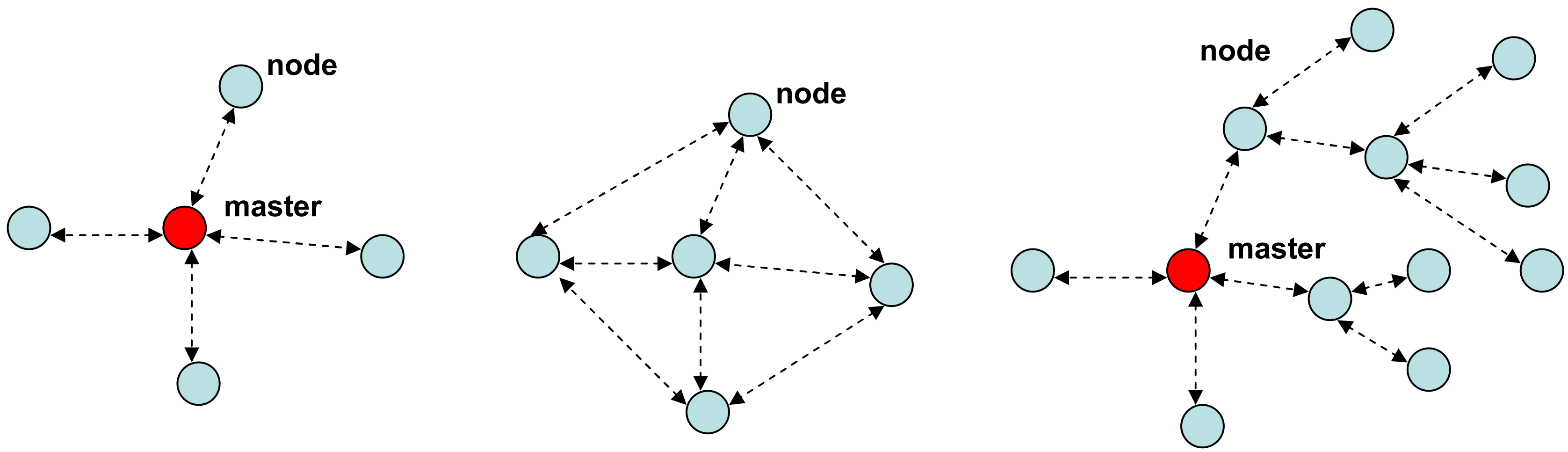


- $p1 = 0.2$
- $p2 = 0.1$
- $R1 = 10$
- $R2 = 5$
- $T1 = 30$

- Combining DPT and HCA, critical nodes also have much higher packet success rate

3) Nested Access Period for Tree Topology Support

Topology choices for wireless networks



a) star b) mesh a) tree

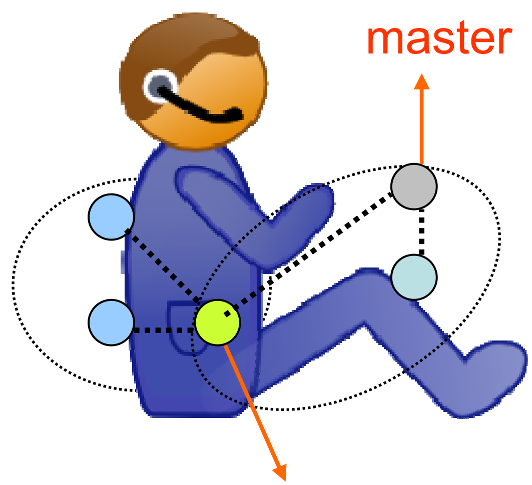
- There are many topology choices for general wireless networks
- Each topology has its advantages and disadvantages

Considerations of WBAN Topology Design

- **Special characteristics of WBANs include**
  - Network coverage usually < 2m around human body
  - Nodes may have non-line-of-sight (NLOS) channels
  - NLOS is especially problematic for high data rates, and usually OK when data rate is low
  - Medical applications require strictly low latency
  - Transmit power is strictly limited by specific absorption rate (SAR) regulation
- **Consequently, WBAN topology should**
  - be designed as simple as possible
  - avoid NLOS channels, especially for high data rates
  - comply with SAR regulation
  - satisfy low latency requirement of medical applications

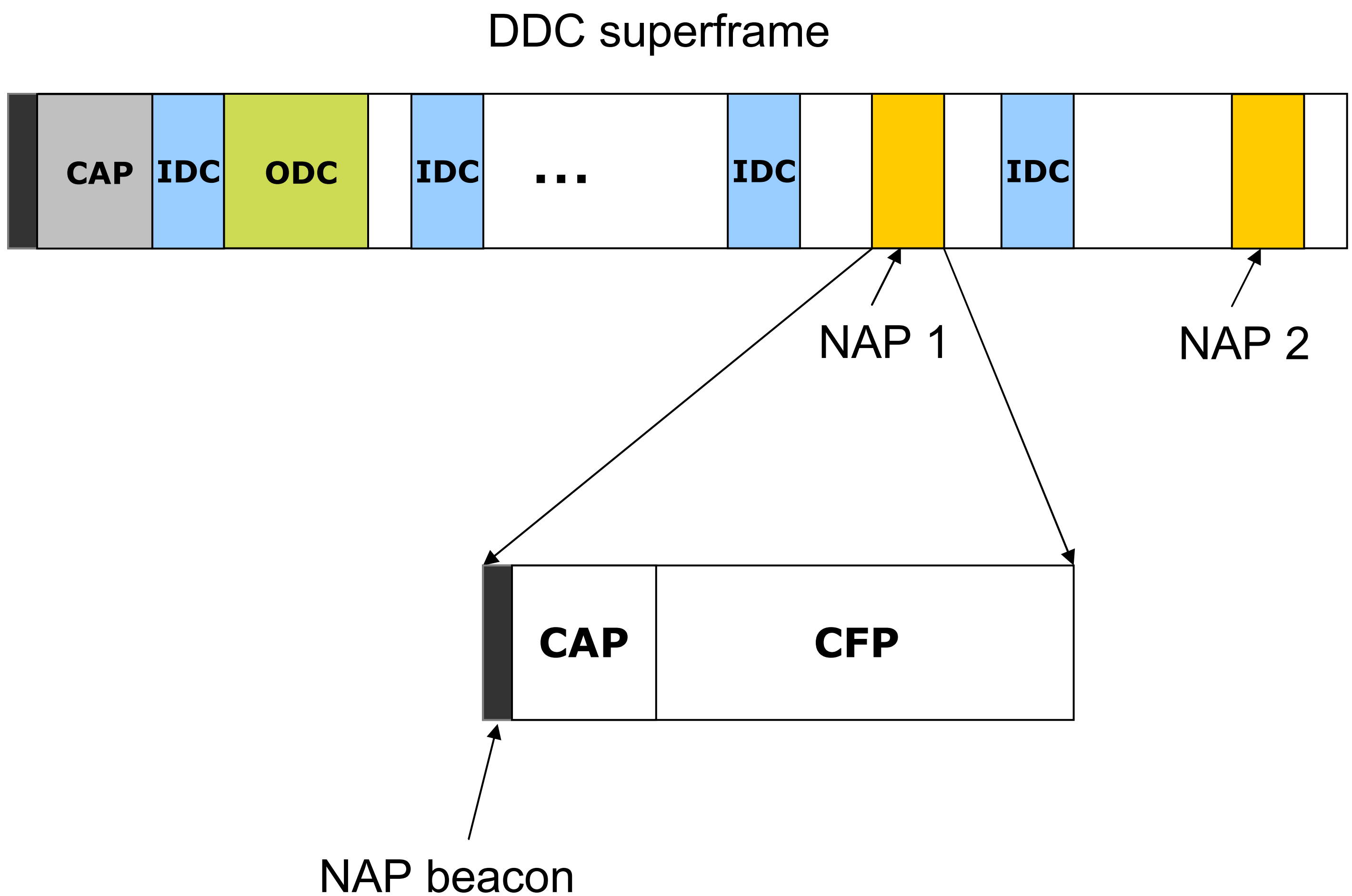
Restrained Tree Topology (RTT)

- Default mode remains star
- Severe channel degradation (eg, a NLOS scenario) will trigger to form a *restrained tree topology*



- In RTT, relay nodes form sub-networks to include nodes having degraded channels with the master
- RTT is restrained so that
  - limit tree depth to two
  - limit the maximum number of relays to five

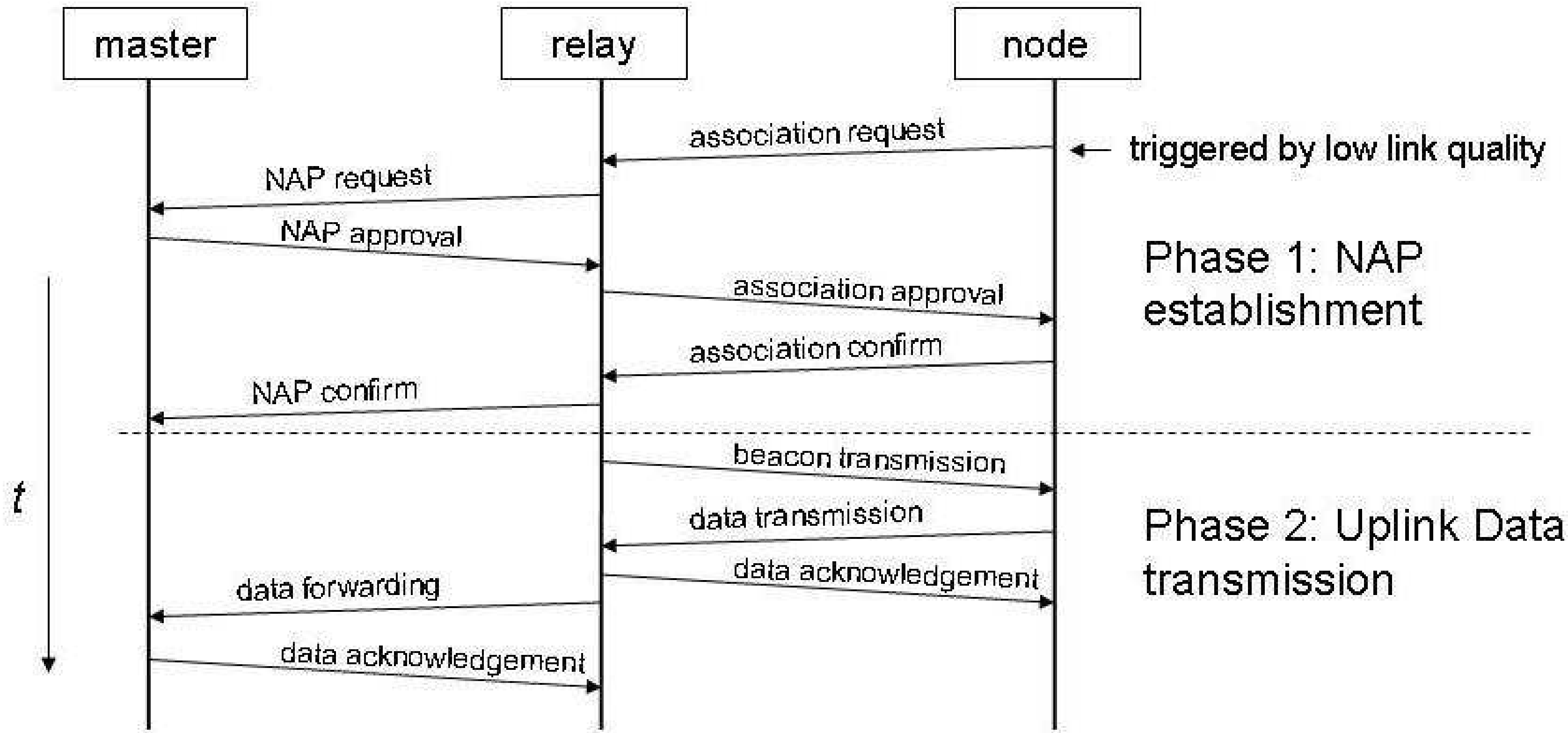
Nested Access Period (NAP) - 1



Nested Access Period (NAP) - 2

- A relay node acts as "*proxy*" for associated nodes
- A relay can have multiple associated nodes
- A NAP can
  - operate on a different channel to avoid interference
  - consist of beacon, contention free period (CFP), and CAP period

NAP establishment and uplink data transmission



Conclusions

- MAC solution specifically tailored for WBAN applications, well-suits UWB and narrow-band
- MAC proposal consists of
  - dual duty cycling, flexible & power efficient for continuous data flows with different periods
  - an enhanced slotted Aloha with QoS differentiation
  - nested access period, a mechanism to support tree topologies in BANs