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A Novel Method for Service Differentiation in IEEE 802.15.4 : Priority Jamming

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Abstract: IEEE 802.15.4 employs carrier sense multiple access with collision avoidance (CSMA/CA), which is known to have difficulty for supporting quality of service (QoS). In this paper, a new priority scheme called priority jamming (PJ) is proposed for service differentiation for IEEE 802.15.4. The main idea of the proposed scheme is deferring the low priority packet transmission for the high priority packet. Clear channel assessment of IEEE 802.15.4 is modified to support the proposed PJ. The efficiency of the proposed scheme is validated by comparing the delay, throughput, and energy-per-bit with those of standard CSMA/CA. Simulations results showed that PJ improves the delay and throughput simultaneously while maintaining marginal difference in energy efficiency.
Keywords: CSMA/CA, QoS, priority jamming, service differentiation, IEEE 802.15.4

1 Introduction

IEEE 802.15.4 is originally designed for low duty cycle and low rate applications such as wireless personal area network (PAN) [1]. However, it can be adopted for some delay-sensitive applications such as emergency detecting, intruder alarming, health care, and so on. For supporting these applications, QoS (quality of service) requirements need to be supported.

IEEE 802.15.4 adopts carrier-sense multiple access with collision avoidance (CSMA/CA) mechanism. Therefore, every node has a statistically equal chance to use the wireless medium and to transmit packets. Because of unpredictable and undeterministic nature of CSMA/CA cased by collisions and random backoff algorithm, to provide QoS in CSMA/CA is generally known to be difficult.

Some works such as [2], [3], [4] studied the QoS support in IEEE 802.15.4. In [2], guaranteed time slot (GTS) mechanism is exploited for the real-time service when enabling beacon mode. The GTS uses the contention-free period (CFP), which is optional feature in IEEE 802.15.4 standard. In addition, if the available resources are not sufficient, i.e., the number of nodes requires real-time service is large, the GTS may not be sufficient because of limited number of GTS slots. In [3], differnet backoff exponent(BE) and contention window(CW) are used to provide service differentiation in IEEE 802.15.4. However, nodes with different priorities can have the same value of BE and/or CW based on slotted carrier-sense multiple-access with collision avoidance (CSMA/CA) algorithm of IEEE 802.15.4, which leads to collisions among the nodes with different priorities and increased delay for successful packet transmission. In [4], the frame tailoring (FRT) and the priority toning (PRT) are proposed to support QoS. Using the FRT, i.e. padding zeroes, IEEE 802.15.4 nodes with high priority performs one clear channel assessment (CCA) only. However, the FRT causes a packet overhead and the acknowledgement packet of the normal priority node and the data packet of the high priority node can collide. To prevent collisions among high priority and normal priority packets, the priority toning (PRT) is used to defer the normal priority packets by allocating some active portion of active period for the

Table 1: Parameters of IEEE 802.15.4

Parameters	**Values**
aMinBE	3 (default)
aMaxBE	5 (default)
CW	2 (default)
macMaxCSMABackoffs	5 (default)
Slot duration (*UnitbackoffPeriod)*	20 symbols
CCA duration of low priority packet	20 symbols
CCA duration of high priority packet	8 symbols
Jamming signal duration	8 symbols

high priority packet transmissions. However, if the number of the high priority packets is large and network load is high, collisions may frequently occur among the high priority packets in the allocated portion by the PRT. Moreover, those methods are designed for the beacon-enabled IEEE 802.15.4 network only.

To support service differentiation, a novel method for supporting priority called priority jamming (PJ) is proposed in this paper. The core idea of the PJ is deferring the normal priority packet transmissions using a jamming signal transmitted for high priority nodes who have packets ready to transmit. Because the proposed method exploit channel sensing part of IEEE 802.15.4, i.e., clear channel assessment (CCA), it can be applied both beacon and non-beacon enabled network. Although the proposed method considers slotted CSMA/CA in this paper, it can be used both slotted and unslotted versions of IEEE 802.15.4 CSMA/CA.The paper is organized as follows. The suggested PJ is described in the next section. Section 3 evaluates the performance of PJ and compares with standard CSMA/CA. Finally, we draw our conclusions in Section 4.

2 Priority Jamming

In this paper, non-beacon enabled network with slotted CSMA/CA is assumed. Let's examine the operation of standard CSMA/CA of IEEE 802.15.4 first. IEEE 802.15.4 CSMA/CA works as follows. 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, related to the backoff periods a device should wait before attempting carrier sensing. When a device needs to transmit, it delays for a random number of backoff periods (up to $2^{BE} - 1$ periods) and then determines if the channel is clear. If the channel is busy, the MAC increases both NB and BE by one, and resets CW to 2. If NB is less than or equal to $macMaxCSMABackoffs$, the CSMA/CA delays for a random time again, otherwise it terminates with a failure. If the channel is assessed to be idle, it must ensure that the contention window is expired before starting transmission. For this, the MAC sublayer first decrements CW by one. If CW is not equal to 0, it must go to another channel sensing step. Otherwise, it starts transmission on the boundary of the next slot period [1].

In an IEEE 802.15.4 network, it is assumed that there are two data categories, namely, high and normal priority packets. The main idea of PJ is to provide high priority packets with greater possibility to access the channel compared to normal priority packets. Figure 1 describes the operation of the proposed scheme and some parameters related to both PJ and standard MAC

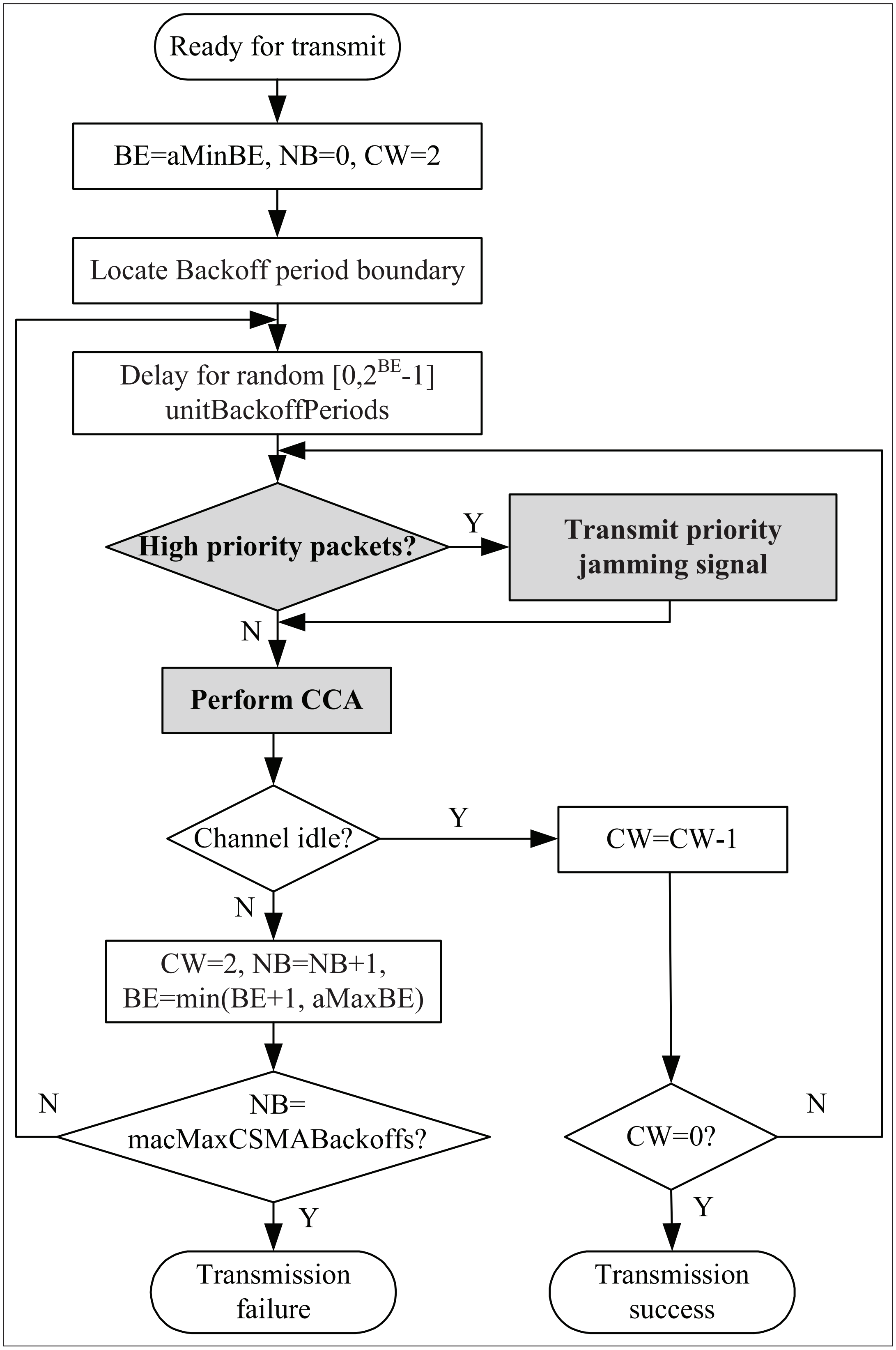

Figure 1: Operation of Priority Jamming in IEEE 802.15.4

operation are summarized at Table 1. To transmit either a high or normal priority packet, nodes will contend to access channel using CSMA/CA of IEEE 802.15.4 as described earlier. To introduce PJ into IEEE 802.15.4, grey-colored portion is changed or modified compared to standard CSMA/CA of IEEE 802.15.4 as shown in Figure 1. When a node is ready to transmit high priority packet, it not only performs CCA to see whether the channel is busy or idle, but also set aside some slot time to send a jamming signal to notify other nodes that a high priority packet is ready to be transmitted. In other words, a node with high priority packets, performs CCA during 8 symbol times as defined in IEEE 802.15.4 standard and transmits a jamming signal. For jamming signal, any signal whose duration is less than (slot duration-8) symbols can be used. In this paper, we used the preamble of IEEE 802.15.4 packet for the jamming signal.

With PJ, a node with normal priority packets performs CCA for entire slot time (20 symbol time), not for just 8 symbol times. Because a node with normal priority packets listens entire slot time and then the channel will be assessed to be busy due to jamming signal by the node with high priority packets ready to be transmitted. Then, a node with normal priority packets will defer its transmission and perform another random backoff procedure. By deferring the transmissions of normal priority packets, the collision probability among nodes with high and normal priority packets will be reduced compared to standard CSMA/CA. In other words, the effective node numbers which contend for the channel will be reduced by adopting PJ.

Note that if all the packets have the same priority level, i.e., under either 100% high priority or normal priority traffic, the behavior of PJ nodes will be identical to standard CSMA/CA. Also, when nodes with standard CSMA/CA coexist with nodes using PJ, they are considered as nodes with high priority packets. This means that PJ guarantees backward compatibility with legacy IEEE 802.15.4 standard.

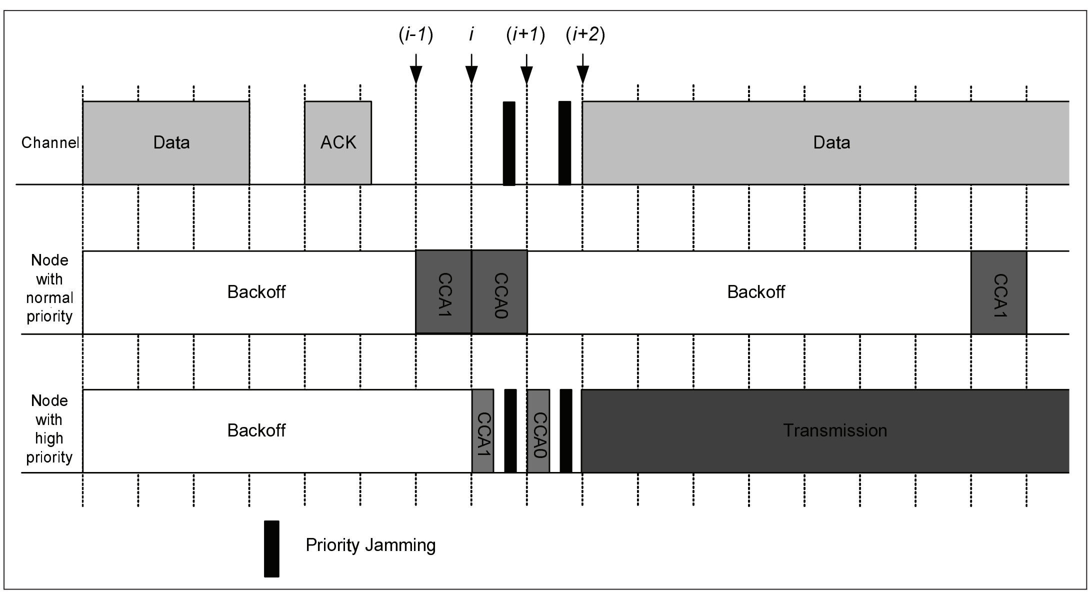

Figure 2: An Example of Priority Jamming in slotted CSMA/CA of IEEE 802.15.4

Figure 2 shows an example of PJ operation with one node with a high priority packet and one node with normal priority packet. As illustrated, a node with normal priority packet finishes backoff at $(i-1)$-th slot and performs the first CCA, CCA1. At this time, the channel is assessed to be idle and $(CW = CW - 1)$. At i-th slot, a node with high priority packet finishes its backoff and performs CCA1 with PJ. At the same time, the node with normal priority starts the second CCA, CCA0. Now the channel is assessed to be busy because of the jamming signal transmitted by the node with high priority packet. Then, at $(i+1)$-th slot, another random backoff and CCA0 are performed by the node with normal priority and the node with high priority, respectively. Finally, the node with high priority has a chance to transmit packet at $(i+2)$-th slot.

3 Performance Evaluation

To evaluate the performance, we developed an OPNET simulation model of the slotted CSMA/CA and priority jamming of IEEE 802.15.4. Star topology network with one coordinator and 20 end devices is used for the simulations as illustrated in Figure 3.

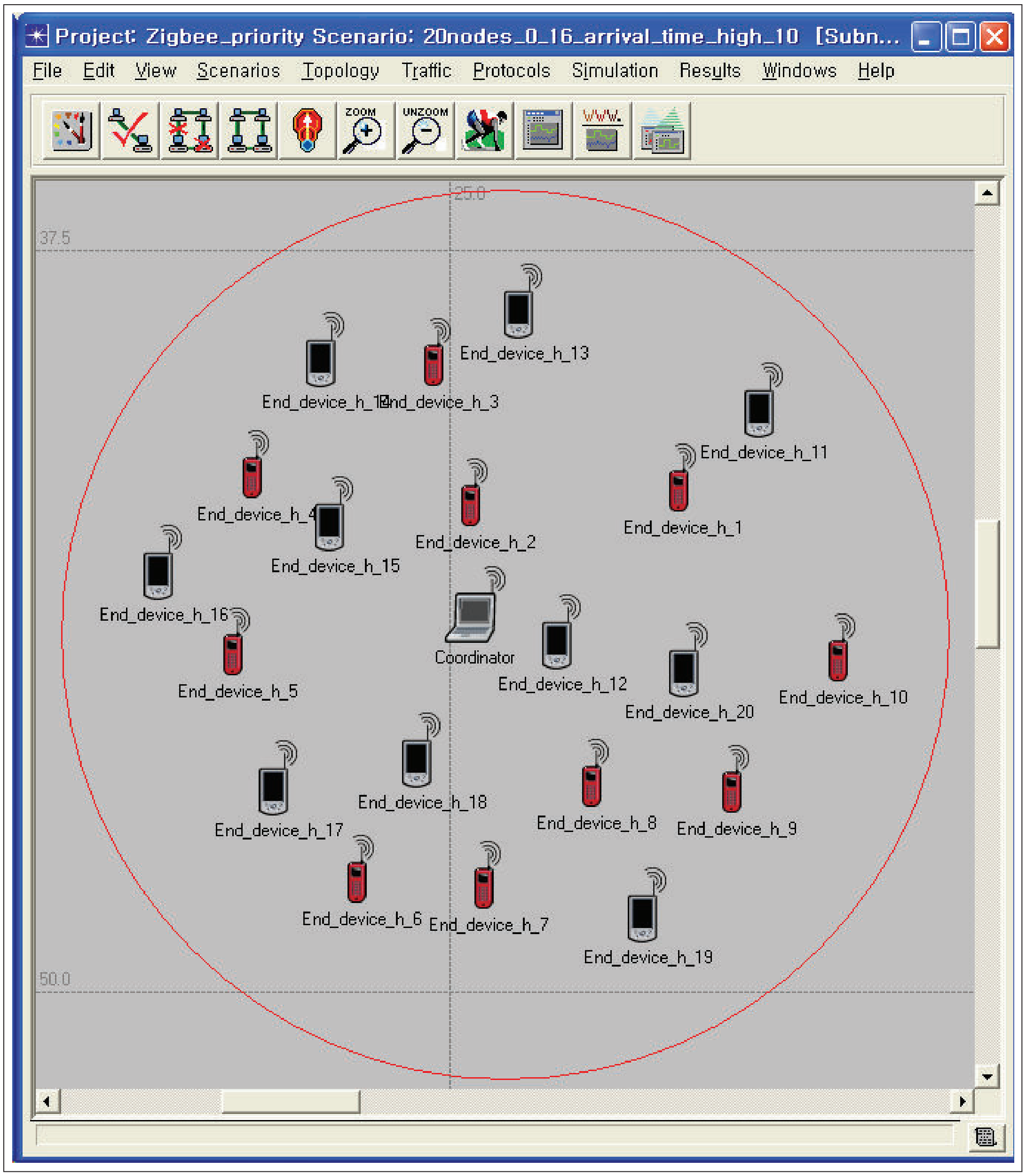

Figure 3: Simulation scenario of IEEE 802.15.4 CSMA/CA with Priority Jamming

All end devices send data packets to Coordinator, which responds with corresponding ACK packets. All end devices generate 102 bytes long packets based on exponential distribution with mean $1/\lambda$. Two simulation parameters are inter-arrival time, i.e. λ, and ratio of high priority packets in the total traffic. The λ varies from 0.15 to 0.4, which means the traffic introduced to the network varies from 108.8 to 40.8 kbps. The ratio of high priority in the traffic, is one of 10, 30, and 50 %. As the measure of performance, delay, throughput, and energy efficiency are used in this paper. Then, the performances of PJ are compared to those of standard slotted CSMA/CA.

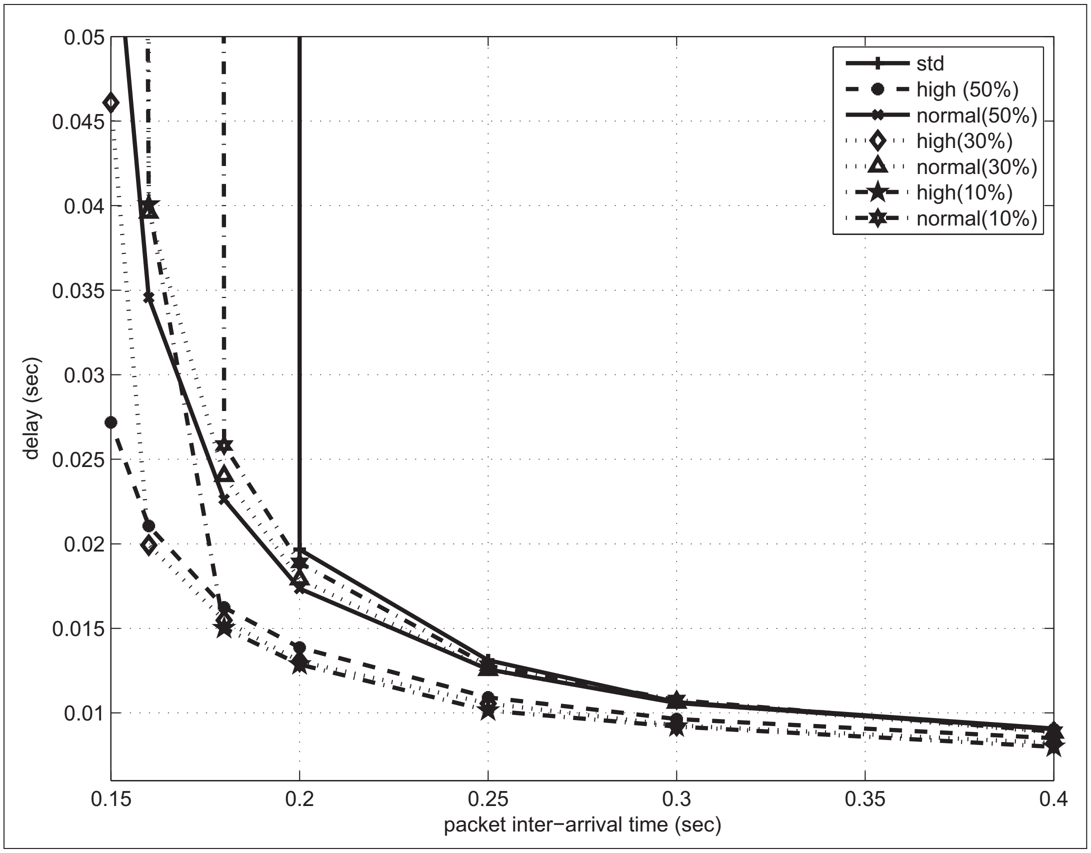

Figure 4: Delay vs. inter-arrival time

Figure 4 shows packet delays as the inter-arrival time increases. Here, (x %) in the legend of Figure 4 means that x percentage of the total traffic introduced to IEEE 802.15.4 network is high priority packets. The parallel lines to y-axis means the delay doesn't converge. In other words, there are so many collisions that the packet delay increases. For example, with $\lambda < 0.2$, the delay of standard CSMA/CA doesn't converge.

However, when PJ is applied, the delays of high priority packets are bounded even for $\lambda = 0.15$. This is because the collision probability of high priority packets decreases due to service differentiation provided by PJ. For example, at $\lambda = 0.2$, the collision probabilities of the high and normal priority packets are 0.007, 0.026, 0.049, and 0.111, 0.089, 0.060 for 10, 30, 50 % cases, while that of the standard is 0.129. As the ratio of high priority packets increases, the collision probabilities of high priority packets and those of normal priority packets increase and decrease because the node numbers of high priority and normal priority increases and decreases, respectively. Note that the delays of normal priority packets with 10% high priority packages at

$\lambda = 0.18$ are about 5 second.

For $\lambda \geq 0.18$, the delays of the high priority packets increases at the ratios of the high priority packet increases. As λ decreases, the channel will be more crowded, even for the CCA of the high priority nodes. Then, channel could be assessed as "busy" and may cause many random back-offs. [1]

As the packet inter-arrival time decreases, the channel occupation by packet transmissions is more dominant than collisions. For larger λ, the channel is not frequently occupied, the delay is more dependent on the collision probability. Hence, the delay of high priority packet decreases as the ratio of high priority decreases.

Note that the delay experienced by both high and normal priority packets in PJ is less than that of standard slotted CSMA/CA (std).

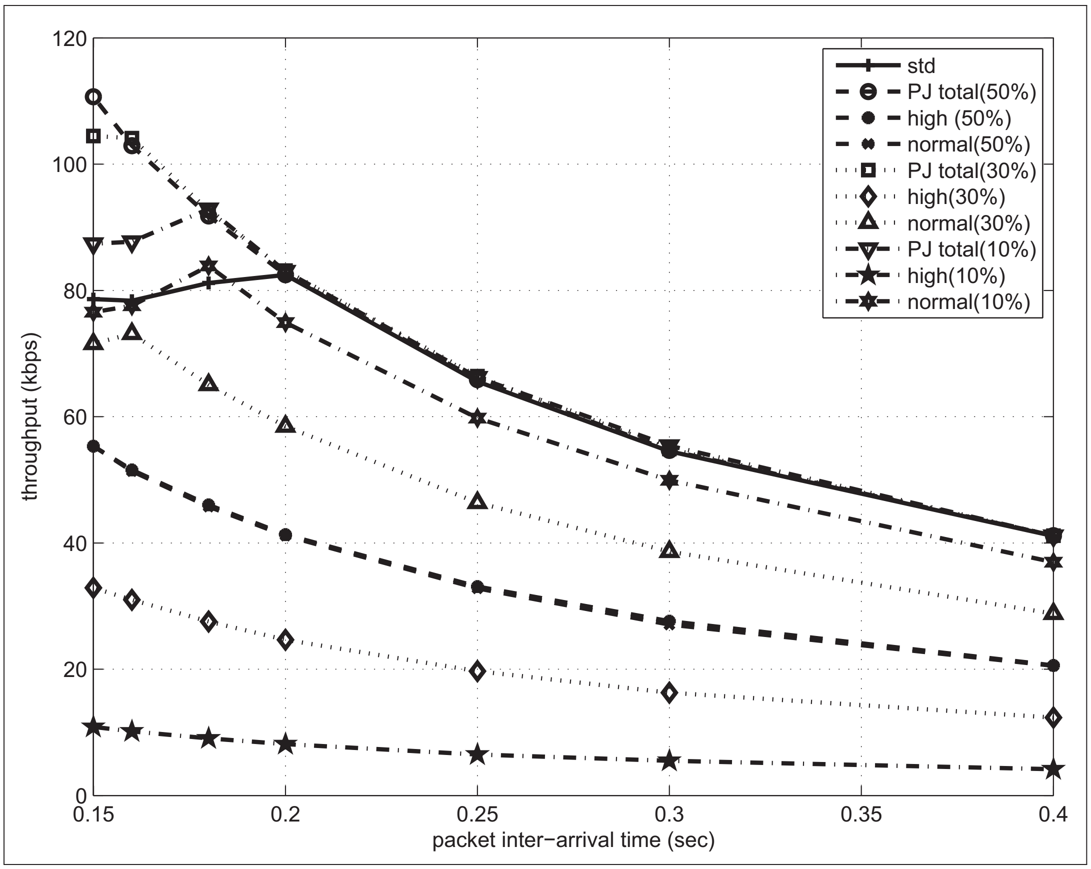

Figure 5: Throughput vs. inter-arrival time

Fig. 5 illustrates throughput of PJ with high priority, low priority, and total (sum of high and normal priority throughput) and compares to throughput of standard IEEE 802.15.4. The throughput for high priority packets are monotonically increases as the inter-arrival time decreases. This is because the high priority packets really have priority to access the channel by priority jamming. The total throughput with PJ outperforms that of standard IEEE 802.15.4 due to decreased collision probability as mentioned earlier. Why the delay with the standard CSMA/CA diverges when $\lambda = 0.18$? The reason is that the throughput is 81.2 kbps, smaller than the generated traffic, 90.7 kbps. Contrarily, throughput with PJ are 91.8 kbps (50% of high

[1] In standard CSMA/CA, channel is already saturated at $\lambda = 0.2$.

priority), 92.6 kbps (30% of high priority), 92.9 kbps (10% of high priority), which are higer that the generated traffic, so delays with PJ are still bounded.

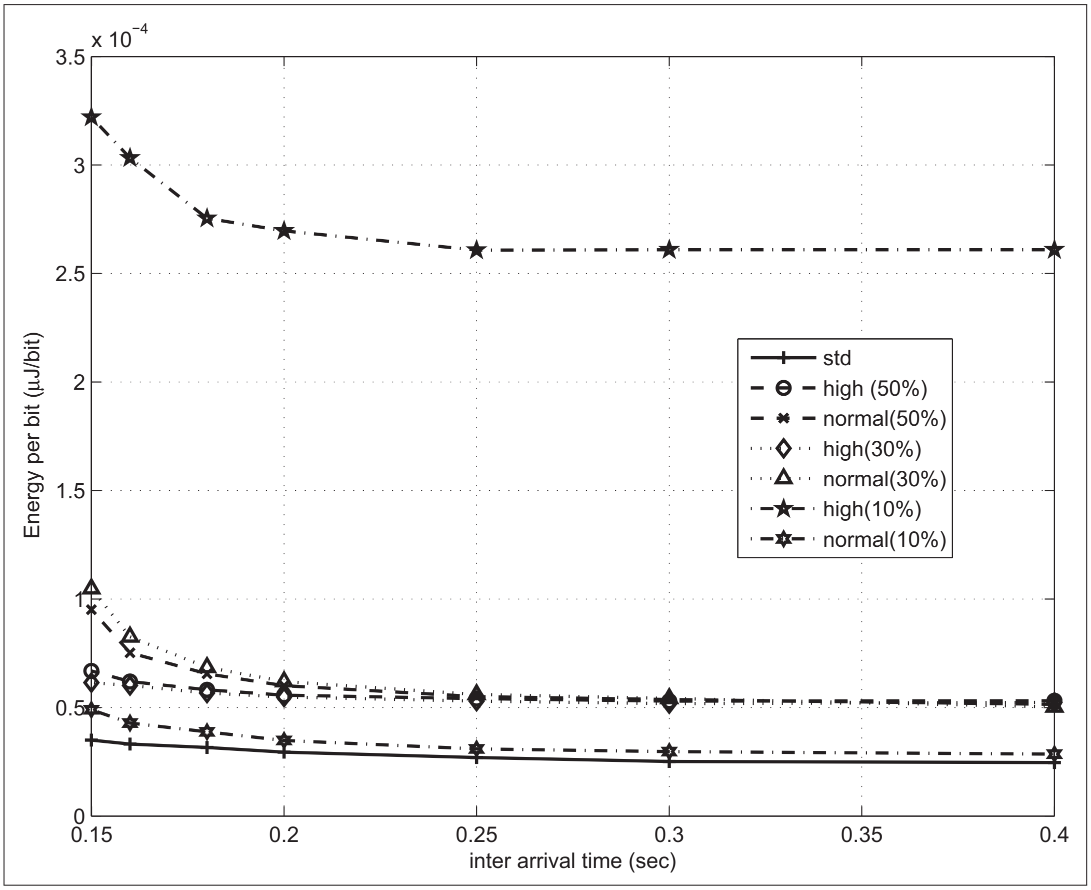

Figure 6: Energy-per-bit vs. inter-arrival time

Fig. 6 compares the energy efficiency of PJ and standard CSMA/CA using the concept of energy consumption for transmitting a bit. The power consumption of idle, transmit and receive states are set to P_{idle}=712 μW, P_{tx}= 31.32 mW, and P_{rx}=35.28 mW, respectively [5]. Because PJ scheme has energy consuming elements such as jamming signal (node with high priority packets) and longer CCA time (node with normal priority packets), the energy consumption of PJ is higher than that of standard CSMA/CA. However, the $\mu J/bit$ differences are relatively small because throughput with PJ are increased and energy-per-bit values are the same order of magnitude.

4 Conclusion

In this paper, a new service differentiation scheme which is called priority jamming (PJ) is proposed for IEEE 802.15.4. The main idea of the proposed priority jamming is deferring the transmissions of normal priority packets using a jamming signal transmitted for high priority nodes who have packets ready to transmit. By using the proposed scheme, the average delay of high priority packets is reduced. In addition, the net throughput of IEEE 802.15.4 is increased and delay of normal priority packets is decreased because of lowering the collision probabilities among IEEE 802.15.4 nodes.

Although PJ consumes more energy for a packet transmission because energy consuming factors such as jamming signal transmission and long CCA time, PJ shows better performance both in the delay and the throughput. Therefore, the differences in PJ and standard IEEE 802.15.4 are relatively small.

The proposed algorithm can be used both beacon-enabled and non-beacon enabled mode of IEEE 802.15.4 and guarantee backward compatibility with legacy IEEE 802.15.4 standard.

By providing the service differentiation using PJ, this paper may contribute to enlarge the delay-sensitive application area of IEEE 802.15.4 such as as emergent alarms and intruder detections.

Acknowledgments

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