Synchronized-slotted CSMA-CA Algorithm for Energy Efficient Peer-to-peer Multihop Communication in IEEE 802.15.4

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Abstract: IEEE 802.15.4[1] is designed for low-rate wireless personal area networks(LR-WPAN). It is characterized by low-data-rate, low-cost, low-power consumption. And low-power consumption is a very important feature in composing WPAN. In this standard, two network topologies are supported: star and peer-to-peer topology which can be extended to the multi-hop tree as WPAN increasing. And slotted(beacon mode) or unslotted(non-beacon mode) CSMA-CA is used for the devices to communicate with each other. But slotted and unslotted CSMA-CA have a problem in terms of energy efficiency especially when WPAN is extended. So we will analyze the problem and suggest our algorithm, SSCC(Synchronized Slotted CSMA-CA) which can enhance energy efficiency.

1. Introduction

In recent, the application is diversified like a home automation, PC peripherals, toys, which require the longer battery life and lower data rate and less complexity. So IEEE 802.15.4 standard is developed. However, because of the diversity of the application, the network is hard to avoid being expanded. Especially enlargement of the peer-to-peer topology, as peer-to-peer multi-hop tree topology, is indispensable. But there is a problem the network topology is larger, the device consumes the more energy.

2. Technical Overview

The main objectives of the LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol.

2.1 Componenet of the IEEE 802.15.4 WPAN

The most basic is the device. A device can be a full-function device(FFD) or reduced-function device(RFD). A network shall include at least one FFD, operating as the PAN coordinator. The FFD can operate in three modes: a personal area network (PAN) coordinator, a coordinator or a device. An FFD can talk to RFDs while an RFD can only talk to an FFD.

2.2 Network topologies

IEEE 802.15.4 supports star and peer-to-peer topologies. In the star topology, the communicaton is established between devices and a single central controller, called the PAN coordinator. The PAN coordinator may be powered while the devices will most likely be battery powered. After an FFD is activated for the first time, it may establish its own network and become the PAN coordinator(Figure1).

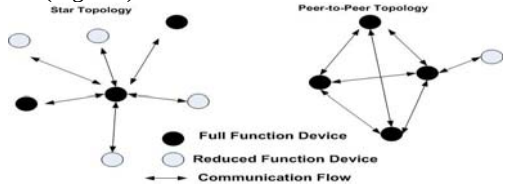

Figure 1. Peer-to-peer multi-hop tree network

In the peer-to-peer topology also has a PAN coordinator. However it differs from the star topology in that any device can communicate with any other device as long as they are in range of one another(Figure1). One device will be nominated as the PAN coordinator by virtue of being the first device to communicate on the channel. An example of the use of the peer-to-peer communcations topology is the cluster-tree(Figure2).

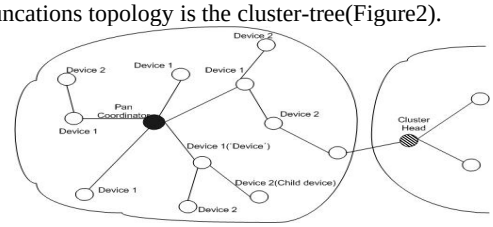

Figure 2. Peer-to-peer multi-hop tree network

2.3 Superframe structure

The LR-WPAN standard allows the optional use of a superframe structure. To communicate with each other device, two mode can be selected. One is non-beacon mode which use unslotted CSMA-CA. The other is beacon mode which use slotted CSMA-CA. In unslotted CSMA-CA, every each device should be awaken always because it is impossible to know when they should receive data, or send data. That cause the unnecessary energy consumption. In slotted CSMA-CA, the superframe structure is used.

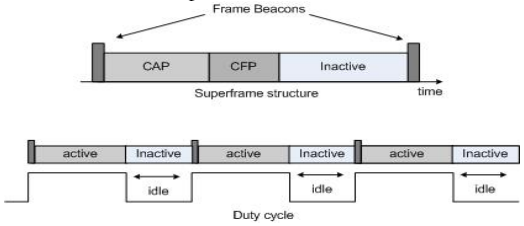

Figure 3. Superframe structure and duty cycle

The superframe is bounded by network beacon, is sent by the coordinator. The beacon frame is transmitted in the first slot of each superframe. The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the superframes. The superframe can have an active and an inactive portion. During the inactive portion(Figure3), the coordinator shall not interact with its PAN and may enter a low-power mode. An active portion can be devided into the CAP(Contention Access Period) and CFP(Contention Free Period). After the beacon frame, the CAP is followed. The coordinator may allocate up to seven of GTSs(Guaranteed Time Slot), and a GTS may occupy more than one slot period. The GTSs form the CFP(Figure4). In the GTS, only one device can communication with its coordinator.

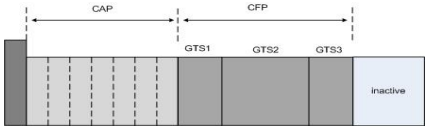

Figure 4. Superframe structure with GTS

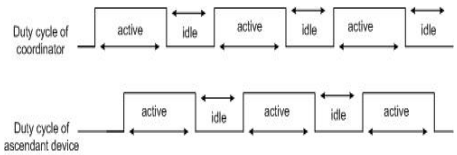

Figure 5. Broken duty cycle case

Each device can make the duty cycle with the active and inactive portions in superframe(Figure3). In peer-to-peer multi-hop tree toplogy, the duty cycle can be broken. Because the beacon timing is different between each device. Although the descendant device which receives the beacon from the coordinator is in its inactive portion, but it should be awaken to communicate with its coordinator. Because its coordinator is in active portion. By that the energy efficiency is reduced. In this case, the problem of the duty cycle broken is happened(Figure5). So we suggest SSCC(Synchronized Slotted CSMA-CA) which can conserve the duty cycle of each device by synchronizing the beacon timing.

3. SSCC

SSCC can maximize the energy efficiency by preserving the duty cycle of each device in peer-to-peer multi-hop tree topology. In this section we will present our algorithm.

3.1 GFB

The coordinator allocate one slot GTS from the last slot in inactive portion to its descendant devices only when the descendant devices request(Figure6). The descendant device which have no its descendant device can't request the GTS to the coordinator. Through the allocated GTS the descendant devices can send the beacon to their descendant devcies. This GTS is called GFB(GTS For Beacon). When the GFB is in the last, the energy efficiency is maximized. So the coordinator allocates the GFB to descendant devices randomly or can give the priority to some devices.

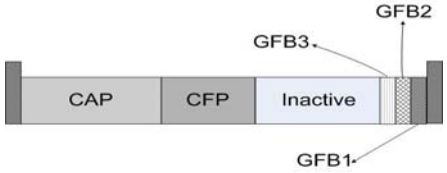

Figure 6. GFB

3.2 Synchronization

SSCC can synchronize the beacon timing among the devices by virtue of the GFB. We exclude the densely deployed network. So the beacon delay between devices(coordinator,descendant device) can be at most two or three slots. However the beacon is relayed in the all networks, so the duty cycle can be synchronized between devices(coordinator, descendant coordinator).

By that the descendant device can get the almost full inactive portion(Figure7). It means that the energy efficiency is maximized.

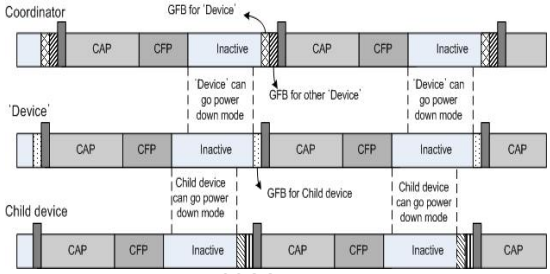

Figure 7. SSCC structure timing

Then the CFP period is also synchronized, so the CFP period can collide between coordinator and descendant device. So data can be crushed like a Figure8.

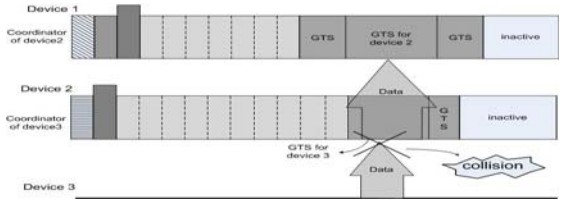

Figure 8. GTS collision problem

3.3 Collision avoidance

The collision in GTS can cause a decline of network performance and destruction of IEEE 802.15.4 standard. In order to prevent the GTS collision, a device which has its coordinator and desendant devices like a device2 in Figure2 should play an important role. If there is a GTS request from the device3 after the device2 is allocated the GTS from the coordinator(device1), the device2 should allocate the GTS to device3 as avoiding same time. Another case is that the device3 is allocated GTS from device2 before the device2 is allocated GTS from coordinator. If the allocated GTS of the device2 and GTS of device3 overlap, then the device2 should request GTS again to the coordinator. When the device2 request GTS again, the device2 should include the time of GTS of the device3 in the request packet. The GTS request is should be finished in CAP period. If the device2 can't finish requesting another GTS in CAP period, then the device2 give up sending data to the coordinator in the former allocated GTS and just receive the data from the device3.

4. Simulation and Results

We simulate the energy consumption in peer-to-peer multi-hop tree topology. The results is depicted in Figure 9. Unslotted and slotted CSMA-CA and SSCC protocol are compared. We use enegy comsumption rate as 18.4mA which is the everage value of the CC2420. We can find that SSCC can preserve more energy than any other CSMA-CA protocol. As we expected, the energy efficiency of unslotted CSMA-CA is worst.

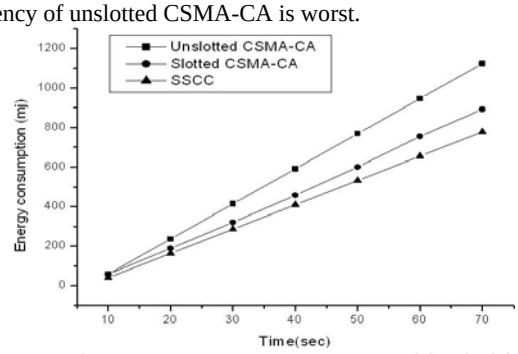

Figure 9. Energy consumption in various CSMA-CA

5. Conclusion

Peer-to-peer topology in IEEE 802.15.4 is impossible to avoid being extended as peer-to-peer multi-hop tree topology. As the networks are enlared, the low power consumption becomes more improtant. So we suggest our algorithm, SSCC, to complement slotted and unslotted CSMA-CA protocol in the energy efficiency aspect. SSCC synchronize the beacon among devices and that can reduce the energy consumption by concuring the duty cycle of each device. We can find from simulation result that the energy efficiency of unslotted CSMA-CA is very low, and SSCC consumes less energy than any other two topologies.

Reference

[1] IEEE P802.15.4/D18, Draft Standard: Low Rate Wireless Personal Area Networks, Feb.2003.