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Contents

Abbreviations **ii**

1 Wireless Sensor Networks **1**

2 Energy-efficiency MAC protocols for Wireless Sensor Networks **2**
2.1 Energy-efficiency MAC protocols 2

3 Fast Traffic Adaptive MAC protocol **3**
3.1 Protocol design 3
3.1.1 Traffic Status Register (TSR) based protocol 3
3.1.2 Fast Traffic Adaptive (FTA) MAC protocol design 3
3.1.3 Frame structure 3
3.1.4 Energy consumption models 3
3.2 Implementation 3
3.3 Evaluation 3

4 FTA-MAC Extensions **4**

5 Aggregation MAC protocol **5**
5.1 State of the art 5
5.2 Aggregation MAC protocols 5
5.2.1 Fixed Aggregation 5
5.2.1.1 Protocol design 5
5.2.1.2 Aggregated packet structure 7
5.2.2 Dynamic Decision Aggregation 8
5.2.2.1 Limitation of Fixed Aggregation 8
5.2.2.2 Dynamic Decision Aggregation 9
5.3 Implementation and Evaluation 11
5.3.1 Implementation of the aggregation MAC protocols in RICER3 . . 11
5.3.1.1 RICER3 Fixed Aggregation (RICER3-FA) 11
5.3.2 Evaluation 11
5.3.2.1 Simulation parameters 11
5.3.2.2 Results 11

Abbreviations

WSNs	Wireless Sensor Networks
WB	Wake-up Beacon
I_{WU}	Wake-up Interval
Δ_{max}	The limited duration of a packet in queue (millisecond)
τ_{Q_i}	The duration of the i^{th} packet in queue (millisecond)
b_{rate}	The bit rate of sensor node (bit/s)
l_{WB}	The length of WB packet (byte)
l_{ACK}	The length of ACK packet (byte)
l_{DATA}	The length of DATA packet (byte)
l_{DATA_h}	The length of DATA packet header (byte)
$l_{DATA_{agg}}$	The length of aggregated DATA packet (byte)
τ_{CCA}	The Clear Channel Assessment time (millisecond)
τ_{WB}	The time taken to send WB packet (millisecond)
τ_{ACK}	The time taken to send ACK packet (millisecond)
$\tau_{DATA_{agg}}$	The time taken to send aggregated DATA packet (millisecond)

Chapter 1

Wireless Sensor Networks

The introduction of WSN come here

Chapter 2

Energy-efficiency MAC protocols for Wireless Sensor Networks

2.1 Energy-efficiency MAC protocols

Chapter 3

Fast Traffic Adaptive MAC protocol

3.1 Protocol design

3.1.1 Traffic Status Register (TSR) based protocol

3.1.2 Fast Traffic Adaptive (FTA) MAC protocol design

3.1.3 Frame structure

3.1.4 Energy consumption models

3.2 Implementation

3.3 Evaluation

Chapter 4

FTA-MAC Extensions

The extensions of FTA-MAC in multi-hop network

Chapter 5

Aggregation MAC protocol

In the Wireless Sensor Networks with the multi-host topology, the communication between the source node and the destination node can be established through many relay node.

5.1 State of the art

5.2 Aggregation MAC protocols

5.2.1 Fixed Aggregation

5.2.1.1 Protocol design

A simple algorithm of aggregation mechanism which is implemented in the relay node is that each time the relay node receives a data packet from the source nodes, it does not re-transmit immediately to the next relay node or to the destination node. The data packet will be stored in a queue to wait the others data packets. After the Δ_{max}, the relay node aggregates all the data packet with same destination in queue into a aggregated data packet and sends it to the next relay node or to the destination node. With the limitation of resources in sensor node, here is the number of data packet can be stored in the memory, some time the relay node needs to active the process of data aggregation before the Δ_{max} reached. We define the τ_{Q_i} is the duration of the i^{th} packet

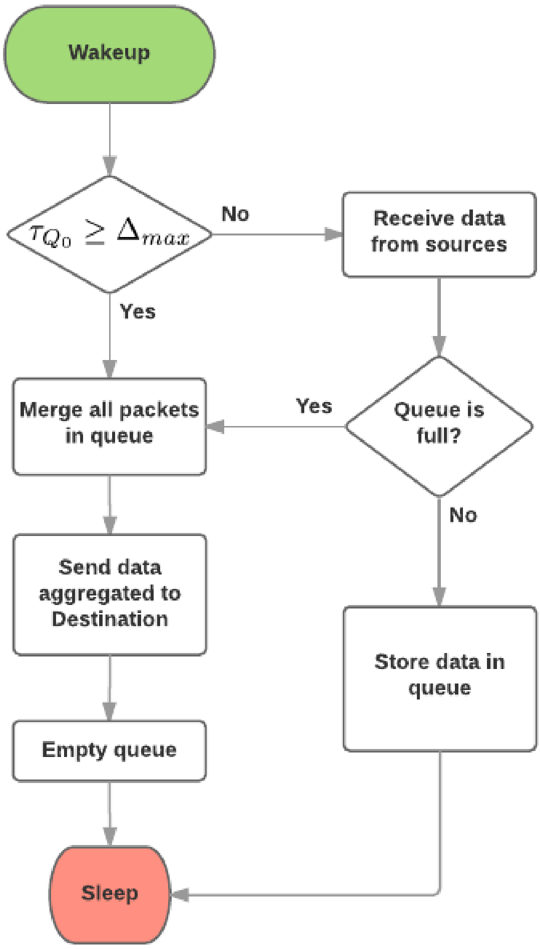

FIGURE 5.1: Behavior of sensor node with Fixed Aggregation MAC protocol.

in the queue. The condition of data aggregation is defined in the following equation :

$$\tau_{Q_0} \geq \Delta_{max} \mid\mid qu_{size} = qu_{max} \tag{5.1}$$

where τ_{Q_0} is the duration of the 1^{st} packet in queue, Δ_{max} is the limited duration of a packet in queue, qu_{size} is the number of packets in queue and qu_{max} is the limited size of queue depends on the resources of sensor nodes.

The behavior of sensor node which is implemented the Fixed Aggregation MAC protocol is described by the state machine schema in Fig.5.1. As other sensor nodes, the relay node uses also the technique duty cycling, it switches between sleep and awake state. But unlike the source or destination nodes, at the beginning of awake state, the relay node will decide to turn on the radio in listening state to receive data from the source nodes or in sending state to transmit the data to the next relay node or to the destination node. To avoid the packet lost caused by the queue is full, the data aggregation is higher priority than receiving data.

5.2.1.2 Aggregated packet structure

As the discussion in the section 5.2.1.1 above, the relay node will aggregate all data packets in the queue and sends a big packet to the destination. A new structure of data packet is proposed in Fig.5.2 below. With the new structure defined, the size of aggregated data packet is dynamic and can be calculated by the equation following

$$l_{DATA_{agg}} = l_{DATA_h} + n(l_{DATA} - l_{DATA_h} + 4) \tag{5.2}$$

$$t_{DATA_{agg}} = \frac{l_{DATA_{agg}} * 8}{b_{rate}} \tag{5.3}$$

where l_{DATA} and l_{DATA_h} is the length of data packet and its header, n is the number of packet will be aggregated, the condition to use the new structure is $n > 1$, 4 is the number of byte of source address field in header (which is defined in Sec. 3.1.3)

By applying the new structure of data packet and the energy consumption model in duty cycling 3.1.4, the energy saved by sending a new aggregated data packet instead of many single data packet is estimated :

$$\begin{aligned}
\Delta_E &= n(E_{TX_{DATA}} + E_{RX_{DATA}}) - (E_{TX_{DATA_{agg}}} + E_{RX_{DATA_{agg}}}) \\
&= n[4t_{CCA}P_{RX} + (t_{ACK} + t_{DATA})(P_{RX} + P_{TX})] \\
&\quad - [4t_{CCA}P_{RX} + (t_{ACK} + t_{DATA_{agg}})(P_{RX} + P_{TX})] \\
&= (n-1)[4t_{CCA}P_{RX} + t_{ACK}(P_{RX} + P_{TX})] + (P_{RX} + P_{TX})(nt_{DATA} - t_{DATA_{agg}})
\end{aligned} \tag{5.4}$$

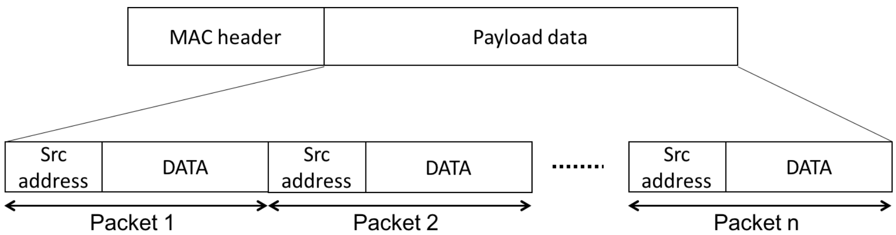

FIGURE 5.2: New structure of aggregated packet.

From the equations 5.2, 5.3 and 5.5 we have :

$$\Delta_E = (n-1)[4t_{CCA}P_{RX} + t_{ACK}(P_{RX} + P_{TX})] + (P_{RX} + P_{TX})\frac{8[(n-1)l_{DATA_h} - 4]}{b_{rate}} \quad (5.5)$$

The equation 5.5 shows that the more packets aggregated, the more energy saved. But the length of aggregated packet is limited by the hardware of sensor node. So we can not aggregate too much data packets into one big aggregated packet. The number of packets can be aggregated is depend also on the size of data packet which is used in MAC protocol.

5.2.2 Dynamic Decision Aggregation

5.2.2.1 Limitation of Fixed Aggregation

In the previous section, we discussed about the Fixed Aggregation mechanism and its advantage in saving energy consumption. An other advantage of Fixed Aggregation is that the relay nodes do not require any addition information from the source nodes. This feature allows this mechanism is implemented facilely in the MAC protocols. But the fixed waiting duration will increase unnecessarily the delay of data packet in end-to-end communication. This problem is described more detail in the Fig.5.3. In this example, after receiving data packet from S_1, the relay node (R) stores this data packet in the queue and makes a schedule to aggregate this packet with the others coming in Δ_{max} and send the big packet to the destination (D). But within the Δ_{max} second, there is

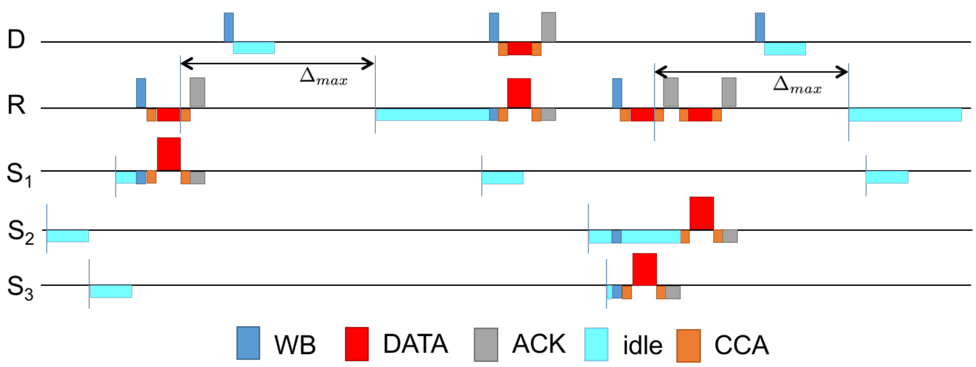

FIGURE 5.3: Wasted delay time of Fixed Aggregation.

not any packet arrive so the relay node wasted the Δ_{max}s. The problem is also existed in 2^{nd} case when the relay node receives the data packets from S_2 and S_3, it continues wait Δ_{max}s after receiving the 1^{st} packet (from S_3). This waiting is wasted also.

An other limitation of Fixed Aggregation mechanism is its compatibility of integration with the MAC protocols. In some asynchronized MAC protocols (RICER [1], FTA-MAC [2], TAD-MAC [3]) the communication of sender and receiver is initiated by the receive's WB packet. The waiting duration Δ_{max} may be caused the missing of destination's WB packet in relay node. In example shown in Fig. 5.3, after the waiting duration Δ_{max}, the relay node wakes up and wait the WB packet from the destination, but it already missed the destination's WB packet so it must stay awake to wait the next WB packet. This problem will increase the *idle listing* time and the relay node wastes the energy.

5.2.2.2 Dynamic Decision Aggregation

Dynamic Decision Aggregation is an other approach of data aggregation which avoids the problem of wasted delay time presented in Sec. 5.2.2.1. Unlike Fixed Aggregation mechanism, the relay node does not go to sleep after pushing the data packet into the queue, it estimates the next coming data packets. If there is one or more data packet arrive within Δ_{max} second, the relay node will wait the coming data packet to aggregate and send to the destination. But note that the duration of staying in queue of a data packet is no longer than Δ_{max}, so the condition of aggregation in Dynamic Decision Aggregation is proposed in the equation following

$$\Delta t_j = \widehat{t_j} - t_c \ (\forall j \neq i) \tag{5.6}$$

$$\Delta t_j \leq \Delta_{max} - \tau_{Q_0} \tag{5.7}$$

where i index is the index of current source node, $\widehat{t_j}$ is the arrive time of data packet of j^{th} source node, t_c is the current time of system. Because the estimated time $\widehat{t_j}$ is calculated in relay node so it does not require to synchronize the system clock between the sensor nodes.

To estimate the next coming data packet, the method of calculation is depended on the MAC protocols in which the Dynamic Decision Aggregation is implemented. These are some MAC protocols which calculated or allow to calculate easily this value such as

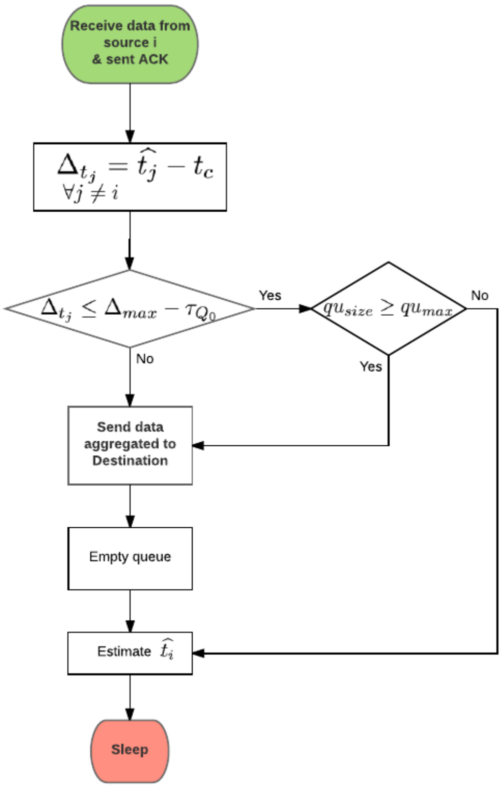

FIGURE 5.4: The state machine of Dynamic Decision Aggregation mechanism.

PW-MAC [?], TAD-MAC, FTA-MAC. Almost MAC protocols do not calculate or have not any additional information which is allow to calculate the next arrival of data packet but we can estimate this value by measuring the traffic. A light weight algorithms is proposed when applying the Dynamic Decision Aggregation in RICER3 (RICER3-DDA protocol). This algorithms is presented in next section.

In considering the problem of wasted delay time presented in Sec. 5.2.2.1, this problem will be resolved by applying the new condition of aggregation in the equation 5.7 and 5.6 which is shown in Fig.5.5. Precisely, at the 1^{st} case, after sending the ACK packet back to S_1, the relay node calculates these values Δ_{t_2} & Δ_{t_3} to make the decision of aggregation. The next arrival of data packets from S_2 & S_3 is so long to make the aggregation so the relay node does not go to sleep, it stays awake to wait the WB from the destination and transmits the data packet to destination. In the 2^{nd} case, we suppose the MAC protocol already has mechanism to solve the problem of data conflict, so the process of aggregation will be started after sending the ACK packet back to S_2, when all communications between the relay node and the source nodes are finished. This applying will not change the algorithm of MAC protocol.

5.3 Implementation and Evaluation

To evaluate the performance of Fixed Aggregation and Dynamic Decision Aggregation, we implement them in the exist MAC protocols like RICER3, FTA-MAC.

5.3.1 Implementation of the aggregation MAC protocols in RICER3

5.3.1.1 RICER3 Fixed Aggregation (RICER3-FA)

The implementation of Fixed Aggregation in RICER3 is applied on the relay node. The basic behavior of RICER3-FA is described in Fig. 5.6. The modification is applied on the relay node only. In this example,

5.3.2 Evaluation

5.3.2.1 Simulation parameters

5.3.2.2 Results

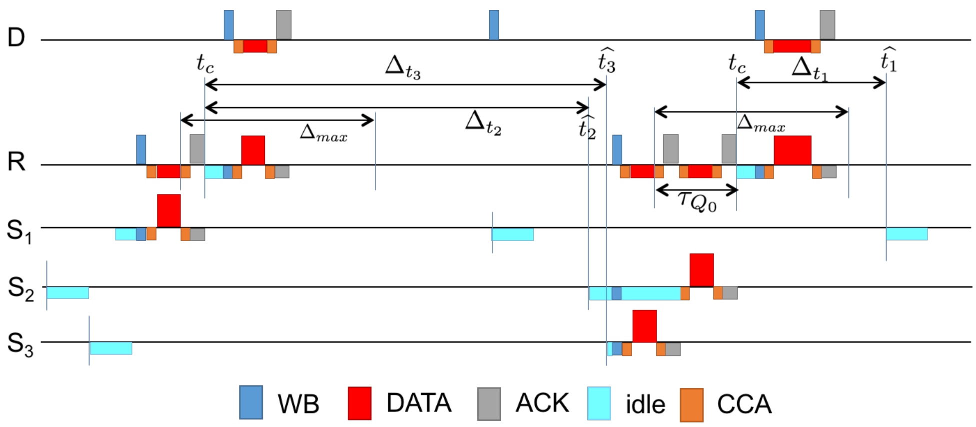

FIGURE 5.5: Solution of wasted delay time in Dynamic Decision Aggregation mechanism.

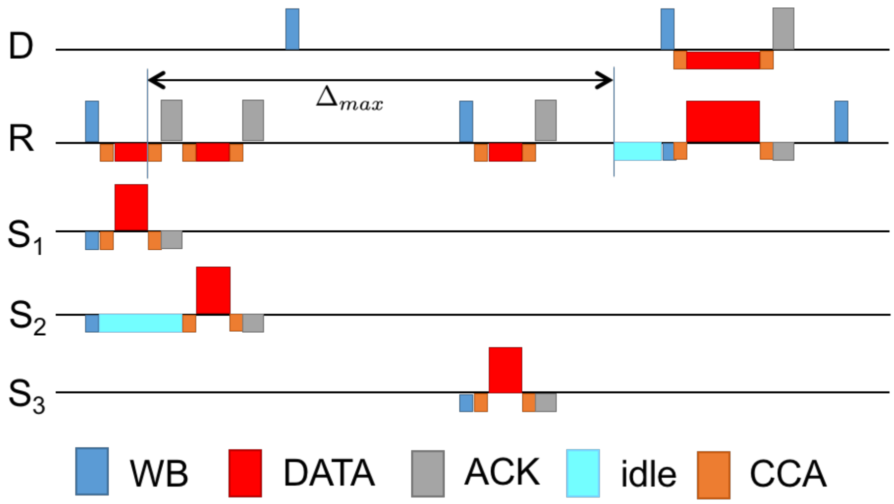

Figure 5.6: Basic behavior of RICER with Fixed Aggregation.

Bibliography

[1] En yi A. Lin and Jan M. Rabaey. Power-efficient rendez-vous schemes for dense wireless sensor networks. In *Proceedings of the 11th IEEE International Conference on Communications (ICC)*, pages 3769–3776, June 2004.

[2] Nguyen Van Thiep, Matthieu Gautier, and Oliver Berder. FTA-MAC: Fast Traffic Adaptive energy efficient MAC protocol for Wireless Sensor Networks. In *Proceedings of the 11th International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM 2016)*, pages 207–219, May 2016. ISBN 978-3-319-40352-6. doi: 10.1007/978-3-319-40352-6_17.

[3] Muhammad Mahtab Alam, Olivier Berder, Daniel Menard, and Olivier Sentieys. TAD-MAC: Traffic-Aware Dynamic MAC Protocol for Wireless Body Area Sensor Networks. *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, 2(1):109–119, 2012. doi: http://dx.doi.org/10.1109/JETCAS.2012.2187243.