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IEEE 802.15.4 와 IEEE 802.11의 공존 방법 : ACROS

Coexistence Mechanism between IEEE 802.15.4 and IEEE 802.11 : ACROS

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Abstract

In this paper, a new coexistence mechanism between IEEE 802.15.4 and IEEE 802.11, ACROS (Active Channel Reservation for cOexiStence), is proposed. The key idea of ACROS is to reserve the channel for IEEE 802.15.4 transmission. During the reservation, IEEE 802.11 transmissions cannot be occurred. Request-to-send/clear-to-send mechanism of IEEE 802.11 is used to reserve channel. The proposed ACROS mechanism is implemented into PC based prototype. By the experiments, the efficiency of ACROS is proved.

Keywords

Coexistence, IEEE 802.15.4, IEEE 802.11, ACROS, request-to-send, clear-to-send

I. Introduction

Recently, a low rate wireless personal area network (LR-WPANs), IEEE 802.15.4, has been standardized [1],[2]. The goal of the IEEE 802.15.4 is to provide a standard, which has the characteristics of ultra-low complexity, low-cost and extremely low-power for wireless connectivity among inexpensive, fixed, and portable devices such as sensor networks and home networks. To provide the global availability IEEE 802.15.4 devices use 2.4GHz industrial scientific and medical (ISM) unlicensed band.

Because this ISM band is commonly used for the low cost radios such as IEEE 802.11b (WLAN)[3] and IEEE 802.15.1 (Bluetooth)[4], an unrestricted access to the ISM band exposes the IEEE 802.15.4 devices to a high level of interference. Since the IEEE 802.15.4 and the IEEE 802.11b have beendesigned for different purposes, they can be coexisted within the communication range of each other. For example, the IEEE 802.15.4 network is used for a sensor and control network and the IEEE 802.11b network is used for an audio/video (A/V) network within a home. In the case a notebook supports these two standards, the coexistence distance may be smaller than 1 m.

Some related researches study the coexistence problem between the IEEE 802.15.4 and the 802.11b [5]-[8]. In [5], the packet error rate (PER) of the IEEE 802.15.4 under the IEEE 802.11b and IEEE 802.15.1 is obtained by experiments. In [6], the impact of an IEEE 802.15.4 network on the IEEE 802.11b devices is analyzed. In [7], the PER of IEEE802.15.4 under the interference of IEEE 802.11b is evaluated using simulation. In [8], the PER of

IEEE 802.15.4 under the interference of IEEE 802.11b is analyzed. Most of researches analyzes performance measures such as PER, throughput using experiment [5], simulations [7] and analytic methods[6],[8] when interferences between IEEE 802.11b and IEEE 802.15.4 exists, but haven't provided any methods to improve performance measures.

By the way, the IEEE 802.15.2 recommended practice shows some coexistence mechanisms between IEEE 802.11 and IEEE 802.15.1 [9]. An adaptive frequency hopping (AFH) introduced in IEEE 802.15.2, which is already accepted in Bluetooth standard Ver. 1.2, avoids the frequency interfered but can't be applied to IEEE 802.15.4 because IEEE 802.15.4 standard doesn't support a frequency hopping method. Therefore, coexistence mechanism for IEEE 802.15.4 and IEEE 802.11 is required.

To the best knowledge of the authors, the coexistence method between IEEE 802.15.4 and IEEE 802.11 has not been reported yet in the literature.

In this paper, a new coexistence mechanism is proposed, which is called is ACROS (Active Channel Reservation for cOexiStence). The key idea of ACROS is reservation for active part of superframe in IEEE 802.15.4, during which IEEE 802.11 can not be allowed to transmit. The ACROS exploits the virtual carrier sense property using request-to-send (RTS)/clear-to-send (CTS) mechanism of IEEE 802.11. When a RTS is generated, the destination of RTS responds with CTS. The other legacy IEEE 802.11 stations postpone their transmission by setting network allocation vector (NAV). The ACROS spoofs the destination address of RTS into unspecified address to prevent real transmission. In this way, the channel, i.e., medium can be reserved for interval of interest set by NAV. The proposed mechanism doesn't require any modification in H/W and S/W of IEEE 802.15.4 and IEEE 802.11 except that an IEEE 802.11 station has a small added S/W part. The proposed ACROS mechanism is implemented into PC based prototype and the efficiency of ACROS is proved by real experiments.. By the experiments using ACROS prototype, the efficiency of ACROS is proved.

This paper is organized as follows. Section 2 briefly introduces IEEE 802.15.4. In Section 3, the ACROS coexistence mechanism between IEEE 802.15.4 and IEEE 802.11b is proposed. Section 4 describes the implementation of ACROS. In Section 5, the performances of ACROS are described. Finally, this paper concludes in Section 6.

II. IEEE 802.15.4 Overview

A new IEEE standard, 802.15.4, defines both the physical layer (PHY) and medium access control (MAC) sublayer specifications for low-rate wireless personal area networks (LR-WPANs), which support simple devices that consume minimal power and typically operate in the personal operating space (POS) of 10 m or less. Two types of topologies are supported in the IEEE 802.15.4: a one-hop star or a multi-hop peer-to-peer topology. However, the logical structure of the peer-to-peer topology is defined by the network layer. Currently, the ZigBee Alliance is working on the network and upper layers [9].

A. Operation in the ISM bands and at various data rates

The IEEE 802.15.4 defines two PHY layers, the 2.4 GHz and 868/915 MHz band PHYs. The unlicenced industrial scientific medical (ISM) 2.4 GHz band is available worldwide, while the ISM 868 MHz and 915 MHz bands are available in

Europe and North America respectively. A total of 27 channels with three different data rates are defined for the IEEE 802.15.4: 16 channels with a data rate of 250 kbps at the 2.4 GHz band, 10 channels with a data rate of 40 kbps at the 915 MHz band, and 1 channel with a data rate of 20 kbps at the 868 MHz band. The relationship between the IEEE 802.11b (non-overlapping sets) and the IEEE 802.15.4 channels at the 2.4 GHz is illustrated in Fig. 1.

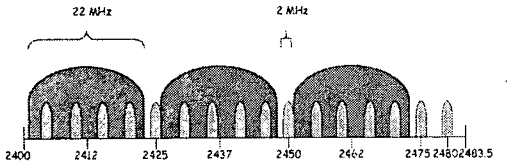

Fig. 1. Channels of IEEE 802.11 and IEEE 802.15.4

To prevent the interference between IEEE 802.15.4 and IEEE 802.11b, the standard of IEEE 802.15.4 recommends to use the four channels that fall in the guard bands between (or above) the three IEEE 802.11b channels

(n = 15, 20, 25, 26 for North America; n = 15, 16, 21, 22 in Europe). While the energy in this guard space will not be zero, it will be lower thanthe energy within the channels; and operating an IEEE 802.15.4 network on one of these channels will minimize interference between systems.

However, if there will be more IEEE 802.15.4 networks, these four channels are not enough.

B. Different data transmission methods

An IEEE 802.15.4 network can work 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 unicast a beacon to a device that is soliciting beacons.

A superframe structure is used in beacon-enabled mode. The format of the superframe is determined by the coordinator. A superframe consists of an active part and an optional inactive part, and is bounded by the beacons. The length of a superframe (i.e., beacon interval, BI) and the length of its active part (i.e., superframe duration, SD) are determined by the beacon order (BO) and superframe order (SO), respectively. The active part of a superframe is divided into aNumSuperframeSlots (with the default value of 16) equal-sized slots, and a beacon frame is transmitted at the first slot of each superframe.

The active part can be further classified into two periods, a contention access period (CAP) and an optional contention-free period (CFP). The optional CFP may accommodate up to seven guaranteed time slots (GTSs) to provide the data with quality of service (QOS), and a GTS may occupy more than one slot period. However, a sufficient portion of the CAP shall remain for contention-based access of other networked devices or new devices wishing to join the network. A slotted CSMA-CA mechanism is used for channel access during the CAP. All contention-based transactions shall be completed before the CFP begins. Moreover, all transactions using GTSs shall be done before the time of the next GTS or the end of the CFP.

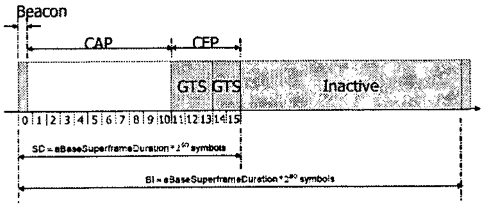

Fig. 2. Superframe Structure

III. Proposed Coexistence Algorithm: ACROS

The coexistence scenario of IEEE 802.15.4, WPAN, and IEEE 802.11b, WLAN, can be illustrated as Fig. 3.

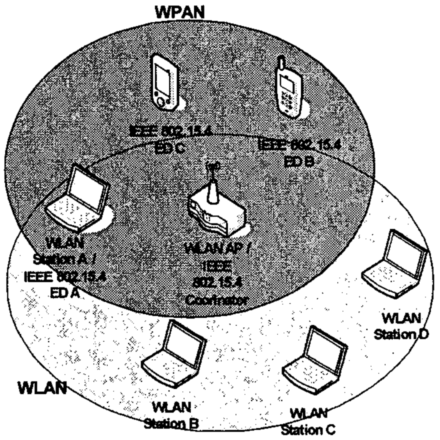

Fig. 3. IEEE 802.11b and IEEE 802.15.4 Coexistence Scenario

As illustrated in Fig. 3, the coordinator of IEEE 802.15.4 and access point of IEEE 802.11b can be collocated within the same physical unit. And the personal operating space (POS) of IEEE 802.15.4 and the basic service set (BSS) of IEEE 802.11b are assumed to be overlapped. The IEEE 802.15.4 network is assumed to be beacon-enabled mode to maximize the network life time.

To avoid interference, a new coexistence mechanism is proposed, which is called ACROS (Active Channel Reservation for cOexiStence). The key idea of ACROS is guaranteeing IEEE 802.15.4 LR-WPAN devices to communicate without interference originated by IEEE 802.11b WLAN traffic by reserving channel periodically. Since IEEE 802.15.4 is assumed to be beacon enabled network, the exact timing and duration of interference-free period, which means active part of IEEE 802.15.4 superframe, are important. To make interference-free period, ACROS exploits the virtual carrier sensing property of IEEE 802.11b. IEEE 802.11b stations do not attempt to transmit a packet if other station has already reserved mediumby using request-to-send (RTS)/ clear-to-send (CTS) exchange mechanism, even though the medium is idle. To do this, the IEEE 802.11b nodes update their network allocation vector (NAV) when they receive a RTS or CTS frame. The proposed algorithm, ACROS, reserves the interval of interest, whichis active part of IEEE 802.15.4, and makes IEEE 802.11 stations not transmit data. The timing diagram of reservation channel using ACROS is illustrated in Fig.4.

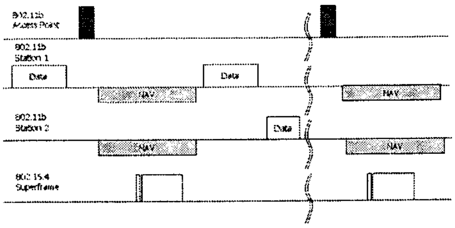

Fig. 4. Timing Diagram of ACROS Algorithm

However, an IEEE 802.11b network interface card (NIC) cannot transmit RTS or CTS frame without actual data packet to transmit. To send arbitrary RTS or CTS packet, the NIC must be modified at the MAC or PHY level. However, since modifying the NICs is very expensive and not practical, ACROS modifies the device driver to command its NIC to send any dummy packet with spoofing receiver's MAC address. That means ACROS tries to send any dummy data with setting the destination address field which does not exist inside of BSS. Note that this modification doesn't affect any operation of IEEE 802.11b. Algorithm 1 shows the pseudo code of the device driver in the IEEE 802.11b AP.

In Figure 4, ACROS NIC will send a RTS frame and the receiver of this dummy packet.

However, no one use the wireless medium because indicated MAC address in RTS packet does not exist in the network as the same with spurious RTS/CTS attack [11]. During the unused time interval, stations of IEEE 802.15.4 network can communicate.

Since the IEEE 802.15.4 network is in beacon-enabled mode, dummy packets should be generated periodically for guaranteeing interference-free time interval.

When a packet is arrived from the next upper layer, AP driver determines the packet is dummy or not using the identifier field. If the packet is not dummy packet, the device driver compares the current time with the expectedtime of IEEE 802.15.4 beacon. If the difference between the current time and the expected time of beacon is smaller than specified time, the packet is stored in the buffer to guarantee the period of IEEE 802.15.4 superframe. Otherwise, the device driver sends the packet.

If the arrived packet is the dummy packet, the device driver spoofs its destination address into unknown address to reserve the interval for transmissions of IEEE 802.15.4. During this interval, newly arrived packets will be stored in buffer. After specified time for transmissions of IEEE 802.15, the device driver transmits all the buffered packets.

Fig. 5 shows the state diagram of ACROS daemon for periodic dummy packet generation.

Algorithm 1 Pseudo Code for AP device driver

```
if !(packet is a dummy packet) then
  if dummy packet is expected within specified time
  then
    buffer the packet
  else
    transmit the packet
  end if
else
  spoof the address of the dummy packet
  transmit the packet
  while buffer is not empty do
    transmit buffered packets
  end while
end if
```

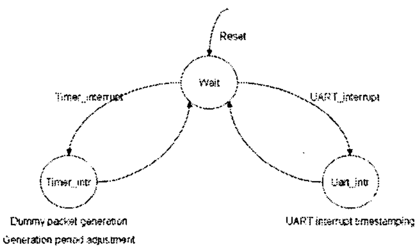

Fig. 5. State Diagram of ACROS daemon

IV. Implementation of ACROS

ACROS prototype consists of collocated IEEE 802.11b WLAN AP and IEEE 802.15.4 LR-WPAN coordinator, their device drivers or firmware, and ACROS daemon software as illustrated in Fig.6.

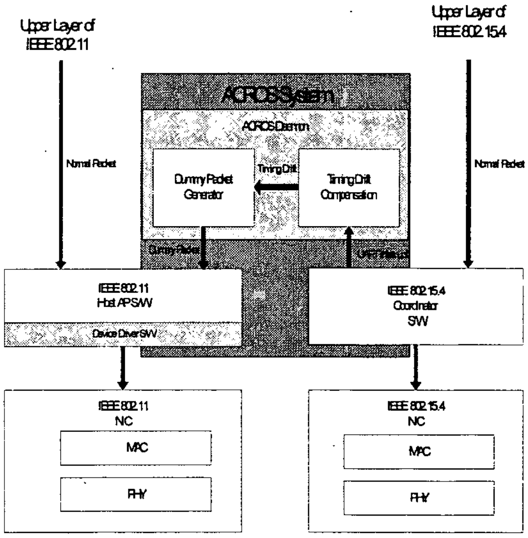

Fig. 6. Structure of ACROS System

ACROS is implemented on Debian Linux machine with kernel version 2.4.26. The CPU is Intel Pentium III 700 MHz with 384 Mbytes RAM. To implement ACROS system, one IEEE 802.11b NIC and one IEEE 802.15.4 are required as shown in Fig. 7

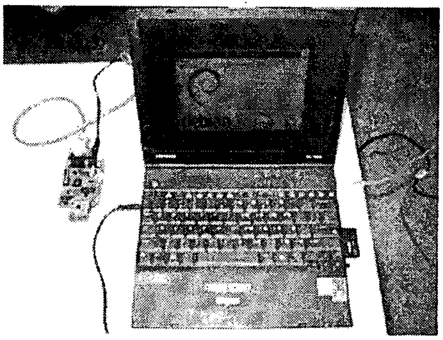

Fig. 7. ACROS System Prototype : IEEE 802.11b AP and IEEE 802.15.4 Coordinator

ACROS can be implemented into IEEE 802.11b WLAN AP or a general IEEE 802.11 WLAN station.

A. IEEE 802.15.4 LR-WPAN network

The IEEE 802.15.4 LR-WPAN coordinator and device are implemented with KORWIN IEEE 802.15.4 Development Kit as shown in Fig.8 [12].

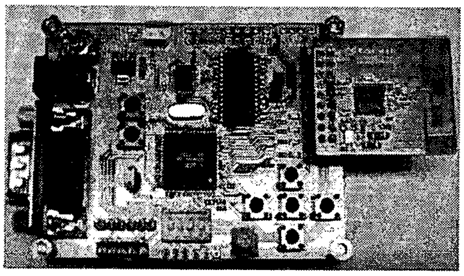

Fig. 8. Korwin IEEE 802.15.4 Development Kit

The MCU of the board is Atmel's ATMEGA128L which has 128K bytes of programmable flash and 4Kbytes of data memory. The radio transceiver on the board is the CC2420 from Chipcon, which is 2.4GHz RF transceiver for the IEEE 802.15.4. The SO is set to 0 and BO to 4 of IEEE 802.15.4 LR-WPAN, thus SD is 15.36 ms and BI is 245.76 ms.

B. IEEE 802.11b WLAN Access Point

The IEEE 802.11b WLAN AP is implemented using HostAP, the famous open-source AP device driver for Linux[13]. The IEEE 802.11b NICs are Buffalo WLI-CF2-S11G based on Intersil PRISM chipset and its device driver is modifiedas follows. By examining the field that indicates whether a packet is the dummy packet or not, the device driver can determine whether to spoof destination address or not. The upper layer of the source that generates the dummy packet waits for the corresponding CTS. However, since the device driver spoofed the destination address, the destination of RTS is not existed within the BSS. So, RTS retransmissions will occur, which could reserve unnecessary time interval that can decrease the throughput of IEEE 802.11b network. These retransmissions can be suppressed by alternate retry count (ARC) field that Intersil PRISM chipset supports. By setting ARC 0, the ACROS NIC attempts to transmit RTS frame just once. By making the dummy packets 2300 bytes long and setting destination's basic service rate to 1 Mbps, the time interval reserved by a RTS can be 19.406 ms which is longer than SD of IEEE 802.15.4 LR-WPAN. And by setting the RTS/CTS threshold to 2250 bytes, normal transmissions do not use the RTS/CTS mechanism.

To reserve the channel on time, the device driver buffers packets if the dummy packets generation is expected within specified time, 2.5 ms, which is obtained by experiments. Because of periodicity of IEEE 802.15.4, the prediction can be easily done. Instead oftransmitting, the device driver keeps those packets in its buffer and transmits them after transmission of the dummy packet as shown in Algorithm 1.

C. ACROS daemon

The ACROS daemon performs two major functions. One is generating a dummy packet periodically. The reserved op-code field of ARP (address resolution protocol) is used for the identifier that distinguisheswhether the packet is dummy packet or not at WLAN device driver level [14]. Raw socket that Linux kernel supports is used for dummy packet generation [15]. For more accurate time processing, high-res-timer is patched into Linux kernel [16] and RDTSC (Read Time Stamp Counter) instructions of Intel Pentium architecture is used.

Another function is overcoming the timing drift problem. Because IEEE 802.15.4 LR-WPAN is connected to Linux machine via RS-232 interface and serial interrupt handling of Linux is not real-time based, the ACROS daemon cannot guarantee the reservation of wireless channel precisely on time. To solve timing drift problem, define the maximum and minimum time thresholds from serial interrupt to generating dummy packet. Whenever the IEEE 802.15.4 coordinator sends beacon, it generates the serial interrupt to the ACROS daemon. If the serial interrupt generation time is not in the range of predefined min-max thresholds, the ACROS daemon increase or decrease the dummy packet generating time to prevent timing drift.

V. Experiment Results

Constant bit ratio (CBR) traffic of IEEE 802.11b WLAN is generated from the AP and sent to the WLAN client. The traffic of IEEE 802.15.4 is generated on the IEEE 802.15.4 End device and sent to the Coordinator. The End device of IEEE 802.15.4 continuously transmits the packets of 126 bytes long in an infinite loop, while IEEE 802.11b WLAN AP transmits the packet of variable length with variable arrival rate. The Coordinator of IEEE 802.15.4 sends beacon periodically. Performance of IEEE 802.11b WLAN is calculated by IEEE 802.11b WLAN sniffer and that of IEEE 802.15.4 LR-WPAN is calculated by IEEE 802.15.4 coordinator. Each performance measures are averaged after about 2 hours experiment. Fig. 10 shows the test bed for the experiment of the ACROS system. The offset between the center frequencies of IEEE 802.11b and IEEE 802.15.4 is set to 7 MHz, and the clear channel assessment mode 2 (carrier sense mode) is used for the channel detection of IEEE 802.15.4. Each experiment takes 2 hours, and each experiment is executed 10 times.

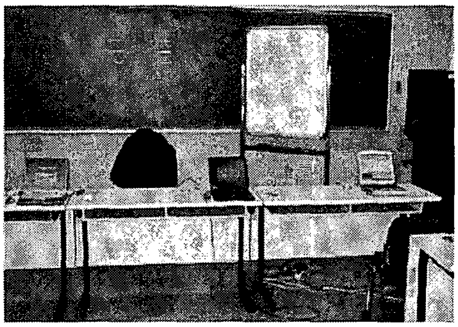

Fig. 10 Test Bed of ACROS System

There are two types of packet throughput : goodput and badput. The goodput is the throughput of successfully transmitted packets and is interpreted as the bandwidth usage for successful packet transmission. The badput is the throughput of corrupted packets, which provides a measure of wasted network resources. Then, the throughput is defined as

$$throughput = goodput + badput \quad (1),$$

which is interpreted as the total transmission attempts [1765]. Fig. 11 shows the goodput of IEEE 802.11b network on and off ACROS coexistence algorithm. The packet arrival rate of IEEE 802.11b is 5 ms and the packet lengths are 125, 250, 500, 1000, and 1500 bytes.

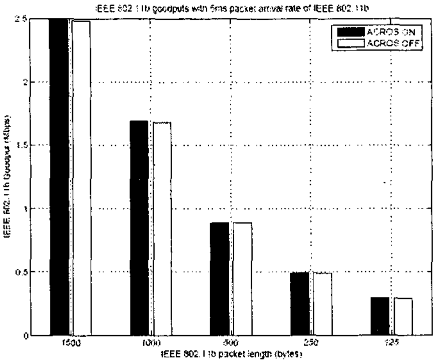

Fig. 11 IEEE 802.11b Goodput on and off ACROS :

5ms packet arrival rate of IEEE 802.11b

As illustrated in Fig. 11, the ACROS system does not affect the goodput of IEEE 802.11b. This means that IEEE 802.11b WLAN goodput reduced due to ACROS's channel reservation is negligible.

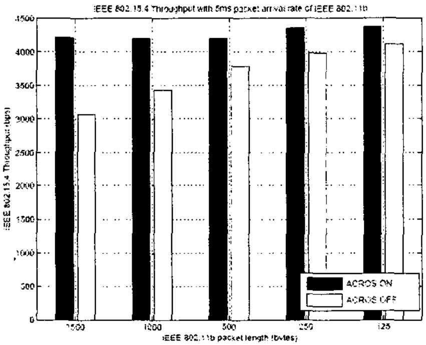

Fig. 12 IEEE 802.15.4 Throughput on and off ACROS :

5ms packet arrival rate of IEEE 802.11b

Under the same environment as Fig.11, the throughput of IEEE 802.15.4 network is illustrated as in Fig. 12. Because the ACROS algorithm reserves the time interval for the transmissions of IEEE 802.15.4, the throughput of IEEE 802.15.4 could be guaranteed over about 4 kbps with variation of the length of IEEE 802.11b packet size. When ACROS is off, throughput of IEEE 802.15.4 is minimum 3.06 kbps and maximum 4.12 kbps. However, if ACROS is off, the IEEE 802.15.4 transmissions could be interfered by the transmission of IEEE 802.11b. And, as the packet size of IEEE 802.11b is larger, the medium is much busier because of transmission of IEEE 802.11b. Then, the number of transmission attempts of IEEE 802.15.4 will be reduced as illustrated. Also, the throughput of IEEE 802.15.4 without ACROS is much smaller than that with ACROS while that with ACROS remains about 4 kbps.

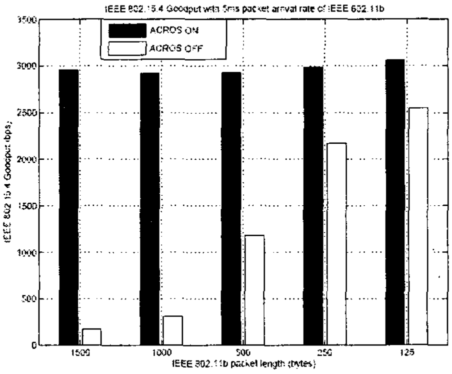

Fig. 13 IEEE 802.15.4 Goodput on and off ACROS :

5ms packet arrival rate of IEEE 802.11b

Fig. 13 shows the goodput of IEEE 802.15.4. Contrary to the throughput, the goodput of IEEE 802.15.4 is highly dependent on ACROS. As the packet size of IEEE 802.11b is smaller, the medium is less crowded. Therefore, the transmissions of IEEE 802.15.4 can be successfully done about 62% of the transmission attempts in the case of 125 bytes IEEE 802.11b packet. However, as the packet length of IEEE 802.11b increases, the goodput without ACROS decreases. Contrarily, by reserving channel using ACROS, the goodput of IEEE 802.15.4 can be achieved about 70 % of the throughput. Considering that the goodput of IEEE 802.15.4 without interference of IEEE 802.11b is about 80%, the performance of ACROS is fairly acceptable.

Fig. 14shows the goodput of IEEE 802.11b network with and without ACROS coexistence algorithm using 2ms packet arrival rate of IEEE 802.11b. By reducing the packet arrival time to 2ms, medium is much busier than 5 ms case. This time, the packet lengths are variable with 125, 250, 500, and 1000 bytes. Like Fig. 11, the IEEE 802.11b WLAN goodput reduced due to ACROS's channel reservation is also negligible.Because the packet arrival time of IEEE 802.11b is smaller, the goodput of IEEE 802.11b is better than that of Fig. 11.

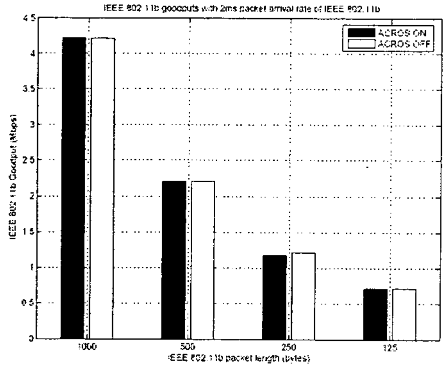

Fig. 14. IEEE 802.11b Goodput on and off ACROS :

2ms packet arrival rate of IEEE 802.11b

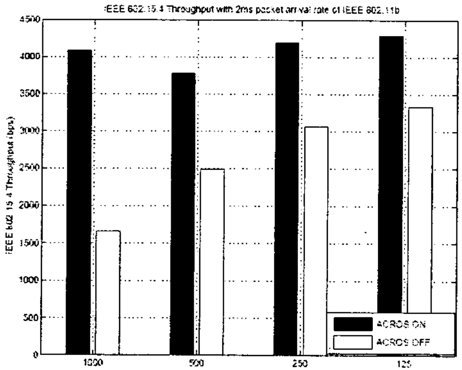

Fig. 15 IEEE 802.15.4 Throughput on and off ACROS :

2ms packet arrival rate of IEEE 802.11b

The throughputof IEEE 802.15.4 network is illustrated in Fig. 15. The transmission attempts without ACROS decrease compared to those of 5 ms case because of much busier medium. Since ACROS algorithm reserves the time interval for the transmissions of IEEE 802.15.4, the throughput of IEEE 802.15.4 could be guaranteed over 4 kbps with varying the packet size of IEEE 802.11b. Comparing to the 5 ms case, the IEEE 802.15.4 throughput is relatively small, minimum 1.6 kbps and maximum 3.3 kbps. Because of the 2ms packet arrival time of IEEE 802.11b packets, medium is more frequently used. And, as the packet size of IEEE 802.11b is larger, the medium will be much busier. Then, the transmissions of IEEE 802.15.4 will be reduced as illustrated in Fig. 15. Also, the throughput of IEEE 802.15.4 without ACROS is smaller than that with ACROS.

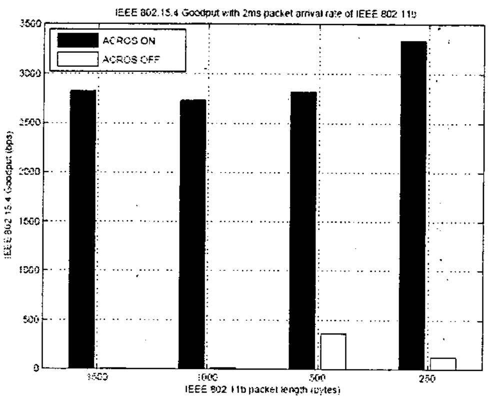

Fig. 16 IEEE 802.15.4 Goodput on and off ACROS :

2ms packet arrival rate of IEEE 802.11b

Fig. 16 shows the goodput of IEEE 802.15.4. Intuitively,, the goodput of IEEE 802.15.4 is highly dependent on ACROS. As illustrated, the goodput without ACROS is smaller than 12% of the throughput at most, in the case of 250 bytes packet. It is because the packet arrival time, 2ms, is much smaller than the packet duration of IEEE 802.15.4, 4.192ms. That means every IEEE

802.15.4 packet experiences interference of IEEE 802.11b, and the goodput is nearly 0. However, when ACROS is on, the averagegoodput of IEEE 802.15.4 can be achieved about 71.5% of the throughput. Noting that the goodput of IEEE 802.15.4 without interference of IEEE 802.11b is about 80%, 71.5% goodput is fairly acceptable.

VI. Conclusion

In this paper, the coexistence mechanism between IEEE 802.15.4 and IEEE 802.11b, active channel reservation for coexistence (ACROS), was proposed. ACROS reserves the time interval periodically for IEEE 802.15.4 networks to transmit packets. To reserve channel, ACROS exploits the virtual carrier sensing property using request-to-send (RTS)/ clear-to-send (CTS) exchange mechanism of IEEE 802.11b. All other IEEE 802.11b WLAN stations that hear RTS or CTS frame would not attempt to access the medium because they set network allocation vector (NAV) until the requested packet transmission is over. The proposed ACROS is implemented into PC based prototype.

The performance of ACROS is proved using experiments. By using ACROS system, the goodput of IEEE 802.15.4 under interference of IEEE 802.11b can be achieved about 4 kbps without affection to the goodput of IEEE 802.11b. In the best case, the goodput of IEEE 802.15.4 under IEEE 802.11b is improved about 517 times by using ACROS, when the arrival rate and packet length of IEEE 802.11b are 2 ms and 1500 bytes, respectively. And the ACROS is practical and easy to implement because it doesn't require any the modification of other IEEE 802.11b NICs. Moreover, although the prototype is experimented under IEEE 802.11b, this ACRO algorithm can be applied to the other IEEE 802.11 standards such as IEEE 802.11g that uses 2.4 GHz band.

ACROS has one problem that it can only guarantee the smallest superframe duration of IEEE 802.15.4. However, 4 kbps goodput is fairly enough for some applications with low duty cycle.

The result of this paper provides the coexistence mechanism for the IEEE 802.15.4 and IEEE 802.11b can be useful for designing and implementing networks using both IEEE 802.15.4 and IEEE 802.11b.

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