# EDMAS -A Latency Minimization Protocol with Low Ducy-Cycle for Wireless Sensor Networks

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***Abstract***

*Energy conservation can be the most important concern in the deployment of wireless sensor networks. Among all methods, finding an efficient sleep/transmission schedule must be most effective to achieve energy conservation. There are many researches and solutions for sleep schedule, transmission schedule, or topology/routing creation in the past. Nevertheless, almost none of them can solve all of these problems in the same time. Our prior DMAS protocol could be the first cross-layer protocol that can solve all these problems simultaneously in a distributed way with very low duty cycle. This paper presents the DMAS protocol and an enhanced version of it named EDMAS. The enhancements of EDMAS over DMAS include significant reductions in transmission latency, packet collision probability, and duty cycle.*

***Keywords****: Wireless Sensor Network, MAC Protocol, Transmission Schedule, Latency Minimization, Energy Conservation*

## 1. Introduction

Because wireless sensor networks (WSNs) devices are usually cheep and limited in processing power and energy, and they are self-organized in a distributed and ad hoc manner, low energy consumption, low transmission latency, scalability, and fault-tolerant are all important concerns for WSNs. It is also a general demand that the networks could dynamically adapt its topology (when nodes join/leave the network), and could find suitable transmission paths in such environments. Many of WSN applications are for emergency alerting, so minimization of transmission latency is usually an important requirement of WSNs.

All these requirements are very rigorous challenges for WSN devices that have only simple hardware and limited energy, so protocols for them must be extremely simple and extending the operating life time of them is always the most important concern in designing WSNs.

Since WSNs are usually close systems and are deployed in relatively smaller regions, layering the network functionalities in the way like the ordinary networks could not be suitable for them. Suitable integration of these functionalities is very likely to get a better and simpler solution for WSNs.

The most effective methods to solve energy conservation problems should be applying appropriate sleep schedule and transmission schedule. By this way, sensor devices can perform sensing and transmit/receive messages at the short scheduled time, and change to sleep state in the rest of the time.

There have been lots of researches dealing with sleep or transmission schedule. However, almost none of them have incorporate topology creation and routing problems into their solutions. These problems are usually excluded as pre-processed problems. It could be possible to solve these problems in one stage and obtain a much more light-weighted solution.

There have been many researches for the problems of WSNs. For example, S-MAC [1], WiseMAC [2], DSMAC [3] deal mainly with the sleep schedule problem, and DMAC [4], Flexi-TP [5], ISOMAC [6], LEMMA [7] are for transmission time scheduling to conserve energy and avoid collisions. Among them, only Flexi-TP gives total solution in two stage for topology creation and transmission schedule. However, the overheads of Flexi-TP in creating the topology are very weighty.

Our previous solution named DMAS [8] should be the first method that can solve, in the same time, the sleep and transmission scheduling, topology creation/adaptation, routing, and transmission latency minimization problems. The properties of DMAS can include: (1) It is very simple, so it consumes only very little of the processing power; (2) Its duty cycle can be reduced to the level of 2% or below; (3) It could easily adapt its topology and establish new routing paths when sensor nodes join/leave the networks. Although DMAS has many advantages, there is still much possible space for improvement in transmission latency. In this paper, we propose a new super-frame structure with which the transmission latency could be minimized to a very low level.

The rest of paper is organized as follows: Section 2 presents the related works about sleep/transmission scheduling. The details of EDMAS are explained in section 3. Section 4 presents the analysis and experimental results for EDMAS, and section 5 concludes this paper.

## 2. Related Works

For WSNs, contention-free and distributed approaches are preferred because contentions among sensor nodes could introduce many collisions, idle-listening, and overhearing, and centralized approaches may introduce lots of control packet overheads for the central processors to collect information about the entire networks. If we can avoid the synchronization problem and make transmission schedule in distributed ways, TDMA could be the best approach for WSN MAC design. For this reason, we will survey only previous TDMA protocols in this section, and ignore CSMA protocols like S-MAC, WiseMAC, and DSMAC etc.

DMAC [4] assumes that a network is organized as a cascading data gathering tree. It can achieve very good latency. However, DMAC excludes the tree topology creation problem and assumes that it is pre-processed. FlexiTP [5] is a more recent method applying centralized scheduling. Its functions can be divided into network setup phase and periodic data gathering phase. Advantages of FlexiTP may include good transmission latency, and energy efficiency in phase two. However, the overheads for network setup is extremely heavy and the schedules are fragile when nodes join/leave the network. LEMMA [7] is a distributed approach that uses a different type of super-frame to perform scheduling. Each node has to determine a transmission slot that can avoid the interference from its neighbors and cascade its packets to its parent in the most suitable time. The advantages of LEMMA are that it is distributed and it is relatively simple to other approaches. The disadvantages could be that it also excludes the topology creation problems and its transmission latency is still much longer than that of DMAC.

## 3. DMAS and EDMAS

Our previous MAC protocol is named “Distributed MAC with Asynchronous Superframe” (DMAS) [8]. In DMAS, sensor nodes operate according to a predefined periodic super-frame.

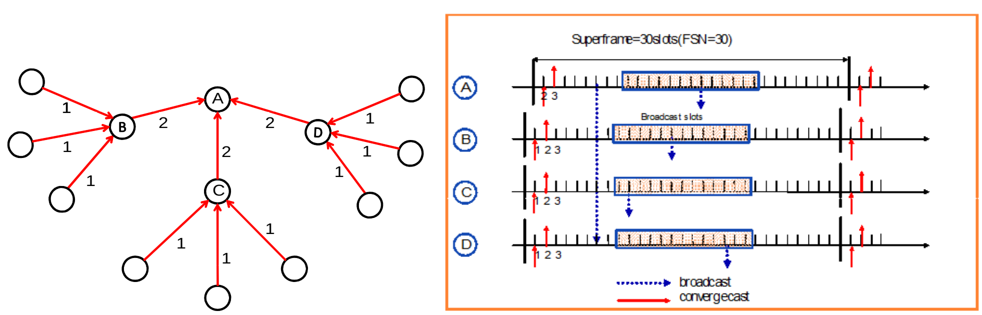
In the super-frame, the time for sensor node actions is pre-determined. So, a sensor node has only to determine the starting time of the super-frame. When it is done, the topology of the network and the routing paths are also determined. The starting time of the super-frame should be arranged in the way that the packet transmission time meets the receiving time of its parents. The topology of the network is constructed as trees. EDMAS which is the abbreviation of "Enhanced DMAS" redesigns the operations of DMAS and effectively minimize the transmission latency. The super-frames of nodes are not synchronized, that is, they are only local timers. The operations of other nodes are divided into two phases. The purpose of the first phase is for joining to the tree topology of the network. Once the node join to the topology, it changes to phase two immediately and begins the periodical data transmission/receiving.

In the first phase, each sensor arbitrarily wakes up for one slot, listens for broadcast packets and requests the sender to become its parent. When the request is accepted, the node will arrange a loose alignment of its super-frame to that of its parent so that it can interact with its parent in the proper time. The node has, from this time, joined the tree topology. If there are multiple sinks, the network can contain multiple trees. We can freely add any number of sinks in the network without any modification of the protocol.

After a node has joined the network, it transits immediately to the phase two. In the second phase, the sensors begin to perform sending/receiving according to the super-frame. A super-frame is a period of fixed length during which the time of sending converge-cast and broadcast, receiving converge-cast and broadcast is defined. The sensor node has to wake up only during the short actions, and goes to sleep in the rest of the time.

In this paper, slot time is denoted as ST, slot number in a super-frame is denoted as FSN. In general, FSN is set to 30. In addition, we also define a basic time unit of wake-up interval as active time (AT). Transmitting/receiving data use time of one or two AT, and it does not occupy the entire time slot.

Considering most WSN applications like fire alerting or pollution detection etc., the sensing events are sporadic. The regular and frequent traffic in DMAS is not necessary. For this reason, we propose a modified version of DMAS named EDMAS that deal with only sporadic sensing events. Because there are no frequent traffics in the network, the superframe is modified to contain only one converge-cast receiving slot. That is, the children of a node should share the same slot to send converge-cast packets. The children of a node should compete for the slot to send converge-cast packets. Because the traffic is sporadic, this competition seldom happens. When such a competition occurs, the random back-off mechanism is applied to minimize the probability of collisions.




(a) (b)

**Figure 1. Interactions of Super-frames for EDMAS**

The modified super-frame of EDMAS and the interactions among a parent and its children is illustrated in Figure 1. Figure 1(a) denotes the timing of the transmission schedule for EDMAS. We can see that the children of a node share the same time slot so they have to compete when there is traffic. The grandsons of the node also share another same slot. But because they are distributed more far away, there is not much probability of collision among them. By the cascading transmission the latency can be minimized.

To avoid collisions of broadcast messages, we let each node to choose a broadcast slot from a pool in the super-frame as that depicted in Figure 1(b). The chosen broadcast slot number should be also contained in the broadcast message because it is used by its children to calculate the super-frame beginning time. To reduce the load of the system, we reduce the frequency of broadcast packets to one packet per several super-frames. This further reduces the load of the network and the probability of collisions.

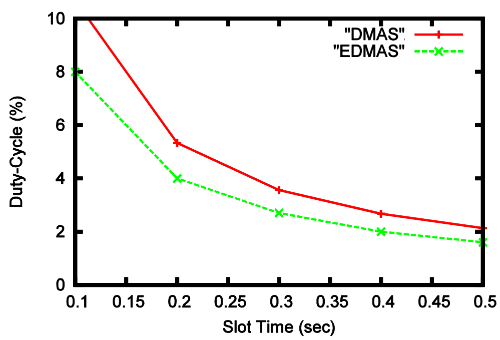



**Figure 2. Slot time vs. duty-cycle**

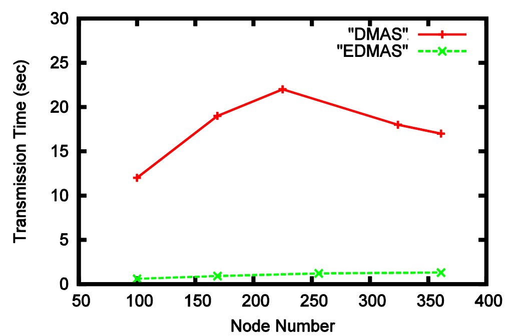



**Figure 3. Network size vs. Latency**

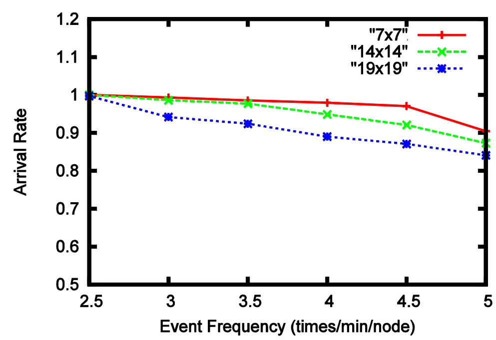



**Figure 4. Traffic load vs. arrival rate**

## 4. Experimental Analysis

The development and experiments of DMAS and EDMAS are completely utilized in the ns-2 simulation environment. In the following, we will illustrate the benefits of EDMAS by several experimental results.

If the system allow less frequent reports of the sensing data, we can apply a long super-frame duration to save energy. A larger FSN or longer ST leads to a longer super-rame. When we let FSN be 30 and let AT be 40ms, duty-cycle is directly related to the length of ST in EDMAS. Setting the length of ST from 0.1 to 0.5 second incrementally, the duty cycles of DMAS and EDMAS are depicted in Fig. 2. The duty-cycle can be as low as about 2% for a long slot time. It is also so clear that EDMAS can make about 20% of improvement over

DMAS.

In the following set of experiments, we analyse the mean transmission latency from a sensor node to the sink. The tested sensing areas are 1000m × 1000m, 1300m × 1300m, 1600m×1600m, and 1900m×1900m with 100, 169, 256, 361 nodes respectively in the areas. From Fig. 3 we can see that the transmission latency of EDMAS is all below 2 seconds, and it is much better than the DMAS protocols. The results show that EDMAS can minimize the transmission latency by the cascading transmission without delay between the stages.

For different applications, the required frequency of reporting event data may be very different. In this set of experiments, we test the packet arrival rates under traffic loads of different event frequency. The traffics are generated using different mean intervals with uniform distribution. Networks with different node numbers are also tested in these tests. Fig. 4 shows that the mean arrival rate approaches 100% when the traffic load is low. There will be slight degradation of the rate when the network size increase or when the traffic generation is more frequent.

## 5. Conclusions

From the discussions and the experimental results, we can summarize the benefits of DMAS and EDMAS as that it is simple and distributed, it can achieve very low duty-cycle, it can perform the cross-layer functions including routing and the sleep/transmission scheduling in the same time and it can minimize the transmission latency.

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