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Traffic Adaptive Contention Differentiation Scheme for LR-WPANs

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SUMMARY IEEE 802.15.4 is a new standard, uniquely designed for low rate wireless personal area networks (LR-WPANs). It targets ultra-low complexity, cost, and power, for low-data-rate wireless connectivity. However, one of the main problems of this new standard is its insufficient, and inefficient, media access control (MAC) for priority data. This paper introduces an extended contention access period (XCAP) concept for priority packets, also an traffic adaptive contention differentiation utilizing the XCAP (TACDX). The TACDX determines appropriate transmission policy alternatively according to the traffic conditions and type of packet. TACDX achieves not only enhanced transmission for priority packets but it also has a high energy efficiency for the overall network. The proposed TACDX is verified with simulations to measure the performances.

key words: *contention differentiation, QoS support, adaptive transmission control, energy efficiency, wireless ubiquitous network, 802.15.4, LR-WPAN*

1. Introduction

Low Rate Wireless Personal Area Networks (LR-WPANs) have been designed for short range wireless communication, based on low power consumption as well as being a low cost technology. In this type of network, the communication capacity may be limited by the low hardware specifications, such as small memory size and low processing capacity. IEEE 802.15.4 [1], which was recently standardized, shows great potential for ubiquitous and pervasive computing for LR-WPANs. In IEEE 802.15.4, a beacon enabled mode is one of the predominant schemes for low power consumption where a coordinator periodically transmits a beacon frame, informing the network of the superframe structure, and manages its active/inactive periods. Any associated nodes are allowed to communicate in the active periods, and energy is conserved by turning off their transceivers during the inactive periods. In the active periods, high priority data, such as real-time traffic, should use Guaranteed Time Slots (GTS) allocation to provide QoS support. GTS is a contention free mechanism for supporting high priority traffic applications. However, GTS is an expensive approach for low data rate applications [2]. Allocating specific bandwidth can lead to more contention in the remaining bandwidth. In addition, the number of nodes supporting GTS is limited to seven, which can be insufficient according to the node density. Framing tailoring (FRT) [3] is proposed to avoid acknowledgement and data packet collisions, while allowing one-time CCA, so that it can be exploited to provide strong prioritization in addition to the standard CSMA-CA. However, this scheme requires hardware support for zero padding, which is difficult to apply in low cost devices, and at present, is not suitable for applications to currently available devices. [4] proposes a QoS mechanism by controlling three variables, which are the BE (Backoff Exponent), the CW (Contention Window) and the NB (Number of Backoffs). These variables are assigned according to the packet type. However, it is difficult to know the exact influence of the variables on the performance in dynamic traffic conditions, which makes it difficult to adapt this algorithm to support QoS in real network environments.

This paper introduces an extended contention access period (XCAP) for priority events in LR-WPAN applications; specifically for networks using IEEE 802.15.4, a traffic adaptive contention differentiation scheme utilizing the XCAP (TACDX) is proposed. The TACDX adapts the length of the XCAP dynamically to the volume of priority traffic without exchanging control messages. The TACDX achieves not only enhanced transmission for the priority packets but it also has high energy efficiency for the overall network. The remainder of this paper is organized as follows: the proposed scheme is described in detail in Sect. 2. Section 3 evaluates the performance, and finally, conclusions are provided in Sect. 4.

2. TACDX Scheme

Data transmissions in high traffic conditions can cause continued backoff[†] operations and data collisions. These overheads affect the network performance. In this case, priority packets cannot be transferred safely, and the loss of priority packets can become critical. This is our motivation that we propose the TACDX. We consider beacon-enabled mode in which the inactive period is much longer than the active period. Considering that the main merit of beacon-enabled mode is low power consumption, it is acceptable. Assume that CAP can be extended dynamically. If priority packets are able to be transmitted in CAP, or alternatively extended CAP according to the traffic status, it will be beneficial not only for the priority packets but also for the overall network performance. Figure 1 shows overviews of IEEE 802.15.4 and TACDX. In 802.15.4 (Fig. 1 (a)), a superframe structure consists of an active and inactive period. The active period is divided into two parts, a contention access pe-

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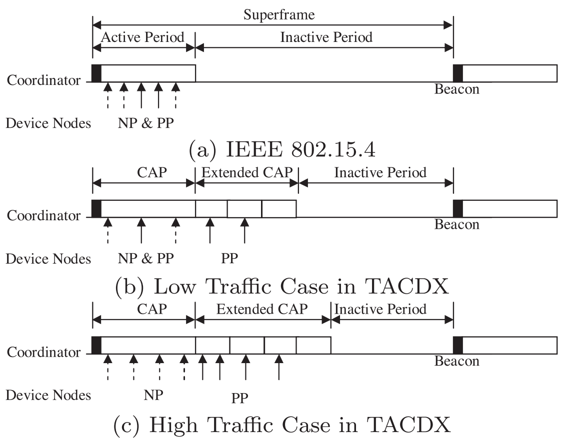

Fig. 1 Operation comparison.

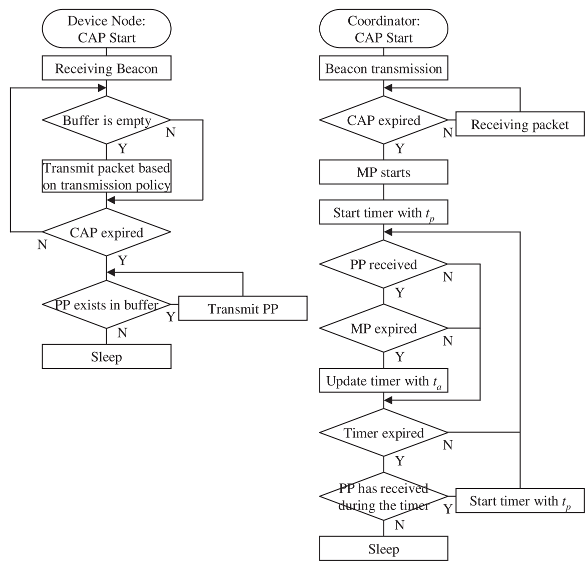

Fig. 2 Operation flow of TACDX.

Algorithm 1 Transmission Policy Determination

In CAP:
if $\overline{S_j}(i) > \tau H$ **then**
  Both NP and PP are transmitted
else if $\overline{S_j}(i) < \tau L$ **then**
  NP is transmitted
else
  Maintain current transmission policy
end if
In XCAP:
PP is transmitted

riod (CAP) and a contention free period (CFP). CFP is optional. In CAP, both normal packet (NP) and priority packet (PP) are transmitted based on CSMA/CA mechanism. Each node randomly selects a backoff time in the range $[0, 2^{BE}-1]$. The initial value of backoff exponent (BE) is given as *macMinBE*, and can be incremented up to *macMaxBE* according to the backoff retrial count if the channel is busy. Meanwhile, TACDX provides different transmission policies according to the traffic type and the traffic conditions. If the length of CAP is enough to the traffic volume (Fig. 1 (b)), each node sends both an NP and a PP in the CAP. If PPs are remained when the CAP is expired, they can be transmitted by extending the CAP. However, if the traffic condition is not good enough (Fig. 1 (c)), the node transmits packets separately according to the packet type. In this case, NPs are transmitted in CAP, while priority packets are transmitted after the CAP, that is, in the XCAP mode. In TACDX, we do not consider CFP in the active period.

How each device node measures the recent traffic level is defined, and the transmission policy is determined, based on the traffic level. The delivery ratio in the active period is stored in s_i of the matrix S_j. i denotes the i-th active period since the first power-on, and j denotes the sending node j.

$$S_j = \begin{bmatrix} s_{i-k} \\ \vdots \\ s_{i-2} \\ s_{i-1} \end{bmatrix} \quad (1)$$

$$\overline{S_j}(i) = \frac{\sum_{m=i-1}^{i-k} s_m}{k} \quad (2)$$

When the current time is given as the i-th active period, each device node stores maximum k times of recent delivery ratio information, and calculates the average $(\overline{S_j}(i))$. Based on the $\overline{S_j}(i)$ and the thresholds, each node determines its transmission policy as described in Alg.1. τH and τL denote the high and low thresholds, respectively. When the CAP has expired, the coordinator extends the active status for the priority event gathering time (t_p). We call this period as the Mandatory Period (MP) since the coordinator node must wait for time t_p. Additional waiting is determined by the existence of the arrival of a packet when the timer has expired. If the coordinator receives any PPs during the time period t_p, it maintains its active status for the same period (t_p) again. In this case, the coordinator extends its active state whenever it listens to the PP as long as it has additional gathering time (t_a). t_p and t_a are the maximum backoff time when BE is *macMinBE* and *macMaxBE*, respectively. If the coordinator has not received any PPs when t_p or t_a has expired, it enters into its sleep mode until the following CAP begins. Figure 2 shows operation flows of TACDX as described above.

3. Simulation Results and Discussion

The NS-2 simulator (version ns-2.31) [5] has been used after modifying the NS-2 802.15.4 MAC module. Simulations have been performed under the following assumptions and environments. There are neither channel errors nor any propagation delays. The network consist of a coordinator and ten device nodes and the transmission range of all the nodes is limited to 10 meters, and every device node is located approximately 10 meters away from the coordinator, making a circle around it. Each node performs a data transmission, requiring an ACK frame. The packet generation is

Table 1 Parameters used in simulation.

Parameter	Value	Parameter	Value
Traffic Type	CBR	Transmit Power	52.2 mW
Data Size	70 Bytes	Receive Power	59.1 mW
k	10	Idle Power	0.06 mW
τH	90	*macMinBE*	3
τL	85	*macMaxBE*	5

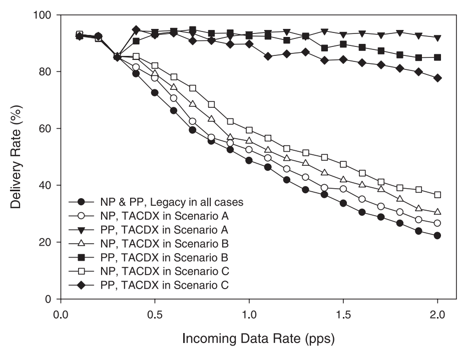

Fig. 3 Delivery ratio.

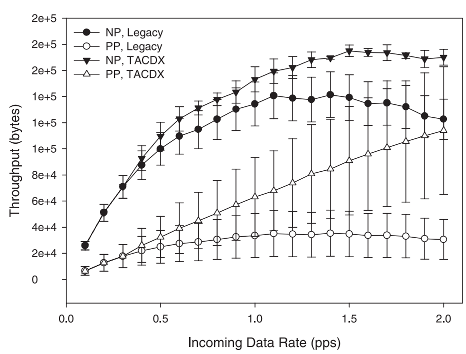

Fig. 4 Throughput.

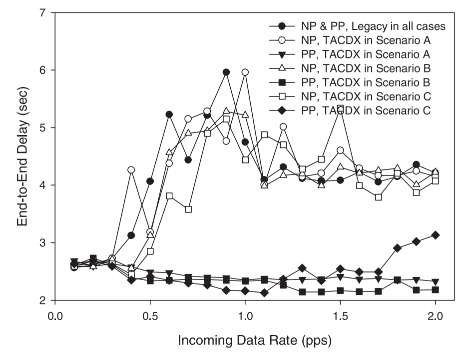

Fig. 5 End-to-end delay.

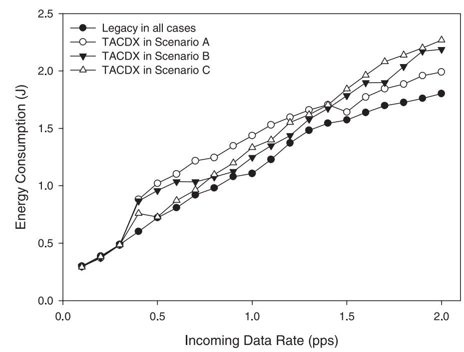

Fig. 6 Energy consumption.

based on a Poisson process and the type of each packet is either PP or NP. The ratio of priority data traffic to the total traffic volume is approximately 10% in scenario A, 20% in scenario B, and 30% in scenario C. The simulation time is 100 seconds and retransmissions have not been considered. The main parameter values used in the simulated studies are listed in Table 1. In the case of the IEEE 802.15.4 simulation case study, the results for NP and PP are almost identical since there is no differential control according to the packet type. To simplify the graph, only one result is represented, using the average value regarding the legacy scheme.

Figure. 3 shows the percentage of the transmitted packets that are successfully delivered. The results show that the delivery rate is similar when the length of CAP is sufficient to the traffic volume, while TACDX provides better performance by differentiating the traffic based on packet type, if the CAP is insufficient. As a result, the TACDX maintains a high delivery ratio for PPs, while decreasing the delivery ratio for NPs. The legacy scheme shows the lowest delivery rate. Figure 4 presents the amount of data transferred from the device node to the coordinator node. In the legacy scheme, the throughput of NP and PP cannot increase continuously as the traffic increases. However, the TACDX provides higher results for both PP and NP than those of the legacy scheme. In TACDX, the throughput of PPs increases proportionally according to the traffic load, while the throughput of NPs shows relatively similar results in the simulation cases. Figure 5 shows the time taken for a data packet to reach the coordinator. In the legacy scheme, the end-to-end delay increases if the length of the CAP is insufficient compared to the traffic volume. However, TACDX shows a differential delay by using the XCAP mode. It can be seen that TACDX maintains a short delay for the PPs, regardless of the traffic conditions. Figure 6 shows the energy consumption. Though the legacy scheme shows the lowest energy consumption, it cannot be said to provide energy efficient operation when comparing its short CAP and low delivery numbers. The main reason for this is that the legacy scheme consumes a lot of power in carrying out repetitive backoff and CCA (Clear Channel Assessment) before transmission when the CAP is insufficient compared to the contending traffic. The CCA requires the node to maintain the receiving mode for a specific time to prevent transmission collision. As shown in Table 1, receiving power is the most power consuming task. Therefore, continued backoff and CCA should be minimized to increase energy efficiency. Figure 7 compares the energy overhead. To measure the energy overhead, we divide the energy consumption by the number of successfully delivered packets. The portion of energy consumption for the number of transmissions is low

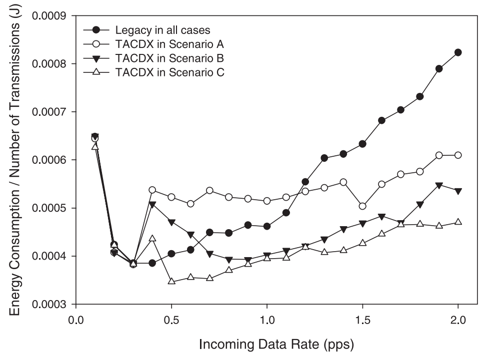

Fig. 7 Energy overhead.

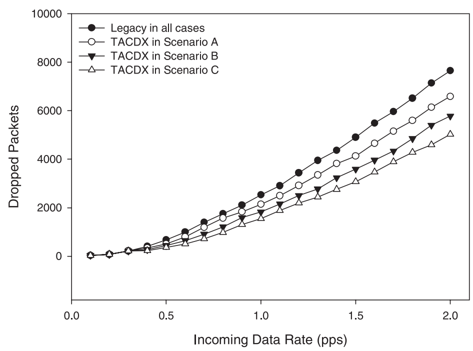

Fig. 8 Dropped packets.

in the case of low traffic, while it increases rapidly as the traffic increases, since the required energy for transmitting and receiving is relatively high. This leads to dropping results in the beginning, as can be seen in Fig. 7. The results show that the energy overhead of legacy scheme increases proportionally according to the traffic load, while the results of TACDX show very gentle ascents. It means that TACDX consumes significant power for the transmission. Considering Figs. 6 and 7, it can be said that TACDX is more energy efficient than the legacy scheme since it can transmit more data while consuming similar, or only slightly higher energy. Figure 8 compares the number of dropped packets. It presents how many packets were failed in transmission. The number of packets dropped does not take into account retransmissions; if retransmissions are allowed, the dropped packets would be retried up to the limit of the maximum number of allowed retransmissions. In this case, the energy consumption would increase. Figure 8 shows that the legacy scheme drops the largest number of packets, and TACDX in scenario C shows the lowest number of dropped packets. It can be inferred that TACDX can be more energy efficient than the legacy scheme if retransmissions are allowed.

4. Conclusion

For longer network lifetimes in LR-WPANs, the networks should work in beacon enabled modes, and the inactive periods should be longer than the active periods. In this paper, a traffic adaptive contention differentiation scheme for IEEE 802.15.4 LR-WPANs utilizing the inactive periods has been proposed. The proposed, TACDX, has two main advantages, which are, 1) that the TACDX utilizes the inactive periods for the priority packets alternatively according to traffic conditions which can be an easily acceptable approach since the inactive periods are generally much longer than the active periods leading to lower power consumptions; 2) that the TACDX does not require additional control messages to determine the XCAP so it does not require lots of additional energy. This also means that TACDX maintains compatibility with IEEE 802.15.4 standard. Simulations, performed by the NS-2 simulator, have shown that the TACDX relaxes the contention in the CAP, which achieves both good QoS support and improves the energy efficiencies.

Acknowledgements

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