비콘을 사용하는 IEEE 802.15.4 네트워크를 위한 가상 도착 메커니즘

Virtual Arrival Mechanism for IEEE 802.15.4 beacon enabled networks

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Abstract

For power constrained applications, IEEE 802.15.4 networks may be operated in beacon enabled mode with inactive period. In this paper, we propose the Virtual Arrival Mechanism (VAM) to avoid the congestion at the beginning of each contention access period (CAP). Virtual Arrival Mechanism (VAM) is a kind of traffic shaping that spread the traffics congested at the beginning of CAP into the whole CAP. By using VAM, collisions and energy consumption can be reduced. Finally, we evaluate the performance enhancement of VAM using NS-2 simulator.

Keywords

IEEE 802.15.4, Beacon enabled networks, Virtual arrival mechanism

I. 서 론

Recently, wireless networking provides more flexible connectivity in daily life. Wireless personal area networks (WPANs) are short-range (from a couple centimeters to a couple of tens meters) wireless networks that can be used to exchange information between devices in the reach of a person. The IEEE 802.15.4 contains a wireless MAC (medium access control) and physical layer specifications for low-rate wireless personal area networks. The standard will be used in some applications such as home automation, industrial sensing and control, environment monitoring and sensing. These applications have more relaxed throughput requirements under tens of kbps and lower power consumption requirements [1]. The main concern of these applications is that of extremely low power consumption, since it is impossible or undesirable to replace or recharge batteries for the devices [2]. For these applications, the IEEE 802.15.4 has been developed to provide low complexity, cost, and power consumption
for low data-rate wireless connectivity.

The standard defines two channel access mechanisms, depending on whether beacon frames (sent periodically by the coordinator to synchronize communications) are used or not. In beacon enabled mode, 802.15.4 networks use slotted carrier sense multiple access mechanism with collision avoidance (CSMA-CA), while those use unslotted CSMA/CA mechanism in non-beacon enabled mode. For energy constrained applications, the beacon enabled networks are essential, since time synchronized sleep and wake-up mechanism can be adopted. There are some researches related to the performance of the IEEE 802.15.4 beacon enabled networks [3,5].

They analytically modelled the access delay and throughput of the IEEE 802.15.4 beacon enabled networks, and [5] proposed a correction to the standard in order to reduce the contention problem at the beginning of the CAP. However, both researches don't consider much about performance of 802.15.4 beacon enabled networks with inactive period. Also, the correction of [5] to reduce the contention problem at the beginning of the CAP doesn't works well in 802.15.4 beacon enabled networks with inactive period. In the applications such as sensor networks, not only the devices associated with the coordinator but also the coordinators have the limited power and require low duty cycle. For these applications, beacon enabled networks with inactive period can be used, because all the device including coordinators can turn off its transceiver during inactive period. In IEEE 802.15.4 beacon enabled networks with inactive period, all the packet arrivals from higher layer have to wait to access the channel until the active region comes. Therefore, to handle the accumulated packets during inactive period is a key issue in IEEE 802.15.4 beacon enabled networks with inactive period.

Due to the accumulated packets during inactive period, a congestion problem happens at the beginning of the CAP in 802.15.4 beacon enabled networks with inactive period. In this work, the virtual arrival mechanism (VAM) is proposed to avoid the congestion at the beginning of the CAP. Lower energy consumption can be achieved by using VAM. Also, the simulation results using NS-2 presents the performance enhancement of VAM.

The rest of this paper is structured as follows. First, an overview of the IEEE 802.15.4 is given. Next, we present the problem to solve in this work. In section IV, the simulation results are given to validate performance enhancement of VAM. Finally, conclusion and futurework is given.

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II. IEEE 802.15.4 Overview

In the following subsections, a brief description of the IEEE 802.15.4 is given. There are many design features in the IEEE 802.15.4 standard. However, this paper introduces some part of that to help understanding of this paper. Complete specifications can be found in [4].

1.Beacon Enabled Mode and Superframe Structure

An 802.15.4 network can operate in either beacon enabled mode or non-beacon-enabled mode. In beacon-enabled mode, a coordinator broadcasts beacons periodically to synchronize the attached devices. In non-beacon enabled mode, a coordinator does not broadcast beacons periodically, but may transmit a beacon when a device request the beacon for some purpose such as scanning the existing network. A superframe structure is used in beacon enabled mode. The format of the superframe is defined by the coordinator and informed by the beacon. From Figure 1, we can see 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 determined by the beacon order (BO) and superframe order (SO), respectively. The two of the most important network parameters are BO and SO in beacon enabled network. Because the ratio of SO to BO determines the active portion of superframe, in other word, power consumption. The active part of the superframe is divided into aNumSuperframeSlots (default value 16) equally sized slots, and the 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). In the CAP, every device accesses the channel using slotted CSMA/CA mechanism. The optional CFP may accommodate up to seven GTSs, and a GTS is a kind of time division multiple access mechanism which is allocated to an device to transmit or receive data without contention. However, we don't consider the optional CFP in this paper. That means the all active portion in this paper is CAP.

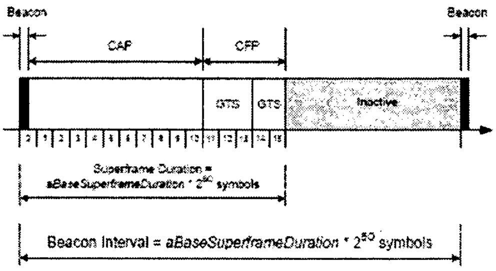

Fig. 1. An example of the superframe structure

2.Slotted CSMA/CA Mechanism of IEEE 802.15.4

Figure 2 illustrates the steps of the CSMA/CA algorithm in IEEE 802.15.4 [4]. The one of the main differences between the slotted version and the unslotted version is that the slotted CSMA/CA algorithm performs any operation on a backoff period boundary and it makes use of CW variable which is described below.

Each device shall maintain three variables for each transmission attempt: NB, CW and BE. NB is the number of times the CSMA/CA algorithm was required to backoff while attempting the current transmission. CW is the contention window length, defining the number of backoff periods that need to be clear of channel activity before the transmission can commence. BE is the backoff exponent, which is related to how many backoff periods a device shall wait before attempting to assess a channel.

First of all, NB, CW and BE are initialized to appropriate values. Naturally, NB is reset to 0. After initializing these values, the MAC sublayer locates the boundary of the next backoff period in the slotted CSMA/CA. Then, it delays for a random number of complete backoff periods in the range 0 to 2^{BE}-1 and then request the physical layer to perform a Clear Channel Assessment (CCA) to check whether the channel is busy or not. In a slotted CSMA-CA system, the CCA shall start on a backoff period boundary. In an unslotted CSMA-CA system, the CCA shall start immediately. If the channel turns to be idle in a slotted CSMA-CA system, CW is decreased and tested if CW is equal to 0. If it reaches to 0, then the MAC sublayer shall begin transmission of the frame on the boundary of the next backoff period. Otherwise the CSMA-CA algorithm returns to step (2). The reason the channel assessment should be performed only twice is due to the power saving aim of the IEEE 802.15.4 protocol. In the IEEE 802.11 protocol, the devices decreases the backoff counter only if the channel is assessed to be idle more than DIFS interval. It means that all devices in the network consume their power observing the status of the channel while performing the backoff procedure in IEEE 802.11. But that is not the case in IEEE 802.15.4. The devices which set the RxOnWhenIdle parameter to False in IEEE 802.15.4 networks turn off its transceiver during the backoff procedure. Therefore, the key consumers of the energy are the CCAs and transmission.

III. Problem Statements and Solution

In this section, we introduce the problem to solve in this paper. Then, the Virtual Arrival Mechanism (VAM) is proposed as the solution of the problem.

1. Problem Statements

For energy constrained applications such as sensor networks, IEEE 802.15.4 networks may be operated in beacon enabled mode. In beacon enabled networks, the devices synchronized to the beacon frames from its coordinator can

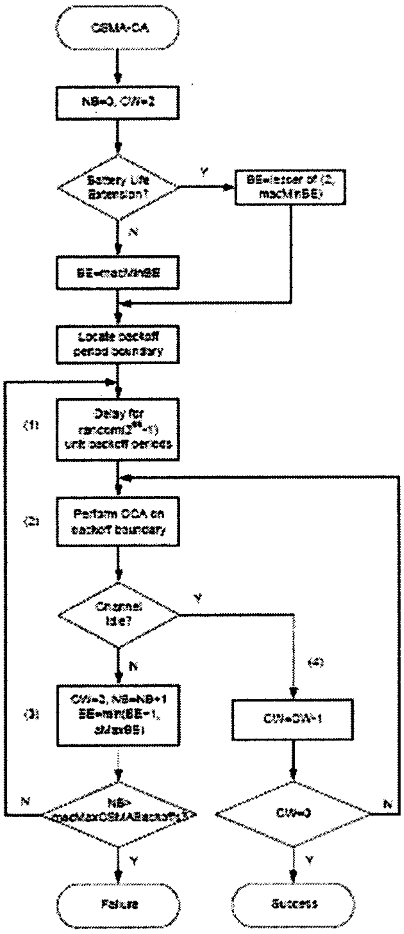

Fig. 2. The CSMA/CA algorithm

turn off its transceiver to save energy during having no frames to transmit or receive, even in the CAP. However, the coordinator should always be turning on its transceiver during CAP to receive the frames from the devices associated with it. Therefore, if the applications require low throughput and low power consumption, the coordinator may have the superframe structure with long inactive portion(BO>SO) to save its energy consumption.

When our group developed a low-power and low-rates WPAN based on IEEE 802.15.4 standard, we found a weakness of the standard which is the congestion at the beginning of CAP. This problem can happen in every 802.15.4 beacon enabled networks and become worse when the superframe has long inactive period. For example as shown in Figure 3, there are five devices which have a data arrival from its higher layer during the inactive period and they are trying to access the channel at the beginning of the CAP, which causes the congestion. Although the length of CAP is enough to transmit all data, the congestion causes collision, transmission failures and unnecessary CCAs. As explained in the previous section, the number of transmission and CCAs is a key factor of energy consumption in IEEE 802.15.4 networks. In conclusion, the congestion at the beginning of CAP consumes more energy.

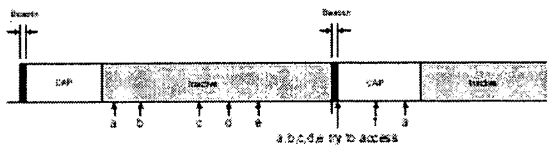

Fig. 3. Congestion Problem at the beginning of CAP

2. Solution

It is evident that the traffic congested at the begging of the CAP should be spread

evenly in the CAP to solve the problem. So, we propose the Virtual Arrival Mechanism (VAM). It is very simple idea that the data arrivals from its higher layer is shifted to the proper position of CAP and begin to contend the channel. As shown in Figure 4, data from node a arrives at the center of inactive region, the arrival a will be shifted to the center of CAP and begin the slotted CSMA/CA
mechanism. By using VAM, the traffic congested at the begging of the CAP can be spread to the all CAP. In VAM, the shift algorithm is one of the main issues. If the correlation of data generations between nodes is small, the shift of VAM can be determined by simple relative position like Figure 4. However, in some applications such as event-driven sensor networks, many data from nodes can be generated at the same time by events. In this case, the shift of VAM should be determined randomly to avoid another congestion by deterministic shift. One of the simplest way is to choose a uniformly random backoff which is similar to that
of CSMA/CA mechanism but the unit of backoff may be larger.

By using VAM, the traffic generated during a beacon interval can be compressed with proper distribution virtually in CAP. Therefore, the VAM is a kind of traffic shaping mechanism. By
using VAM, the congestion can be avoided and the performance can be improved.

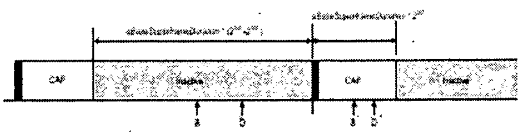

Fig. 4. Virtual Arrival Mechanism

IV. Simulation

We evaluate the performance enhancement of VAM with ns-2 2.28 simulator. The ns-2 IEEE 802.15.4 module was used which was implemented by CUNY, and can be found in [6].

1. Simulation Environment

The environments of our simulations are as follows.

The area of simulation is 20m x 20m.

One coordinator and 100 end devices.

The topology of network is star in which all the end devices is associated with the coordinator.

The traffic source of each node has Poisson distribution.

BO is 4 (245.76 ms) and SO is 2 (61.44ms).

Two kinds of data packet length : 70Bytes and 120 Bytes (including headers)

Energy parameters is from Chipcon CC2420 manual, E_TX=17.4(mA), E_RX=19.4(mA), E_Idle=426(uA) [7].

2. Simulation Results and Discussion

Figure 5 shows the throughput performance of the simulations. There are little differences whether the VAM is used or not. In low traffic applications, almost all data congested at the beginning of CAP can transmit eventually by retransmission of MAC layer (up to three times). However, as shown in Figure 6 and 7, with VAM the collisions and needless CCAs can be avoided. In conclusion, we can save the energy to transmit a data successfully by using VAM. Figure 8 shows that the energy saving can be achieved from 5% to 30% according to the traffic load.

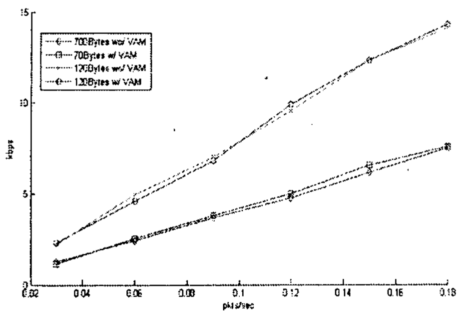

Fig. 5. Throughput

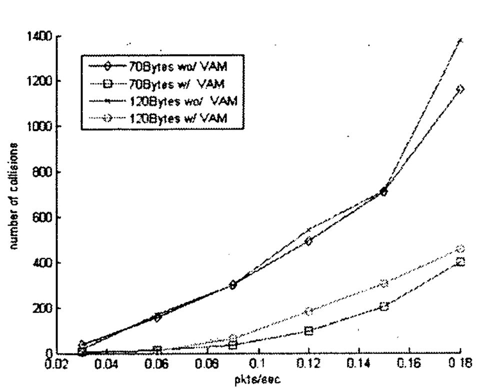

Fig. 6. Number of collisions

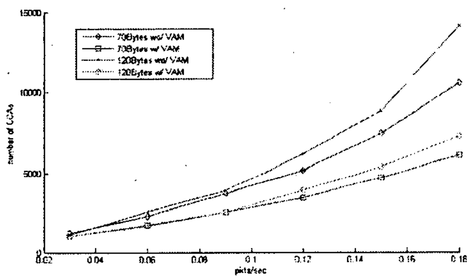

Fig. 7. Number of CCAs

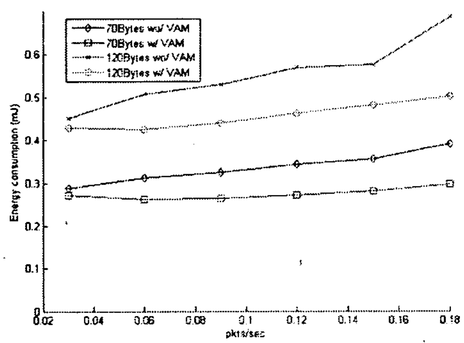

Fig. 8. Energy consumption for a data transmission

V. Conclusion

For power constrained applications, IEEE 802.15.4 networks can be operated in beacon enabled mode with inactive period. Since nodes try to transmit the packets accumulated during inactive period at the beginning of CAP, IEEE 802.15.4 beacon enabled networks have the congestion problem at the beginning of CAP. In this paper, the Virtual Arrival Mechanism (VAM) was proposed as a solution to avoid the congestion problem. The VAM is a simple traffic shaping mechanism that spreads the traffic to the CAP evenly. By using VAM, power saving can be achieved. Finally, the performance enhancement of VAM was evaluated using NS-2 simulator.

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