

Strictly Prioritized Transmission of Urgent Data Based on MAC Coordination in WSNs

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Abstract—Recently, by the spread of Internet of Things (IoT), wireless sensor networks and their applications are becoming more diverse. Future tasks in IoT include healthcare and factory networks, in which urgent data, in case of sudden condition change of elderly people or disaster due to machine failure, must be transferred with minimum delay and loss. However, existing methods for such prioritized transmission support only relative prioritization among different data traffic. In this paper, we propose a strictly prioritized transmission method of urgent data for transmission with minimum delay and loss. Urgent data are transmitted with strictly prioritized manner in MAC coordination between neighbor nodes along the route.

I. INTRODUCTION

In recent years, by the spread of Internet of Things (IoT) [1][2][3], various wireless sensor networks (WSNs) have been used. To deal with the increase in the number of sensors and traffic, many medium access control (MAC) protocols have been proposed [4][5]. However, future problems include pursuing not only the improvement of throughput and load distribution like conventional researches but also the provision of stringent latency with high reliability for specific urgent applications.

Namely reliability improvement is an important future task in the IoT [6]; for example, in healthcare [7][8] and factory [9][10] networks, a sudden change in conditions or an accident can affect reliability. A new framework is needed for low latency and low loss-rate transmission of urgent data.

In this paper, we propose a strictly prioritized transmission method of urgent data for transmission with minimum delay and loss. This proposed method is based on random channel access control. In the proposed method compared with existing methods [11]–[14] that support relative prioritization of some important frames, urgent data frames are transmitted with strictly prioritized manner based on multi-hop wireless channel reservation in MAC coordination between neighbor nodes along the route.

II. RELATED WORKS

EDCA is the current standardization method for prioritized transmission. In EDCA, data frames are classified into four access categories (AC). By setting the inter-frame space (IFS) and the backoff period to shorter values for higher priority ACs, these ACs more easily obtain transmission opportunities.

Alternatively, other methods based on time division multiple access (TDMA) have been proposed. Jawhar and Wu [15] studied routing protocols based on TDMA to support QoS in mobile ad hoc networks. Nasser et al. [16] developed a

method for allocating time slots according to data priority and reserving communication for high priority data frames. Buranapanichkit and Andreopoulos [17] simplified the network topology by introducing TDMA based on synchronization release (DESYNC-TDMA), reducing both energy consumption and packet collision. Kim et al. [18] designed urgent nodes to send interrupt signals so that short time slots are allocated; thus, resources can be used dispersedly among the nodes.

However, TDMA requires time synchronization among all nodes, and the load of calculation processing increases. This is unsuitable for WSNs that should be managed with low cost.

In this paper, we focus on random access control, and aim to establish a prioritized transmission compatible with simple communication equipment and control. The following methods implement prioritized transmission based on random access. Ranganathan and Kannan [11] calculated the backoff interval using fuzzy logic. Geng et al. [12] adjusted IFS according to data priority. Sarang et al. [13] designed the sink to periodically collect the sender's information—if there is urgent data from the collected information, communication is immediately started; in other cases, it preferentially communicates with the nodes with higher priority based on the gathered node information. In addition, ZMAC separately uses CSMA and TDMA according to traffic, yet data with high priority can be transmitted even by using slot time of another node [14].

However, these existing methods transmit urgent data frames only by setting them to relatively higher priority. As a result, they cannot transfer urgent data with strict priority by supporting highly reliable transmission with minimum delay and without collisions to other frames.

III. PROPOSED METHOD

Strictly prioritized multi-hop transmission of urgent data is performed by temporarily prohibiting the transmission of other nodes peripheral to the route from the source node to the sink via the relay nodes. This means the channel is temporarily reserved and urgent data is transmitted with the minimum delay in principle. This reservation is done with new control frames; medium reservation frame (MRF) and completed reservation frame (CRF), via MAC cooperation between the nodes along the transmission route.

A. Control frame format

CRF uses the same format as clear-to-send (CTS). MRF uses the a format similar to request-to-send (RTS) with the addition of another MAC address field (DestAddr), which

stores destination address at end-to-end level, and a data size field. This format is shown in Fig. 1. A node sending an MRF or a CRF sets the Duration field to a reservation period.

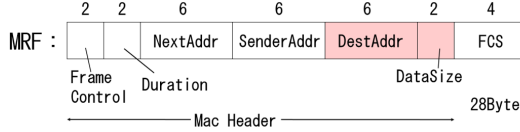


Fig. 1. Format of MRF.

B. Channel reservation process

The channel reservation is realized by setting a network allocation vector (NAV) for only the reservation period to the neighboring nodes that overheard the MRF or the CRF, in which the reservation period is specified in the Duration field. The NAV period is set as follows according to the node transmitting the control frame (Sec Fig. 2).

Source node:

$$D_{SIFS} + D_{MRF} + D_{SIFS} + \Delta T + D_{urgent} + D_{SIFS} + D_{ACK} \quad (1)$$

Relay node:

$$D_R^p - D_{SIFS} - D_{MRF} + D_{SIFS} + D_{urgent} + D_{SIFS} + D_{ACK} \quad (2)$$

Sink:

$$D_R^p - D_{SIFS} - D_{CRF} \quad (3)$$

Here, D_R^p is the period set in the Duration field of the MRF received from the previous hop node. D_{MRF} , D_{CRF} , D_{urgent} , and D_{ACK} are the durations required to transmit MRF, CRF, urgent data, and ACK, respectively. D_{SIFS} is SIFS interval.

C. Procedure of prioritized transmission

The operation of the proposed prioritized transmission is shown in Fig. 2. A source node first transmits an MRF to the next hop relay node, and the relay node also transmits its MRF to the next node after short IFS (SIFS) duration. At this time, if the source node overhears the MRF transmitted by the relay node, it judges that the channel from itself to the next relay node is reserved. After waiting for the period of SIFS and ΔT , it transmits its urgent data. ΔT is the period over which the urgent data could conflict with the MRF transmitted further from the next relay node. Each relay node also determines that the channel has been reserved by overhearing the MRF transmitted by its next hop node. After receiving the urgent data from the previous hop node, the receiving node returns the ACK after SIFS interval and transmits the urgent data to the next hop node. The sink reserves the channel resources around itself by returning a CRF to the previous hop node after receiving the MRF from the previous hop node.

D. Temporary termination and resumption of prioritized transmission

In the channel reservation process, MRF and CRF can be lost in various situations. In a situation where an end-to-

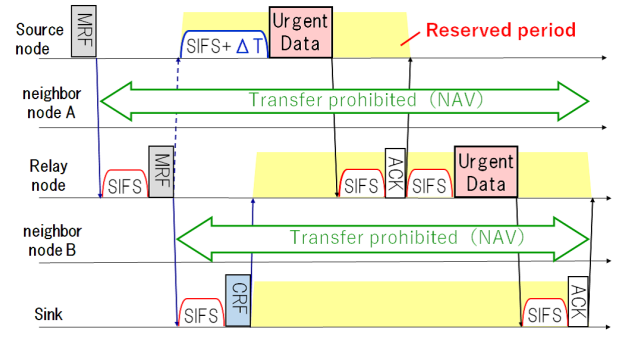


Fig. 2. Procedure of the prioritized transmission.

end channel reservation cannot be performed, the temporary termination and resumption of channel reservation in the relay node is performed as follows. A node that sent an MRF sets a timer to wait for overhearing the MRF from the next hop node. When the timer expires, it judges that the channel cannot be reserved up to the next hop node. Then, urgent data is transferred to the last node where the channel was reserved, and the node resumes the prioritized transmission as a new source node.

E. Transmission processes for each node type

1) *Source node*: The transmission process of the source node is shown in Fig. 3. The circled numbers in the figure are noted in the text for reference. A source node that tries to transmit urgent data waits for point IFS (PIFS) and a backoff period whose range is set by AC_VO of EDCA. PIFS is used for prioritized channel access rather than normal channel access with distributed IFS (DIFS). After acquiring a transmission right, an MRF, where the Duration field is set by Eq. (1), is transmitted. As for the fields in the MRF, NextAddr and DestAddr are set to the address of the next hop node and final destination address of the data frame (obtained from IP header of frame) (①), respectively. Then, the timer for SIFS and the MRF transmission period is set.

If the MRF sent from the next hop node is overheard before the timer expires (②), after waiting for SIFS and ΔT (③), the urgent data is sent (④). Alternatively, if a CRF is received from the next hop node that is the sink, the urgent data is sent after waiting for only SIFS. After transmitting the urgent data, if the ACK from urgent data is not received, retransmission is performed up to the number of retransmission trials.

On the other hand, if the timer expires, the channel from the source node to the next hop node cannot be reserved. Thus, the source node performs the channel reservation as described above, and retransmits MRF until the number of retransmission trials attains to the limitation.

2) *Relay node*: The transmission process of a relay node is shown in Fig. 4. Upon receiving an MRF, the relay node decides itself as a relay node if the DestAddr field is different from itself. Then, it also sends its MRF to its next hop node (①). In the MRF, the Duration field is set to the reservation period calculated with Eq. (2), and NextAddr field is set to the address of the next hop node. After sending the MRF, the timer for SIFS and the MRF transmission period is set.

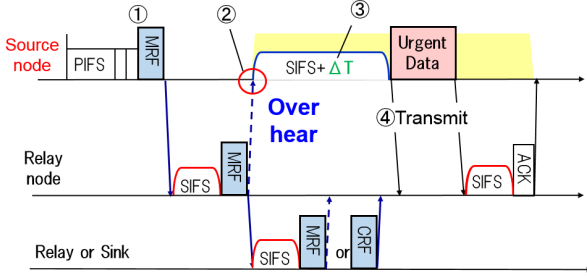


Fig. 3. Transmission process: Source node.

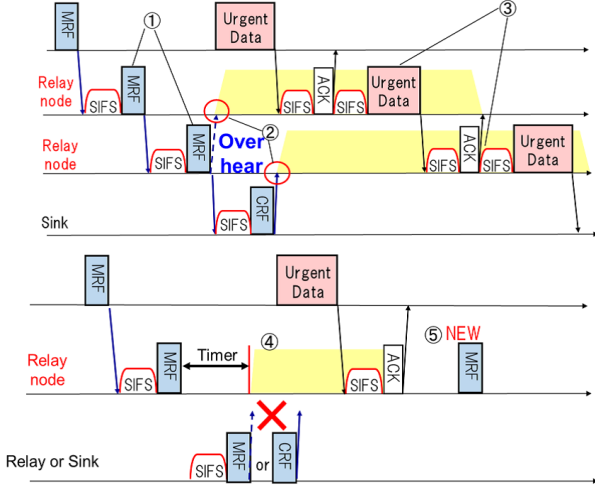


Fig. 4. Transmission process: Relay node.

If the relay node confirms the MRF or CRF sent from the next relay node or the sink (②), it waits for receiving urgent data from the previous hop node. After receiving the urgent data, it replies with ACK, then sends urgent data to next hop node after SIFS interval (③).

On the other hand, when the timer expires, the relay node presumes that the channel to the next hop node cannot be reserved (④). The relay node still receives the urgent data from the previous hop node and sends ACK back. Then, the relay node restarts sending the urgent data in the same way as a source would (⑤), as explained in Sec. III-D.

3) *Sink*: The sink that receives the MRF judges itself as a sink if the DestAddr field is itself, and sends a CRF to the previous hop node. In the CRF, the Duration field is set to the reservation period calculated from Eq. (3), and NextAddr is set to the address of the previous hop node. Subsequently, the sink prepares to receive the urgent data.

IV. EVALUATION

In order to evaluate the performance of the proposed method, we conducted a simulation using QualNet 5.2 [19].

A. Simulation settings in static node placement

The set-up parameters are shown in Table I. As shown in Fig. 5, we placed a sink, an urgent data source node, two normal data source nodes, and other relay nodes to set one 3-hop urgent flow and two 3-hop normal flows in parallel, and the distance between the nodes is 200 m. Here, the

TABLE I
PARAMETERS

parameter	value
Physical layer	802.11b
Data transmission rate	2 Mbps
Packet size	512 byte
Routing protocol	Static Routing
Number of data frame retransmissions	4
Number of control frame retransmissions	7
Communication range of each node	339.322 m
Simulation time	360 seconds
ΔT	$31 \times \text{slottimes}$

generation rate of the urgent flow is fixed at 0.1 Mbps, and the simulation is performed by changing the generation rate of each normal flow. The proposed method is compared to EDCA using RTS/CTS (flow of urgent and normal data transmitted by AC_VO and AC_BE, respectively).

B. Simulation result in static node placement

The average end-to-end delays of urgent and normal data are shown in Fig. 6. In Fig. 6, the proposed method achieves delay suppression of urgent data compared to EDCA, because of the minimum delay transfer. On the other hand, the delay of normal data is slightly larger in the proposed method, because the nodes transmitting normal data must prohibit their transmission by the channel reservation for transmitting urgent data. The average packet loss rate of each flow is shown in Fig. 7. In Fig. 7, the proposed method reduces the loss rate of urgent data compared to EDCA. This is because prohibition of transmission of other nodes reduces probabilistic occurrences of collision events. On the other hand, the loss rate of normal data is larger in the proposed method. This is because the collision probability with another normal frame is increased due to the decrease in transmission opportunities by the channel reservation.

C. Simulation settings in random node placement

Similarly, we evaluated the performance of the proposed method in an environment of random node placement. The set-up parameters are shown in Table I, but only the routing protocol is changed to Bellman Ford routing. As shown in Fig. 8, we placed a sink at the center of a 5×5 lattice topology, where each square cell has 150 m in length, and source nodes are randomly placed in the cells. An urgent data packet flow is generated from each urgent data source node according to the exponential distribution with an average arrival interval of 30 minutes; the packet data generation rate in a flow is 0.1 Mbps (constant), and the flow generation duration is 3 minutes. Here, there is no possibility that no urgent flow will occur within 30 minutes and also there is no more than one urgent flow at the same time. Each normal flow is generated at any normal data generation node at the generation rate of 0.1 Mbps (constant). The simulation is performed by changing the number of normal flows.

D. Simulation result in random node placement

The average end-to-end delays of urgent data and normal data are shown in Fig. 9. In Fig. 9, at times of high load, the proposed method achieves significant delay suppression

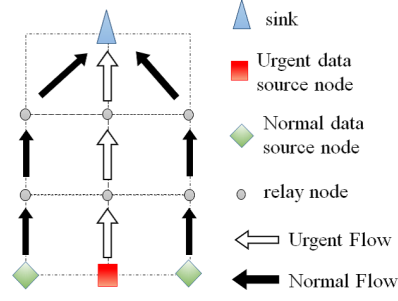


Fig. 5. Simulation environment: Three parallel flows.

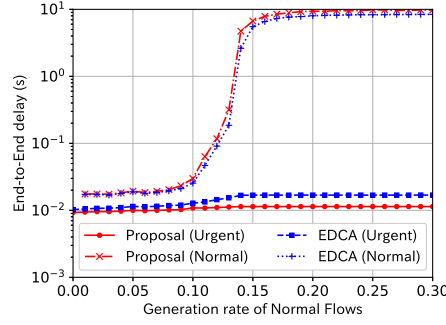


Fig. 6. Static node placement: End-to-End delay.

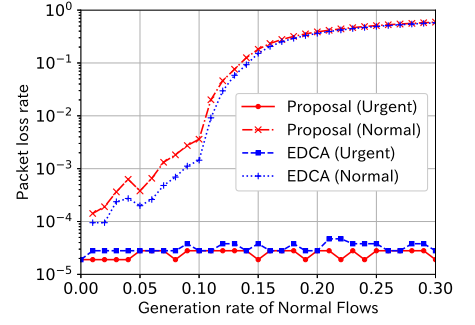


Fig. 7. Static node placement: Packet loss rate.

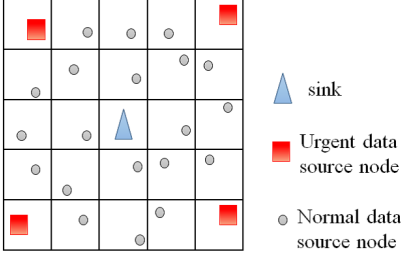


Fig. 8. Simulation environment: Urgent data occurs randomly.

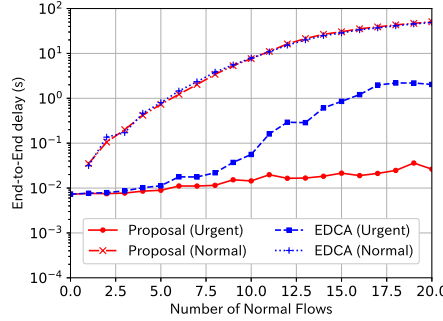


Fig. 9. Random node placement: End-to-End delay.

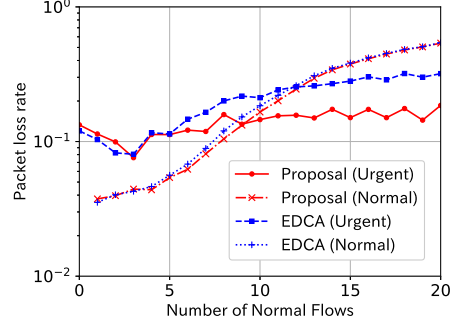


Fig. 10. Random node placement: Packet loss rate.

of urgent data. This is because urgent data is transferred by exclusively using the channel and avoiding collision with neighboring nodes. Additionally, regarding the normal data in Fig. 9, the delays are quite similar. This is because the channel is reserved for only the duration to transfer urgent data, and as a result, the load of the end-to-end channel reservation given to other nodes is small. The average packet loss rates of urgent data and normal data are shown in Fig. 10. For both data types, the proposed method achieves the reduction compared to EDCA. The loss rate of urgent data is reduced because of the proposed prioritized transmission with the channel reservation. In addition, reserving the channel also avoids the collision between urgent and normal data. Thus, the loss rate of normal data is also reduced slightly.

V. CONCLUSION

In this paper, we proposed a strictly prioritized transmission method of urgent data based on temporal channel reservation in MAC coordination between neighbor nodes along the route. We showed that delay and loss rate can be suppressed by the proposed method through simulation. As a future task, we aim to implement the proposed method in real sensor nodes, and evaluate the performance in detail.

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