Submission Title: [Multihop Extension for IEEE 802.15.4e]
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Re: [IEEE P802.15.4e Call For proposal]

Abstract: [This document proposes an enhancement to IEEE 802.15.4-2006 MAC Layer with modified superframe structure, GTS request/response and data transmission method. It corresponds to ‘superframe structure’ and ‘mesh support’.]

Purpose: [This document is a response to call for preliminary proposals.]

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Multi-hop Extension for IEEE 802.15.4e

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IEEE 802.15.4 - 2006

- Superframe structure on the periodic beacon enables
  - Energy saving of Coordinator by defining a long inactive period
  - Guaranteed time services
  - Efficient indirect communication

Superframe Duration = $a_{BaseSuperframeDuration} \times 2^D$ symbols

Beacon Interval = $a_{BaseSuperframeDuration} \times 2^D$ symbols
Multi-hop Extension

IEEE 802.15.4-2006
  - Scheduling outgoing superframe duration in the inactive period of a parent superframe

Issues
  - Beacon collision problem
    - Requiring scheduling algorithm and long enough inactive duration
  - GTS time allocation
    - Limited to one hop of PNC
  - Limited transmission scope and method
    - Only communication among nodes in family
    - Only indirect communication to children
Latency

- Although we believe that the architecture works…
- At each hop
  - A node has to wait for the superframe frame of the next hop for $t_{BI}/2$ on average
- Long beacon interval ($t_{Bl}$) is expected for
  - 1) easy scheduling
  - 2) energy saving
- Ex. From node 4 to 0 (3 hops), when BO=6 (0.983s)
  - If the data is generated at 0,
    - $(3/8 + 6/8 + 7/8) \times 0.983 = 1.966s$
  - On average : $t_{Bl} \times h = 1.474s$
Discussion

• Fundamental remedy for latency
  – To take a small beacon interval
  – To use the inactive time

• Acceptable?
  – Energy consumption
    • Trade off relation. More energy is unavoidable.
    • Hopefully acceptable in 4e scenarios
  – Scheduling complexity
    • Unless it requires more intelligent than current one.
Shared Superframe Duration

[Diagram showing different time slots labeled as OSD and ISD within a superframe]
Shared Suprframe Duration

- Requirement
  - Slotted scheduling of superframe durations
  - Superframe scheduling algorithm for 802.15.4-2006

- Protocol
  - Create ‘superframe image’ from the outgoing superframe
  - Transmit a beacon at the scheduled outgoing superframe
  - Repeat the superframe image at the other time
    - Wait for a beacon for a while
  - Modified data transmission
  - Modified GTS
Modified Data Transmission

Among 4e devices
- Same as existing transmission used in an incoming superframe duration
  - General frame: directly transmission
  - GTS frame: using TxOption of GTS transmission

To 15.4-2006 devices
- If 4b dev is a child
  - Option1) Indirect communication
  - Option2) Adding new SDT (Superframe Dependent Transmission) in TxOption of MCPS-DATA.request
    - Keeping the data in the queue
    - Transmitting OSD of mine or the child’s
- If 4b dev is a parent or a neighbor
  - Similar to the Option2) but transmitting only in OSD of the dev’s

\[ \textit{Superframe Dependent Transmission} \]
GTS Allocation

- **EGTS request**
  - From a src to a dst with available slot list

- **EGTS reply**
  - From a dst to one hop nodes → CTS
  - Broadcasting an assigned GTS slot number

- **EGTS notify**
  - From a src to one hop nodes → RTS
  - Broadcasting an assigned GTS slot number

- **Schedule notification**
  - Beacons of the src and the dst
GTS Allocation Example

2. **EGTS reply**,  
Broadcast  
Payload:  
Dst addr (3)  
new allocated slot number: 2  
Allocated GTS slots (0b01000000)

3. **EGTS notify**,  
Broadcast  
Payload:  
Allocated GTS slots (0b11000000)

1. **EGTS request**,  
Unicast to 1  
Payload:  
Available GTS slots (0b10000000)
Two Examples

- If data is generated at 0
  - Minimum latency: \( t_{SD} \times \frac{9}{16} + t_{SD} / 16 \times 2 = 69.12 + 15.36 = 84.48 \) ms
  - Maximum latency: \( t_{SD} \times \frac{15}{16} \times 3 = 345.6 \) ms
Efficient beacon scheduling (OSD scheduling) can reduce latency of services related beacons – Ex. Association, indirect transmission

For Better Beacon Services
Considering Energy Consumption

- Transmission method is similar to 15.4-2006 devices
  - In my OSD, transmit to any device
  - In other ODSs, transmit to the device
- Also, saving energy in unassigned GTS slots.
Summary

Three proposals for multihop communication

1. Enhancing superframe structure for multi hop latency problem
   • Using existing beacon transmission time scheduling
   • Shared superframe without transmitting beacon

2. Enhancing GTS allocation
   • Three command frames
     • EGTS request/ EGTS reply/ EGTS notify

3. Superframe dependent transmission
   • For co-existing with 15.4-2006
   • For saving energy

More discussion
• Spatial reuse
• Energy saving