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Medium Access Control Protocols for Wireless Sensor Networks Classifications and Cross-Layering

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Abstract

Wireless Sensor Networks (WSNs) have become a leading solution in many important applications such as intrusion detection, target tracking, industrial automation, smart building and so on. The sensor nodes are generally unattended after their deployment in hazardous, hostile or remote areas. These nodes have to work with their limited and non replenish able energy resources. Energy efficiency is one of the main design objectives for these sensor networks. Medium Access Control MAC sub-layer is part of Data Link layer in WSN's protocol stack. The energy consumption of sensor nodes is greatly affected by MAC protocol which controls the node radio functionalities. In this paper, the design requirements of energy efficient MAC protocols for WSNs are reviewed and classified. Several MAC protocols for the WSNs are described emphasizing their strength and weakness. Also, the paper introduces cross-layer protocols as a concept that leads to benefit from the network resources as well as prolonging network lifetime. The paper is appended by comparison between existing protocols regarding protocol's type, cross-layer support, and MAC scheduling. Finally, future research directions in the MAC protocol design are proposed.

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Keywords: Medium Access Control (MAC) Protocols; Wireless Sensor Networks (WSN); Cross-Layering;

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1. Introduction

Here Improvements in hardware technology have resulted in low-cost sensor nodes, which are composed of single chip embedded with memory, processor, and transceiver. Low-power capacities lead to limited coverage and communication range for sensor nodes compared to other mobile devices. Hence, for example, in target tracking and border surveillance applications, sensor networks must include a large number of nodes in order to cover the target area successfully.

Unlike other wireless networks, it is generally difficult or impractical to charge/replace exhausted batteries. That is why the primary objective in wireless sensor networks design is maximizing node/network lifetime, leaving the other performance metrics as secondary objectives. Since the communication of sensor nodes will be more energy consuming than their computation, it is a primary concern to minimize communication while achieving the desired network operation.

However, the medium-access decision within a dense network composed of nodes with low duty-cycles is a challenging problem that must be solved in an energy-efficient manner. Keeping this in mind, we first emphasize the peculiar features of sensor networks in section 2, including reasons for potential energy waste at medium-access communication. The state of the art will be described in section 3 including an extensive survey on existing protocols. Moreover, the survey of MAC protocols is concluded with a comparison of investigated protocols. Section 4 will identify a number of open research issues, before the paper is concluded in section 5.

2. MAC-Layer-Related Sensor Network Properties

The MAC sub-layer is a part of the data link layer specified in the communication protocol stack and is shown in Figure 1. It provides the channel access mechanism to several medium sharing devices. On a wireless medium, which is shared by multiple devices and is broadcast in nature, when one device transmits, every other device in the transmission range receives its transmission. This could lead to an interference and collision of the frames when a transmission from two or more devices arrives at one point simultaneously. Sensor nodes usually communicate via multi-hop paths over the wireless medium in a scattered, dense, and rough sensor field. A MAC protocol manages the communication traffic on a shared medium and creates a basic network infrastructure for sensor nodes to communicate with each other. Thus it provides a self-organizing capability to nodes and tries to enforce the singularity in the network by letting the sender and receiver communicate with each other in a collision and error-free fashion.

Moreover, the typical requirements to increase lifetime of a WSN without the need of any power replacement and/or human interaction has prompted the development of novel protocols in all layers of the communication stack. However, prime gains can be achieved at the data link layer, where the MAC protocol directly controls the activities of the radio, which is the most power consuming component of resource-scarce sensor nodes. Efficient MAC protocols utilize the radio judiciously to conserve its energy. Thus the MAC protocol helps fulfilling important design objectives of WSNs by specifying how nodes employ the radio, share the channel, avoid collision in correlated and broadcasting environments, response the inquirer timely, and survive for a longer period. Hence, designing novel solutions for MAC protocols for WSNs has been and will remain a focal point for many researchers.

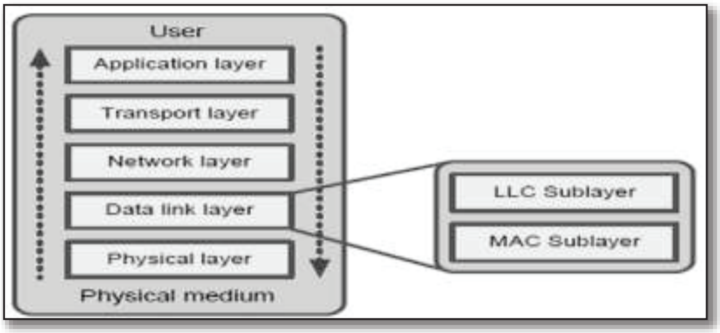

Figure 1: The Communication Protocol Stack. This five-layered simplified model is commonly applied to network research as apposite to the seven-layered OSI model. An end-user can use application specific software/algorithms at the application layer. The transport layer helps maintaining the sensor data flow. The network layer routes data on an appropriate path. The LLC sub-layer of the data link layer provides framing, flow control, error control, and link management facilities, whereas the MAC sub-layer manages collisions and helps in energy aware operations of sensor nodes. The physical layer takes care of the radio, channel, modulation, transmission, and reception of bits on a physical medium.

At the same time, a MAC protocol can be made accountable for the following sources of energy waste in WSNs, which mainly relate to the communication.

- Idle listening: Since a node in a WSN usually does not know when it will be the receiver of a message, it keeps its radio in ready-to-receive mode, which consumes almost as much energy as in receive mode. In low traffic applications, this is considered one of the major sources of energy waste. Note that carrier sensing, which a MAC protocol requires to sense the current status of the channel, is not a part of idle listening.
- Collisions: A collision is a wasted effort when two frames collide with each other and are discarded because the receiver has to drop the overlapped information [1]. A collision usually results in retransmission and drains more energy in transmitting and receiving extra packets. The half duplex nature of the wireless medium precludes collision detection, thereby increasing the responsibilities of the MAC protocol. The high density of the deployed nodes, on one hand, helps improving network connectivity without compromising the transmission power. However, on the other hand, it increases collision probability for the MAC protocol by increasing the number of nodes contending for the channel.
- Overhearing: An overhearing occurs on the wireless broadcast medium when the node receives and processes a gratuitous packet that is not addressed to it. In the dense network and under heavy traffic situations, this could lead to a serious problem.
- Control packet overhead: An increase in the number and size of control packets results in overhead and unnecessary energy waste for WSNs, especially when only a few bytes of real data are transmitted in each message. Such control signals also decrease the channel capacity. A balanced approach is required so that the required number of control packets can be kept at minimal.
- Over-emitting: An over-emitting or a deafness occurs due to the transmission of the message when the destination node is not ready to receive it.
- Complexity: Computationally expensive algorithms might decrease the time the node spends in the sleep mode. They might limit the processing time available for the application and other functionalities of the protocol. An overly simple MAC algorithm can save higher energy than a complex one, but it may not be able to provide the complex functions such as adaptation to traffic and topology conditions, clustering, or data aggregation.

However, MAC protocols are vulnerable to other problems such as hidden and exposed terminal problems [2]. The hidden terminal problem is illustrated in Figure 2 as,; node A sends to node B, while node C cannot receive from A.

Node C wants to send to B, C senses a "free" medium. This will make collision at B, since A cannot receive the collision which means that node A is "hidden" for C.

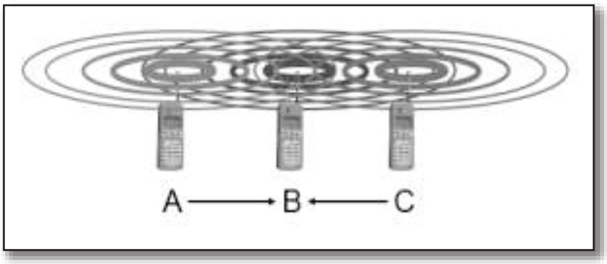

Figure 2: Hidden Terminal Problem.

Figure 3 shows another problem as the Exposed Terminal Problem. In the meantime, node B sends to node A, and node C wants to send to node D. In this case, node C has to wait (medium in use). Since A is outside the radio range of C and the waiting is not necessary which mean that node C is "exposed" to node B.

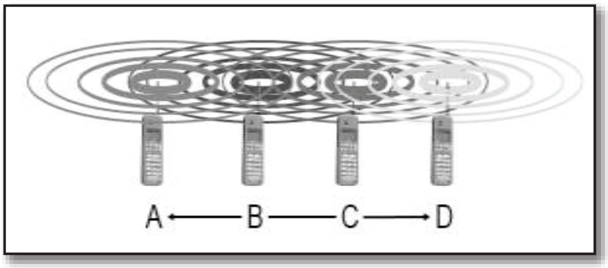

Figure 3: Exposed Terminal Problem.

3. State of the Art

WSN MAC protocols were widely investigated during the last decades. In this section we discuss the main results for MAC and for cross-layer protocols which developed to enhance energy and network lifetime. As a summary of the individual characteristics of the protocols mentioned in the next sub-section, table I at the end represents comparative summary.

3.1. Medium Access Control Protocols

Medium Access Control (MAC) protocol has a frame format which is used to provide the data link layer of the Ethernet LAN system to control access over the communication channel. In general, well-known MAC protocols include Ethernet [3] and MAC is used in the IEEE 802.11 (Wi-Fi) family [4]. However, there are several various types of MACs have been developed for WSNs. This subsection discusses the various types of MAC protocols by categorizing them in different channel accessing classes, but before , we would explicate brief history about channel accessing schemes, as follows:

3.1.1. Channel Accessing Chronology

The nature collision in wireless broadcast medium requires an efficient channel accessing method to control access to the shard medium. Therefore, this collision can be offer free communication among nodes. Specifically, accessing the channel is classified into two major categorizations; contention based networks and contention free networks. In contention based networks, devices are contending each other to gain access of the channel. Whereby, contention free networks uses time or frequency to schedule the channel. In this category, devices can only access their allocated channel slots, and these devices communicate with the central node in a collision free method.

In the other hand, accessing channel scenarios have been already proposed to find the answer of who is allowed to access and how can access. However, the Additive Link On-Line Hawaii System (ALOHA) protocol [5] is proposed in 1970s and also defined as pure ALOHA. This protocol is considered as one of the pioneer protocols in this category. It allows devices' data to be transmitted immediately when they have data to send. ALOHA is a simple and decentralized MAC protocol works seamlessly under low loads, likewise the maximum channel utilization in ALOHA is only 18.4%[5]. In ALOHA, the slotted ALOHA is used to double ALOHA utilization by subdividing the time into slots. In this case, collisions can occur only at the beginning of the slot, since the node is allowed to start a transmission only at the beginning of a slot. However, slotted-ALOHA reduces the collisions probability by doing synchronization among nodes.

Commonly, the Carrier Sense Multiple Access (CSMA) scheme is used in wired and wireless Local Area Networks (LANs). CSMA can capably sense the transmission of other nodes before starting a node its transmission. Therefore, CSMA is considered as a contention based access protocol, as well as it is simple, flexible and robust especially for the dynamic networks topology. However, this scheme is still suffering from serious energy waste, high overhead and throughput degradation on the already resource constrained sensor nodes which are caused by the additional collisions[6]. Moreover, the distributed interfering sensor scheduling (DSS) algorithm proposed in [7] is based on CSMA. This algorithm requires frequently negotiation between the sensor nodes to decide the node tasks and the results in high energy consumption.

In CSMA-CA scheme, Collision Avoidance CA is introduced among other approaches to minimize the impact of the hidden and exposed terminal problems. However, CSMA-CA introduces four-way handshake mechanism to achieve successful communication between sender and receiver. On the other hand, IEEE 802.11 is also considered as a conventional MAC protocol [4].

Having gone through the basic medium access mechanisms in this study, we now turn our focus on the MAC approaches and protocols that have specifically been designed for WSNs. Therefore, the following subsection shows the main classifications of WSN based MAC protocol as follows:

3.1.2. Classification of WSN MAC Protocols

Several MAC protocols have been successfully proposed to meet the stringent design requirements of WSNs. Actually; these protocols depend on how protocol allows nodes to access the channel. We have classified WSN based MAC protocol as depicted in Figure 4 into four categories as; contention based, scheduling based, channel polling based, and hybrid protocols.

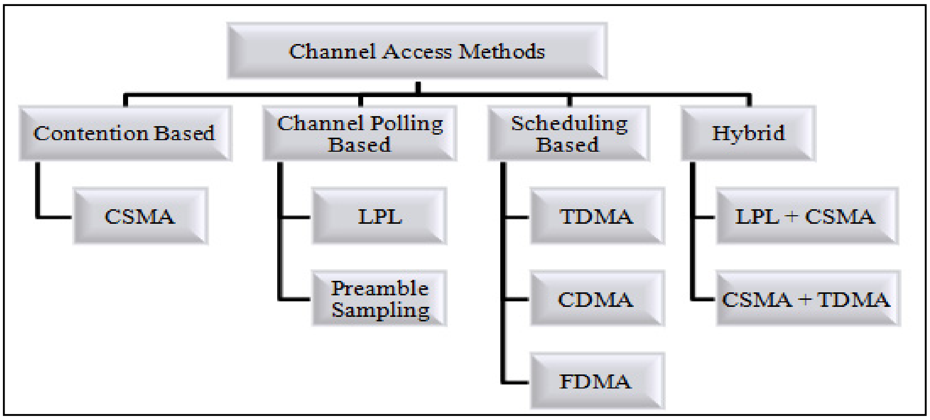

Figure 4: Channel Accessing Taxonomy in WSNs.

3.1.2.1. Contention Based MAC Protocols

As mentioned earlier, nodes using contention based schemes are working on acquiring the channel. Hence, the network node competes with its neighbours to get the channel. This process will be done when the node senses the carrier before getting start with data transmission. If the carrier is set up as idle, then node will start its transmission, otherwise node will defer the transmission for some time randomly. This deferring is usually determined by a back-off algorithm. Event-driven WSN applications use contention based MAC protocols to reduce the processing resources consumption. However, contention based MAC protocols are flexible and dynamics to network scales.

Since, clustering and/or topology information are not required for their works. Hereby, each node in the network can independently decide for contention without controlling the frame exchanges. In this case, the transmission is purely handled by sender, as well as the problems of hidden and exposed terminals may occur causing collisions, overhearing, idle listening, and less throughput in the result.

There are several MAC protocols consider the contention times of nodes are synchronized according to a schedule, i.e., at each periodic interval, all neighbouring nodes wake up simultaneously to exchange packets between them. However, this study shows some representative protocols in [8,9,10, 11].

3.1.2.2. Channel Polling Based MAC Protocols

Channel polling scheme is known as a preamble sampling and Low Power Listening (LPL). Moreover, sending prefixes data packets with extra bytes by node is called preamble. Specifically, node sends the preamble over the channel to ensure that the destination node detects the radio activity and wakes up before receiving the actual payload from the sender. On a wake-up, if a radio activity is detected by receiver, then the receiver will turn on its radio to receive data packets. Otherwise, the node (receiver) goes back to the sleep mode until the next polling interval. This checking should be performed as long as the check interval duration until the preamble is being sent [7].

On other hand, since the common active/sleep schedules are not performed in channel polling based protocols, then the synchronization, scheduling, or clustering among nodes are not needed.

As proposed in [12], the combination of ALOHA with the preamble sampling is considered as the pioneer and typical example of the extended preamble based channel polling scheme. Also, the channel polling scheme has been renamed as the LPL in the Berkeley MAC (BMAC) protocol[13].

3.1.2.3. Scheduling Based MAC Protocols

During the initialization phase, scheduling based schemes assign collision-free links between neighbouring nodes. However, links may be allocated as frequency division multiplexing (FDM) bands, time division multiplexing (TDM) slots, or code division multiple access (CDMA) based spread spectrum codes. Due to the complexities that incurred with FDMA and CDMA schemes, therefore, WSNs prefer TDMA schemes as scheduling methods to reduce the incurred complexity[6]. In TDMA schemes, the system time is divided into slots. These slots are then assigned to all the neighbouring nodes. However, the schedule controls the participant authorization on the resources with regular time. The schedule is typically regulated by a central authority; as well it can be fixed or computed on demand (or a hybrid). On other hand, a node does not need any contention with its neighbours, since it can only access its allocated time slot.

Likewise, the minimum collisions, the less overhearing, and the implicitly avoidance of idle listening are all grouped as the main advantages of scheduling based schemes. Whereby, scheduling based schemes also provide a bounded and predictable end-to-end delay. The average queuing delay is normally high, since the node should wait for its allocated time slot before accessing the channel. However, there are other major concerns with these schemes such as; Overhead and extra traffic, lacking of adaptability, reduced scalability, and low throughput. In scheduling based schemes, allocating conflict-free TDMA schedules is really difficult task. A peer-to-peer based communication is also impossible with scheduling based schemes. Since the nodes are normally allowed to communicate only with the central authority.

However, TDMA- based MAC protocols has attracted attentions of sensor network researchers. This study depicts some of the representative protocols of this category.

As proposed in [14] some numerous design of wireless MAC protocols based on time division multiplexing have been suggested, while some of them need global topology information that may not be scalable for very large-size networks [15,16]. However, many distributed slot assignment schemes have been proposed, such as; DRAND [17], PACT[18], and TRAMA[19] to overcome the difficulty of obtaining global topology information in the large networks. Additionally, the depth first search (DFS) scheme[15], the green conflict free (GCF), and the multicolor-GCF (M-GCF) algorithms [20] obtain local topology and interference information at each node. These approaches compose schedules by exchanging messages between local nodes within a certain range (i.e., the interference range). However, comparing the distributed scheduling with the approaches demanding global topology information is highlighting that the distributed scheduling is more flexible, but the cost is increased according to the schedule length[14].

Flow-Aware Medium Access (FLAMA) [21] is a TDMA - MAC protocol derived from TRAMA, and optimized for periodic monitoring applications. The main idea in FLAMA is to avoid the overhead that associated to the exchange of traffic information. As the message flow in periodic reporting applications is rather stable, FLAMA sets up flows firstly and then uses a pull-based mechanism, so that data is transferred only after being explicitly requested.

Meanwhile, classical slot reservation algorithms tend to be complex and not flexible. Therefore, some researchers have been proposed successfully to investigate simpler schemes which simultaneously aim to achieve good energy efficiency. For example, a low-complexity slot selection mechanism is adopted in[22], whereby a lightweight medium access protocol (LMAC) is already proposed. Mainly, LMAC aims to reduce the radio state transitions and the protocol overhead. To achieve this aim, data is not acknowledged in LMAC, as well the actual slot assignment is based on a binary mask of occupied slot and a random selection among free ones. However, the main drawback of LMAC is based on the fixed length of the frame, which has to be specified prior to deployment, and may be problematic. To this end, authors in [23] proposed an Adaptive Information-centric LMAC (AILMAC), so the slot assignment can be more tailored to the actual traffic needs.

Authors in [24] have proposed protocol to show the joint inter-connect the maximum throughput and the fair rate allocation in a WSN with full consideration for the slot reuse based TDMA.

3.1.2.4. Hybrid MAC Protocols

In order to achieve a joint improvement, hybrid MAC protocols combine the strengths of two or more different MAC schemes. Usually, hybrid MAC protocols combine a synchronized scheme with an asynchronous scheme. Though hybrid protocols cumulative the advantages of multiple schemes, they can also carry, scaling and complexity problems in maintaining two or more different working modes. However, Zebra MAC (Z-MAC) [25] protocol is one of the most important example in hybrid scheme, which combines the strengths of TDMA and CSMA while offsetting their weaknesses. As well as, the Scheduled Channel Polling MAC (SCP-MAC) [26] and Funneling-MAC protocol[27] are also two important examples on this scheme.

3.2. Cross-layer Protocols

As proposed in [15,16,17,18,19,21,22,23] these studies focus basically on MAC layer. However, working with single layer may lead to inefficient utilization of network resources. Recently, the camping between cross-layer design approach and TDMA scheduling is to obtain prolonged network lifetime. In[28], joint routing, link scheduling, and power control are strongly considered to support high data rate for broadband wireless multi-hop networks. A framework for cross-layer design toward energy-efficient communication is presented in [29]. Authors in[29] address the joint link scheduling and the power control with the objective of energy efficiency subject to quality of service (QoS) guarantees in terms of bandwidth and bit error rate (BER). However, a heuristic solution is proposed in Interference-free TDMA schedules are calculated in[30] for a small-scale network by joining the optimization of the physical, MAC, and the network layers. The authors also use convex optimization to solve the cross-layer-based network lifetime optimization problem, in addition to employ the interior point method [31]. On the other hand, a single frame without slot reuse for the whole network is to guarantee non-interference. However, this also leads to significant end-to-end delay, which makes this approach unsuitable for large-size WSNs. In [32], authors consider both of the joint layer optimization and the slot reuse to derive energy-efficient schedules. A convex cross-layer optimization model is proposed and solved iteratively to maximize the network lifetime. The link schedules evolve at each iteration until reaching the specific energy consumption goal or the iteration is performed with no more optimal solution.

Unifying sensornet protocol (SP) in [33] is proposed to provide shared neighbour management and a message pool. This protocol runs on a single link layer technology over a broad range of devices, it supports a variety of network protocols while not losing efficiency. The unified SP allows network level protocols to choose their neighbours wisely based on the available information that in the link layer. Moreover, this abstraction layer promotes the cooperation across the link and network layers that are to utilize the limited resource efficiently. This protocol can be professionally used in some experiments were carried out using two types of radio technology; IEEE 802.15.4 on Telos and B-MAC on micas. However, the determined measurements from these implemented protocols show that performance is not sacrificed with the SP abstraction. In addition, there are some benefits in using a common link abstraction.

The usage of on-off schedules in a cross-layer routing and MAC framework is also investigated in [34]. A TDMA-based MAC scheme is devised [34], where nodes select their appropriate time slots based on local topology information. The routing protocol also exploits the local topology information for routing establishment. In [34], authors support the usage of cross-layer interaction through comparative simulations with a strict layered approach.

In terms of energy and network lifetime, EYES MAC protocol was compared against the sensor-MAC (SMAC) [35], as EYES MAC protocol was also compared against the dynamic source routing (DSR) [36]. However, EYES MAC protocol outperforms SMAC and DSR when nodes are network based mobile system. In a mobile network, there may be regular updates on routing system due to route breakage. EYES MAC protocol minimizes the overhead in routing and re-establishment the route by utilizing the information from the MAC protocol. Whereby, SMAC and DSR perform better when nodes are static as well when the routes are established only once.

The researchers in [37] present the objectives of MAC/Physical layer integration and Routing/MAC/Physical layer integration. They propose a variable length TDMA scheme where the slot length is assigned to some optimum energy consumption criteria in the network. Among these criteria, the most crucial ones are information about the traffic generated by each node and distances between each nodes pair. Based on these values, the researchers in [37] formulate a Linear Programming (LP) problem where the decision variables are normalized time slot lengths between nodes. In general, it is really hard to have the node distance information and the traffic generated by the nodes themselves. LP solver could only be run on a powerful node. However, online decisions are required for the dynamic behaviours of sensor networks, whereby, these decisions are very costly in terms of calculation and hard to be adapted in an existing system.

The unified cross-layer protocol [38] combines the functionalities of the transport, network and medium access protocols into a single module. Although, the unified cross-layer module (XLM) achieves energy efficiency and reliable event communication, simulation results show that XLM outperforms the tradition layered protocol in network performance and communication efficiency.

Authors in [39] address three main issues which are: a cross-layer optimization problem of joint design of routing, medium access control (MAC), and physical layer protocols with cooperative communication. The aim of [39] is majored to achieve the minimum power cost under a specified per-hop packet error rate (PER) objective in wireless sensor networks.

However, TDMA MAC protocol is based upon cross-layer optimization, Physical layers and MAC [14]. The main goal in TDMA MAC protocol is to reduce the energy consumption. It proposes an algorithm for deriving the TDMA schedules by utilizing the slot reuse concept to achieve the minimum TDMA frame length.

CL-MAC protocol [40] is a novel cross-layer MAC protocol. Significantly, it is different from other MAC protocols since it is supporting construction of multi-hop flows. Moreover, all pending packets in the routing layer buffer and all flow setup requests from neighbours are in the CL-MAC considerations, which will be occurred when setting up a flow in CL-MAC. This consideration allows CL-MAC to make more informed scheduling decisions, reflecting the current network status, and optimizing its scheduling mechanism dynamically.

In [41], a cross- layer routing protocol (PLOSA) is designed to offer a high delivery rate, a low end-to-end delay and a low energy consumption. To achieve these goals, the transmission channel is divided into different slots and a sensor has access to a slot related to its distance from the collector. The transmissions are then ordered within the frame from the farthest nodes to the closest ones which is a key point in order to ease forwarding and to conserve energy.

Authors in [42] proposed a cross-layer optimized geographic node-disjoint multipath routing algorithm, that is, two phase geographic greedy forwarding plus. To optimize the system as a whole, their algorithm is designed on the basis of multiple layers' interactions, taking into account the following: physical layer, sleep scheduling layer and routing layer.

In this context authors proposed cross layers protocol in [43], based on the combined use of a duty-cycling protocol and a new kind of active wake-up circuit, based on a very-low-consumption radio frequency (RF).

Authors in [44] investigate the problem of transmission power minimization and network lifetime maximization using cooperative diversity for wireless sensor networks, under the constraint of a target end-to-end transmission reliability and a given transmission rate. By utilizing a cross-layer optimization scheme, distributive algorithms which jointly consider routing, relay selection, and power allocation strategies are proposed for the reliability constraint wireless sensor networks.

Table 1 below represents comparison between different proposed protocols mentioned earlier. The comparison is based on their type, need to time synchronization, ability to adapt with changes and their support to cross-layer design.

Table 1: Comparisons of MAC Protocols.

Protocol [Ref.]	Type	Support Adaptively to Change	Cross-layer Support	Time Sync Needed
DSS [7]	Channel Polling/ CSMA	Good	No	No
Ref[8]	CSMA	Good	No	No
Ref[9]	CSMA	Good	No	No
Ref[10]	CSMA	Good	No	No
Ref[11]	CSMA	Good	No	No
ALOHA [12]	Channel Polling/Slotted Aloha	Good	No	No
BMAC[13]	Channel Polling	Good	No	No
DRAND[17]	TDMA/CSMA	Good	No	Yes
PACT [18]	TDMA/CSMA	Weak	No	Yes
TRAMA [19]	TDMA/CSMA	Good	No	Yes
FLAMA [21]	TDMA	Weak	No	Yes
LMAC [22]	TDMA	Good	No	Yes
AI-LMAC [23]	TDMA	Good	No	Yes
Ref[24]	TDMA	Good	No	Yes
Z-MAC [25]	TDMA/CSMA	Weak	No	Yes
SCP-MAC [26]	TDMA/CSMA	Weak	No	Yes
Funneling-MAC[27]	TDMA/CSMA	Weak	No	Yes
Ref[28]	TDMA	Good	MAC- Network	Yes
Ref[29]	TDMA	Weak	MAC- Network	Yes

Ref[30]	TDMA	Good	Physical- MAC- Network	Yes
Ref[32]	TDMA	Weak	Physical- MAC- Network	Yes
Ref[33]	CSMA/TDMA	Weak	MAC- Network	Yes
Ref[34]	CSMA	Good	MAC- Network	No
EYES MAC [35]	CSMA	Good	MAC- Network	No
Ref[37]	TDMA	Good	MAC- Network	Yes
XLM [38]	CSMA	Weak	MAC- Network- Transport	No
Ref[39]	TDMA	Good	Physical- MAC- Network	Yes
CL-MAC[40]	TDMA	Good	MAC- Network	Yes
Ref[41]	Slotted Aloha	Good	MAC- Network	No

4. Open Research Issues

Although there are various MAC layer protocols proposed for sensor networks, there is no protocol accepted as a standard. One reason for this is that the MAC protocol choice will, in general, be application dependent, which means that there will not be one standard MAC for sensor networks. Moreover most of the suggested solutions only work in networks with exactly defined properties, which makes their application areas very small. Especially mobility and topology factors still need more intensive research. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware.

Common wireless networking experience also suggests that link-level performance alone may provide misleading conclusions about the system performance. A similar conclusion can be drawn for the upper layers as well. Hence, the more layers contributing to the decision, the more efficient the system can be. For instance, the routing path could be chosen depending on the collision information from the medium access layer. Moreover, layering of the network protocols creates overheads for each layer, which causes more energy consumption for each packet. Therefore, integration of the layers is also a promising research area that needs to be studied more extensively.

5. Conclusion and Future Work

Although various MAC protocols have been proposed, there is a possible future work for system performance optimization such as; Cross-layer optimization, Cross-layer interaction, etc. Hence, Cross-layer optimization is a MAC protocol area that should be explored more extensively. Cross-layer interaction can reduce packet overhead on each of the layers, thereby can reduce the energy consumption. Interaction with the MAC layer can provide other layers with congestion control information, as well as it can enhance routing selection. Many existing MAC protocols have been successfully addressed to present the performance studies of the static sensor nodes, but still there is a lack of literature for comparing these protocols with mobile network. However, enhancing the MAC protocol can significantly improve communication reliability and energy efficiency

The area of MAC protocols for wireless sensor networks has drawn much attention from the research community, and therefore a plethora of WSN MAC protocols exists. This paper gives a short overview of the researches in the field of wireless sensor networks. Classification of MAC protocols for WSNs is introduced with the intension of enhancing cross-layer energy efficient optimization. Open research issues are suggested at the end.

The focus of future research should be on trying to find the balance between being able to predict delay, guarantee some kind of QoS, minimising communication overhead and lastly, optimize power usage; a combination of requirements characteristic for wireless sensor networks.

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