IEEE 802..15.4 무선 네트워크의 non-beacon 모드와 beacon 모드에서의 collision에 관한 성능 연구

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Performance study for collision in non-beacon mode and beacon mode of IEEE 802.15.4 wireless network

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요 약

IEEE 802.15.4 is designed for low-rate wireless personal area networks (LR_WPAN) and it attempts to provide a low data rate, low power, low cost wireless networking on the device-level communication. In this paper, I have established a realistic environment for the effect of collision in nonbeacon-enabled mode and beacon enabled mode. The data throughput and delivery ratio are investigated as the performance metrics.

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1. 서 론

The release of IEEE 802.15.4, " Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks " , represents a milestone in wireless personal area networks and wireless sensor networks. 802.15.4 is uniquely designed for low rate, low power consumption and low cost wireless networking and offers device level wireless connectivity. Zheng and Lee[1] developed an NS-2 simulator for 802.15.4 to study its performance with various features. Also Lu et al.[2] implemented 802.15.4 MAC prototype in the NS-2 network simulator and provided simulation-based performance evaluations, focusing on its beacon-enabled mode for a star-topology network. Lee[3] conducted an practical experiment to study its various features. However so far there are no realistic experiments and results available for collision between several devices in nonbeacon-enabled mode and beacon-enabled mode. In this paper, after an overview of network topology and CSMA-CA mechanism in 802.15.4 MAC protocol, I attempt to make performance study for effect of collision between several devices in nonbeacon-enabled mode and beacon-enabled mode. The organization of the paper is as follows. Section 2 introduces network topology and CSMA-CA mechanism. Next, experimental hardware and configuration are illustrated in section 3. Then experimental results of the performance study are described in section 4. Finally, section 5 gives the conclusions.

2. 802.15.4 Overview

A. Network topology

Two types of topologies are supported in 802.15.4: a one-hop star or a multiple peer-to-peer topology. The basic structure is star topology. After FFD(Full Function Device) is activated for the first time, it may establish its own network and become the PAN coordinator. All star networks operate independently from all other star networks currently in operation. This is achieved by choosing a PAN ID, which is not currently used by any other network within the radio radius. Once the PAN ID is chosen, the PAN coordinator can allow other devices to join its network. the communication is established between a single central controller, called PAN coordinator and other devices. On the other hand, in a peer-to-peer topology, each device is capable of communicating with any other device within its radio radius. Further network structures can be constructed out of the peer-to-peer topology. An example is the cluster-tree network, which is a special case of a peer-to-peer network.

B. Beacon and Superframe structure

The standard allows the optional use of a superframe structure. The format of the superframe is defined by the coordinator. The superframe comprises an active Part and an optional inactive part, and is bounded by network beacons. The length of the superframe (beacon interval, BI) and the length of its active part (superframe duration, SD) are defined as follows:

- BI = aBaseSuperframeDuration * 2^{BO}
- SD = aBaseSuperframeDuration * 2^{SO}

Where,

- aBaseSuperframeDuration = 960 symbols
- BO = beacon order, $0 \leq BO \leq 14$
- SO = superframe order, $0 \leq SO \leq 14$

The values of BO and SO are determined by the coordinator. For those PANs that do not wish to use the superframe structure (referred to as a nonbeacon-enabled PAN) shall set both BO and SO to 15. The active part of superframe is devided into aNumSuperframeSlots (default value 16) equally sized slots and beacon frame is transmitted in the first slot of each superframe. The active part can be further broken down into two periods, a contention access period (CAP) and an optional contention free period (CFP). The optional CFP may accommodate up to seven so-called guaranteed time slots (GTSs), and a GTS may occupy more than one slot period. A slotted CSMA-CA mechanism is used for channel access during the CAP.

C. CSMA-CA mechanism

The CSMA-CA algorithm shall be used before the transmission of data or MAC command frames transmitted within the CAP. 802.15.4 uses two types of channel access mechanism, depending on the network configuration.

- Unslotted CSMA-CA : Nonbeacon-enabled networks use this channel access mechanism. Each time a device wishes to transmit data frames or MAC commands, it shall wait for a random period. If the channel is found to be idle, following the random backoff, the device shall transmit its data. If the channel is found to be busy, following the random backoff, the device shall wait for another random period before trying to access the channel again.
- Slotted CSMA-CA: Beacon-enabled networks use this channel access mechanism, where the backoff slots are aligned with the start of the

beacon transmission. Each time a device wishes to transmit data frames during the CAP, it shall locate the boundary of the next backoff slot and then wait for a random number of backoff slot. If the channel is busy, following this random backoff, the device shall wait for another random number of backoff slots before trying to access the channel again. If the channel is idle, the device can begin transmitting on the next available backoff slot boundary.

Three variables are maintained at each device for a channel access: NB, CW and BE. NB is the number of times the CSMA-CA backoffs while attempting the current transmission, and is reset to 0 for each new data transmission. CW is the contention window length, which is reset to 2 either for a new data transmission or when the channel is found to be busy. BE is the backoff exponent, which is related to the backoff periods a device should wait before attempting carrier sensing

2. Experimental Hardware and Configuration

A. Experimental Hardware

As shown in Fig.1, our own developed boards are used as a coordinator and devices. Our developed boards contain a CC2420 single-chip with necessary support components, an Atmel Atmega128L AVR microcontroller with 128K flash and 4K SRAM, as well as LEDs. CC2420 is a IEEE 802.15.4 compliant RF transceiver. It provides a highly integrated, flexible low-cost solution for applications using the 2.4GHz frequency band.

B. Experimental Configuration

The experiments were run in a one-hop star topology, as shown in Fig.1. The distance between the coordinator and each device is 0.5m. The number of devices is 5. Devices are sending continuously data packet to the coordinator. In each experiment, the frame retransmission was disabled and 1000 data packets were transmitted by devices. Each data packet was transmitted at regular intervals (i.e. 18ms, 9ms, 6ms). the total packet length is 113 bytes which are composed of MAC header of 11 bytes and MAC payload of 102 bytes(aMaxMACFrameSize). So, if packet interval is 18ms, the traffic load per device 50kbps. Also if packet interval decreases by 9ms and 6ms, the traffic load per device is 100kbps and 150kbps, respectively. The NB was set to 4 and the backoff exponent was 3. During the data transfer, the addressing mode used is the 16-bit short address. If all transmissions are successful, 1000 acknowledge packets would be transmitted so as to respond to each data packets. The performance study was after all the devices finish channel scanning and the association procedure to join the PAN. In beacon-enabled mode, we choose SO = 4, and BO = 4, which makes the duty cycle to be 100 %.

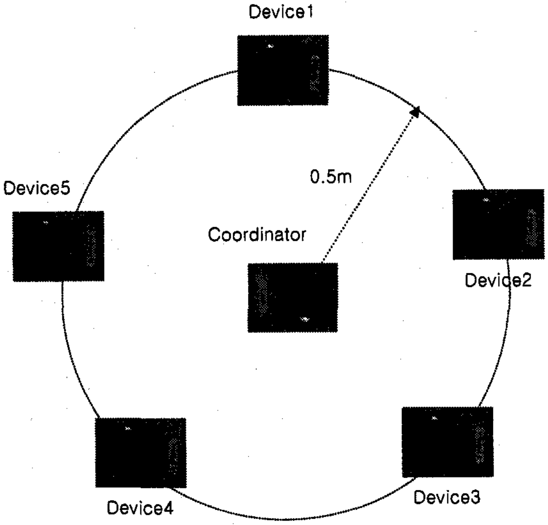

Fig. 1. Experimental setup as a star topology

3. Experimental Results

In this experiment, the effective data rate is defined as

$R = (N_{data} * L_{data}) / T_{end} - T_{start}$.,

where N_{data} is the number of successful data packets, L_{data} is the MSDU length(i.e. MAC payload size), while T_{start} and T_{end} is the time to start and end the transmission. $T_{end} - T_{start}$ is total delivery latency.

The packet delivery ratio is defined as the ratio of packets successfully received to packets sent in MAC sublayer.

The data MSDU size was fixed to 102 bytes (i.e. MAC payload size). 1000 data packets were transmitted from devices to the coordinator. All the following experiments have the same condition.

Fig. 2 and Fig.3 show the effective data rate between the coordinator and devices for different number of devices with varied traffic load. We find that the highest throughput is achieved, when there is only 1 device, at around 100kbps, 70kbps and 40kbps. Note that these are substantially below the nominal value of 135kbps, 90kbps and 45kbps, respectively. This is because the actual total delivery latency is greater than the theoretical total delivery latency due to the existence of random backoffs, ACK messages, as well as inter-frame spacing. Fig.2 and Fig.3 display similar graph pattern as a whole, and as expected we can see that as the number of devices increases, the effective data rate decreases. This is because N_{data} decreases, while there is not much change in tatal delivery latency. In other words, it is analyzed that there is a decrease of the number of usable packets due to collision. In addition we can see that when the traffic load becomes heavier, the effective data rate rapidly decreases.

Fig.4 and Fig.5 show the packet delivery ratio according to the number of devices. As described above, the results show that with the increase of devices, usable packets decrease. They also show that packet delivery ratio becomes lower as the traffic load gets heavier. This is the proof that there is a higher probability of collision when the number of devices increases or the traffic load becomes heavier. In Fig.5, the thing we should notice is that even if the traffic load increases up to 150kbps, packet delivery ratio is maintained at the same value as the result of 100kbps. This is the proof that beacon-enabled mode is more effective than nonbeacon-enabled mode when traffic load becomes heavier.

Fig.6 and Fig.7 is a graph where nonbeacon-enabled mode and beacon-enabled mode have been compared with. In Fig.6, when the number of devices is just one, the effective data rate of beacon-enabled mode is smaller than that of nonbeacon-enabled mode. This is because the total delivery latency of beacon-enabled mode is larger due to slotted CSMA-CA. However, the effective data rate of beacon-enabled mode becomes larger as the number of devices increase by two or more. This is caused by the increase of usable packets of beacon-enabled mode. This means that beacon-enabled mode is stronger in dealing with collision. This is clearly shown in Fig.7.

As mentioned in IEEE 802.15.4, when 16 bit short addresses are used in star topology, it is possible to accommodate 65533 devices(except the address of PAN coordinator and the broadcast address). However, according to the above result, the number of devices that can be actually accommodated is very limited because of the significant influence of collision. Of course, the number of devices that can be accommodated will increase in an environment where data throughput is not an important factor, depending on the characteristics of sensor application. Still, there surely will be a limit in increasing the number of devices to be as many as 65533. Especially, as in the above experiment where there is a simultaneous occurrence of sensing data during a certain period of time, or in case of a application that is very sensitive to the loss of sensing data, the number of devices to be accommodated is highly restricted. So, in this case, not a contention-based CSMA-CA but the scheduling between devices is necessary.

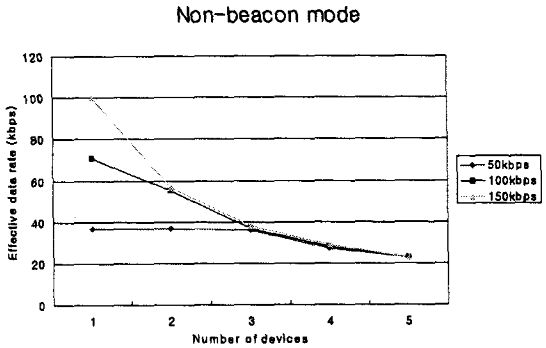

Fig.2 Effective data rate with the varied number of device in a nonbeacon-enabled mode

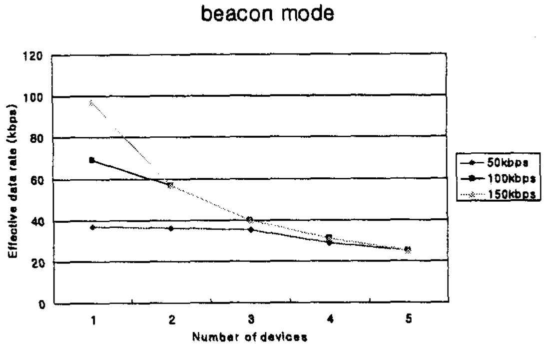

Fig.3 Effective data rate with the varied number of devices in a beacon-enabled mode

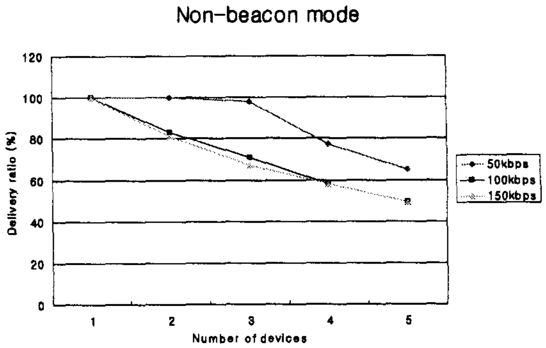

Fig.4 Packet delivery ratio with the varied number of devices in a nonbeacon-enabled mode

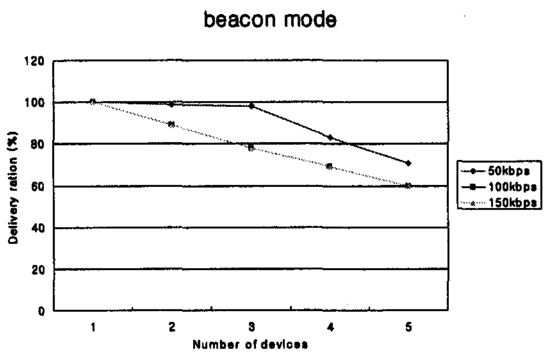
beacon mode

Fig.5 Packet delivery ratio with the varied number of devices in a beacon-enabled mode

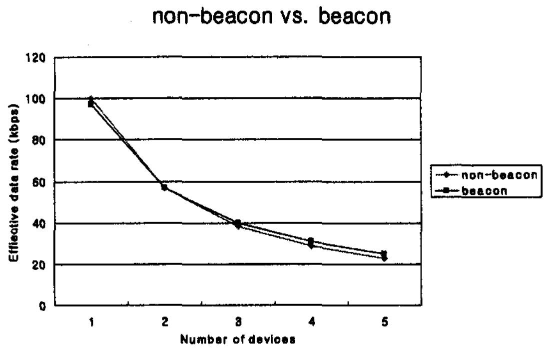
non-beacon vs. beacon

Fig.6 Effective data rate with varied number of devices in nonbeacon vs. beacon-enabled mode

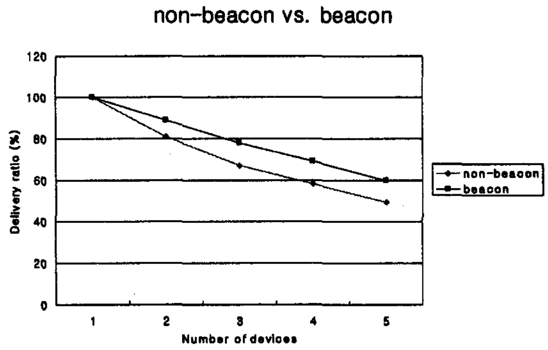
non-beacon vs. beacon

Fig.7 Packet delivery ratio with varied number of devices in nonbeacon vs. beacon-enabled mode

4. Conclusion

The results show that with the increase of devices, both the effective data rate and delivery ratio decreased due to the presence of collisions. Also the beacon-enabled mode is more effective than nonbeacon-enabled mode in terms of collision. This is beacase collision probability of beacon-enabled mode is lower than nonbeacon-enabled mode because of slotted CSMA-CA. When there are many devices in a star topology, the influence of collision between devices is very significant. So the number of devices that can be accommodated in a star topology should be restricted. And according to the characteristics of sensor application, the number of devices should be determined.

We will analyze various parameters which are used in CSMA-CA mechanism of IEEE 802.15.4 and we will find the effect of these parameters on collision through actual experiment in next study.

5. References

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