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Need of Introducing Adaptivity to MAC Protocols According to the Traffic Type in Wireless Sensor Networks

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Abstract—*Different protocols have been proposed in literature, in order to minimize the energy consumption. While minimizing energy consumption, all most, all these protocols also try to achieve high throughput and packet delivery ratio; and low end to end latency. All these protocols are for either of the two types of traffic scenarios, synchronous or asynchronous. There may be situations where the traffic pattern may change from synchronous to asynchronous or vice versa. This paper surveys a number of protocols and finds that none of the proposed protocols adapts itself for such kinds of changes.*

1. INTRODUCTION

WSN technology has gained importance due to its potential for supporting a wide range of applications such as military operations, industrial, surveillance, targeting systems, health needs, monitoring disaster areas and many others. Wireless sensor networks consist of a large number of distributed nodes which are usually deployed in such an environment where it is inconvenient or almost impossible to recharge or replace the power sources of these nodes. These nodes are supposed to be microelectronic devices, which are equipped with limited power sources. Thus, the lifetime of such types of networks strongly depends on the battery lifetime of the sensor nodes. Therefore, in order to extend the network life time as long as possible, it is required to adopt an efficient power management mechanism for these nodes with the aim of providing the best performance at less amount of energy consumption.

Two kinds of traffic patterns have been discussed in the scenario of wireless sensor networks- periodic traffic and aperiodic traffic. Periodic traffic pattern is that in which traffic is generated on regular intervals on each of the nodes, and the aperiodic traffic pattern is that in which traffic is generated irregularly and suddenly. Therefore two different kinds of MAC protocols are employed for two different kinds of traffics. As sleep scheduling is used to be an integral part of any wireless sensor network, the duty cycle of sleep schedules differs largely for two kinds of traffic patterns. In case of periodic traffic, nodes keep waking for a significant duration of time, at regular intervals, and keep sending data in this interval itself. On the other hand, in case of aperiodic traffic, nodes wake only for a small duration of time, and if no data is sensed, they go back to sleep for a long duration. However, if some data is sensed, they extend their wake period into the sleep duration, until the entire data is transmitted to the neighboring node.

A number of different protocols have been proposed, in literature, for both of these kinds of traffic patterns. Following section discusses about such protocols in some detail.

2. LITERATURE REVIEW

As outlined by [2], one of the most important constraints on sensor nodes is the low power consumption requirement. Therefore, while traditional networks aim to achieve high quality of service (QoS) provisions, sensor network protocols must focus primarily on power conservation. As mentioned by [4] a sensor node has a finite energy reserve supplied from a battery. It is often unfeasible to recharge the node's battery. Thus, the design of a wireless sensor network should be as energy efficient as possible.

Wei Y e et al in [5], while proposing their noble S-MAC protocol, specify that energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important. The authors have also pointed out the various causes of the energy waste and have proposed a virtual clustering based protocol to minimize it.

The main causes of the energy waste are 'idle listening, overhearing, collision and control overhead', as pointed out by [5] [6] [7].

Upadhyayula S. et al in [9], have proposed a heuristic solution for the problem of minimum energy convergecast which also works towards minimizing data latency. This algorithm constructs a tree using a greedy approach where new nodes are added to the tree such that weight on the branch to which it is added is less. The algorithm then allocates Direct Sequence Spread Spectrum or Frequency Hopping Spread Spectrum codes.

Dam Tijs van et al in [10], have proposed an adaptive energy efficient MAC protocol for Wireless Sensor Networks. The protocol is given the name T-MAC, and, is a contention based medium access protocol. This T-MAC is an enhanced version of the S-MAC [5], which adds adaptivity to the previous one according to the load, while preserving the virtual clustering feature of the previous one. As quoted by the authors, T-MAC introduces an adaptive duty cycle in a novel way: by dynamically ending the active part of it. This reduces the amount of energy wasted on idle listening, while still maintaining a reasonable throughput

Liu Yang et al in [11], have proposed an energy efficient QoS aware media access control protocol for wireless sensor networks, which minimizes the energy consumption in multi-hop wireless sensor networks (WSNs) and provides Quality of Service (QoS) by differentiating network services based on priority levels. The priority levels reflect application priority and the state of system resources, namely residual energy and queue occupancies.

Safwat Ahmed et al in [12], have proposed a cross layering approach for achieving energy efficiency. In terms of authors, only sleep scheduling cannot be used as a sole means of achieving energy efficiency, rather more of energy conservation can be attained by using cross layering approach in which valuable MAC and PHY layer inputs are passed to the network layer. The authors have proposed two schemes, namely, Energy Constrained Path Selection (ECPS) and Energy Efficient Load Assignment (E2LA), the objective of which is to enhance the operation of the existing power based multi path routing protocols via cross layer design and optimal load assignments.

Nam Yongsub et al in [13], have designed an adaptive MAC (A-MAC) protocol for those kind of wireless sensor networks which are required to survive for a pre- configured lifetime. In terms of authors the protocol has a two-fold concern: guaranteeing the pre-configured network lifetime, and reducing end-to-end latency. In order to achieve both goals, A-MAC introduces an adaptive duty cycle depending on ratio of the remaining energy to the initially supplied energy considering the pre-configured lifetime. The more energy a node has, the more frequently the node will wake up and hence fasten relaying data. As a consequence, each node is expected to run out of energy around the end of the pre-configured network lifetime. Also, nodes with more energy are utilized to reduce the end-to-end delay. Simulation results exhibit significantly lower latency of A-MAC while guaranteeing the pre-configured network lifetime.

Schurgers C. et al in [14], Gu Lin et al in [15] and Dhanaraj M. et al in [16] have taken a completely different approach to achieve energy efficiency. They have talked about using a different radio channel, called ‘wake-up radio’ to wake-up the sensor nodes, when some of the data is required to be transmitted to them. Such kinds of approaches do not require scheduling of nodes for sleeping and waking periods.

Gu Lin et al in [15], have pointed out that the wake-up/sleep scheduling approach has some disadvantages. First, the design of a good wake-up/sleep schedule is often application dependent and complicated. Hence, it is hard to design a general power management service based on wake-up/sleep scheduling. For each application, the designer needs to carefully analyze the timing of the system events and tune the scheduling parameters; otherwise some nodes in the network may miss wake-up calls. Second, a good wakeup/sleep schedule often involves collaboration among a group of nodes, or even all the nodes in the network. This often implies that the network needs a time synchronization service. With low-speed processors and radio communication links, to perform high-quality time synchronization in sensor networks is an even more challenging task than in traditional distributed systems. Finally, a common phenomenon is that, in most of the wake-up periods, no event happens and the nodes enter sleep mode again. This means that nodes wake up too often, and it is a waste of energy.

Dhanaraj M. et al in [16], have raised the point, that such dual channel energy efficiency protocols increase the latency encountered in setting up a multi-hop path. They have proposed in their paper, a reservation scheme based protocol, called Latency minimized Energy Efficient MAC protocol (LEEM), which is a novel hop-ahead reservation scheme in a dual frequency radio to minimize the latency in the multi-hop path data transmission by reserving the next hop’s channel a priori. Simulation results show that LEEM consumes lesser power and reduces end-to-end latency by around 50% than that of the existing schemes.

Data aggregation is one of the methods of achieving energy efficiency. One of the other methods of achieving low latency while achieving energy efficiency, are spanning tree based algorithms. Upadhyayula S. et al in [17], have talked of one such algorithm. The authors have combined the two spanning tree based algorithms, viz Minimum Spanning Tree (MST) algorithm and the Single Source Shortest Path Spanning Tree (SPT) algorithm to develop one combined algorithm (COM).

In [18], [19], [20] and [21] also, various spanning tree based data aggregation algorithms have been discussed. All these algorithms try to minimize energy consumption and end to end delay at the same time.

Tan Wee Lum et al in [22], have taken a completely different approach- ‘A Receiver-Driven MAC Protocol’. This Receiver-

Driven MAC Protocol, called RMAC, is a TDMA based MAC protocol in which the ownership of the timeslots is in the hands of the receiver nodes and here the receiver nodes assign the timeslots to their neighboring sender nodes. By doing so, the RMAC not only eliminates the need for the sender nodes to explicitly wake-up a receiver node for data transmission, but also eliminates any collision or contention overhead among the sender nodes.

Joohwan Kim et al in [24], have focused on the event-driven asynchronous sensor networks with low data rates. They have worked on minimizing the delay and maximizing the lifetime of such networks, for which events occur infrequently. In such systems, most of the energy is consumed when the radios are on, waiting for a packet to arrive. As said by the authors, sleep-wake scheduling is an effective mechanism to prolong the lifetime of these energy-constrained wireless sensor networks. However, sleep-wake scheduling could result in substantial delays because a transmitting node needs to wait for its next-hop relay node to wake up. An interesting line of work attempts to reduce these delays by developing “anycast”-based packet forwarding schemes, where each node opportunistically forwards a packet to the first neighboring node that wakes up among multiple candidate nodes.

Ammar Ibrahim et al in [25], have again picked S-MAC, one of the very initial protocols for wireless sensor networks and modified it for high traffic loads. As quoted by the authors, “S-MAC is a popular protocol designed specifically for WSNs with low duty cycle operation. At its inception, S-MAC has been designed for low traffic loads. In this paper, we propose an enhanced version of S-MAC, called PS-MAC, that shows to support comparatively higher traffic levels while achieving the better energy efficiency. This is achieved using the parallel transmission concept.” Thus the concept of parallel transmission is used in the proposed protocol by the authors.

Like Joohwan Kim et al in [24], Tan Hwee-Xian et al in [26] also, have focused on wireless sensor networks which are event driven i.e. which deal with asynchronous kind of traffic. As pointed by Joohwan Kim et al in [24], that the anycast is a good scheme of minimizing delay that occurs due to the sleep scheduling, Tan Hwee-Xian et al in [26] also have used anycast for minimizing delay in event driven wireless sensor networks. The protocol features independent and random wakeup schedules for each node; adaptive duty-cycles based on network topology; and adaptive anycast forwarders selection. All the other existent protocols do not individually vary the duty-cycle of each sensor according to local connectivity status, to maximize energy savings. The protocol, proposed by the authors of this paper, adds adaptivity, in the sense that the nodes can vary their duty cycles and forwarders’ set. Nodes vary their duty cycles and forwarders’ set in such a way that the energy consumption can be locally minimized for a given local delay performance objective. The proposed protocol also enhances the concept of cooperatively working in order to reduce the duty cycle of forwarding node. Both these mechanisms jointly result in better energy-latency tradeoffs and extended node’s lifetime.

Sun Yanjun et al in [28], have proposed a novel protocol, called DW-MAC, i.e. Demand Wakeup MAC protocol. This protocol also, is a modification of the basic S-MAC protocol [9]; or a variation of the T-MAC protocol [10]. Both the T-MAC and the DW-MAC, add adaptivity to the novel S-MAC protocol, in terms of varying duty cycle for varying traffic. Though both have the same purpose, they differ in their mechanisms; and because of this difference the T-MAC where trades off maximum throughput for low energy consumption in case of low traffic, the DW-MAC increases effective channel capacity. Because of this increased capacity the DW-MAC achieves low delivery latency under a wide range of traffic loads including both unicast and broadcast traffic.

Lei Tang et al in [29], have found a new way of minimizing energy consumption. It is by predicting the receiver’s wake up time. The protocol proposed, is named as Predictive Wakeup (PW) MAC protocol. The usability of the proposed protocol is, in the networks with asynchronous kind of traffics. The authors of the literature have also proposed an on-demand prediction error correction mechanism that effectively addresses timing challenges, such as unpredictable hardware and operating system delays and clock drift in order to enable accurate predictions. The authors have also introduced an efficient prediction-based retransmission mechanism, under the same protocol in order to achieve high energy efficiency even when wireless collisions occur and packets must be retransmitted.

Lei Tang et al in [30], have proposed a multichannel scheme for achieving energy efficiency. Named as EM (Efficient Multichannel) MAC, the protocol addresses many of the challenges faced by wireless sensor networks, such as wireless interference or even possible wireless jamming attacks. The protocol addresses these challenges through the introduction of novel mechanisms for adaptive receiver-initiated multichannel rendezvous and predictive wake-up scheduling. EM-MAC substantially enhances wireless channel utilization and transmission efficiency while resisting wireless interference and jamming by enabling every node to dynamically optimize the selection of wireless channels it utilizes based on the channel conditions it senses, without use of any reserved control channel. EM-MAC achieves high energy efficiency by enabling a sender to predict the receiver’s wake-up channel and wake-up time.

3. COMPARISON

Review of literature as in above section shows that a number of different protocols have been proposed for both kinds of traffics. Following table lists all the kinds of protocols as viewed in literature in a comparative way.

Table 3.1: Comparison of various protocols

S. No.	Type of Protocol	Examples
1.	Tree based protocols	As proposed by [9]
2.	Adaptive protocols	T-MAC [10], Q-MAC[11], A-MAC[13], DW-MAC [28]
3.	Cross layering approach based protocols	As proposed by [12]
4.	Dual or Multi–channel protocols	As proposed by [14], [15], [16], [30]
5.	Data aggregation based protocols	As proposed by [17], [18], [19], [20], [21]
6.	Receiver Driven Protocols	RMAC [22]
7.	Event Driven Protocols	As proposed by [24], [26], [29]

All the adaptive protocols vary their duty cycles as per the desired goal. Such as T-MAC varies, its duty cycle according to the traffic load. For heavy traffics, it increases its wake period and for low traffics it shortens it. The Q-MAC varies its duty cycle according to the type of service required. The A-MAC adds adaptivity to the duty cycle according to the residual energy. DW-MAC adds adaptivity according to the traffic load, like T-MAC, but in a different way to achieve throughput efficiency as well, that T-MAC lacks.

But, it is well to notice, as mentioned by Gu Lin et al in [15] that the design of a good wake-up/sleep schedule is often application dependent and complicated. Hence, it is hard to design a general power management service based on wake-up/sleep scheduling. For each application, the designer needs to carefully analyze the timing of the system events and tune the scheduling parameters; otherwise some nodes in the network may miss wake-up calls.

4. CONCLUSION

In view of the remarks made by Gu Lin et al in [15], this paper emphasizes on the need of application specific MAC protocols for wireless sensor networks. Requirement of adaptivity is another demand of these MAC protocols. All the adaptive protocols discussed above, vary their duty cycles according to the traffic loads, residual energy or other QoS requirements. None of the protocols (up to the knowledge of the author) consider the application or the scenario in which the wireless sensor network is laid.

When considering the application or taking scenario into the consideration, there may be applications in which scenario changes. A number of such examples exist in real world in which the scenario or the need of the application changes. Such changes demand a change in the basic behavior of the protocol, running on the sensor nodes. All the adaptive protocols designed so far do not change their pattern; rather they work only with minimizing or maximizing duty cycles.

Therefore, while considering such applications, there exists a need of designing an adaptive protocol that changes its behavior according to the kind of traffic pattern. It is also required from the protocols come to their original form after completing their work, i.e. the adaptivity introduced, need to be bidirectional.

This has been aim of this survey to bring this need into focus and attract the attention of the society towards this requirement.

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