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CONTENTION AND TDMA-BASED MAC WIRELESS IN SCHEDULED AND UNSCHEDULED SETTINGS

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ABSTRACT

Availability of medium protocol rules make access to such networks that are shared to be accessed in an orderly manner. This allows all involved to share into a limited wireless bandwidth. Wireless channels have their own issues including carrier sensing, which depends on location, time among other issues. This article addresses the problems associated with scheduled access by delving deep and looking at such issues as energy consumption and MAC protocols output in wireless sensor networks. This article therefore analyzes MAC protocols specially developed for use in sensor networks. It is worth pointing out that MAC protocols are different from both scheduled and unscheduled protocols.

Keywords: MAC, scheduling mechanisms, sensor network.

1. INTRODUCTION

The current anyone, anywhere and anytime paradigm networking can be credited to advances made in matters to do with technology, mobility and flexibility of wireless systems. Alongside this is the convergence of telephone, cable and data networks into one network that supports multimedia, making it possible for real-time applications such as voice, video and data to be realized. Wireless communication is one of the fast developing technologies. It makes it possible for anyone to access networks without the need of using a cable (Zulu, 2013). Deployment of wireless can be effected in several ways including use of different devices that belong to one user (mobile telephones, portable computers and personal digital assistants (PDA)) (Sarkar, 2012), devices that interact, in effect making sharing of documents possible, one receiving email on his/her PDA, a shopping outlet where clients display special offers on PDAs and loading of maps (Fischer *et al.,* 2012). Although several experiments are still on course, such possibilities have already become a reality.

Research on Wireless Sensor Networks (WSN), which is propelled by the ever developing digital circuitry has led to small size computer systems. The need for wireless networks that consume minimal energy has prompted development of novel protocols in all areas of communication system. Therefore, research on this aspect was carried by different scholars, for example (Warneke, Last, Liebowitz, and Pister, 2001), addressed the important needs for combining of a sensor, a micro controller and a radio to form a small sensor node. They suggested that several nodes could then be arranged to form a single wireless network, a network allows each node to report on its environment, which opens up a wide range or applications.

Because the radio in a sensor node is the only gadget that consumes most energy, it is at the link layer where savings on energy can be realized by making use of MAC protocol that controls how the radio works (Ye, Heidemann, and Estrin, 2002). Providing better performance and extend the network capability are what has led to the development of MAC protocols. The MAC protocols specially designed for use in WSNs provide for efficient throughout, latency and fairness when it comes to saving on energy consumption and extending network performance (Cormio and Chowdhury, 2009). Each MAC protocol is designed with its own way of switching off the radio. While a basic one operates throughout, an advanced one operates in relation to the environment, meaning traffic at a given time and location (Li and Tan, 2010; Ullah & Kwak, 2012). Whether savings on energy consumption realized is of more importance than the complexities involved depends on an application and a channel’s condition at any given time. This paper classifies the main trends in the design of MAC in terms of energy efficiency in addition to detailing historical advances made.

The functionality of a MAC protocol differs from that of scheduled and unscheduled protocols. Unlike the two, functionality of MAC depends on network, device capability and upper layer requirements. Even so, MAC protocol allows for several functionalities.

- Framing - Defines the format in addition to performing data encapsulation and decapsulation between devices.
- Medium access - Determines the devices that can communicate at a given time. Medium access is the core functionality of MAC protocols because broadcasts corrupt data through collisions.
- Reliability - Ensures smooth transmission of data between devices.
- Flow control - Prevents frame loss caused by overload.

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- Error control - Uses detection and correction codes to control any errors in frames submitted to upper layers.

2. WIRELESS MAC PROTOCOLS

Both commercial establishments and researchers have shown keen interest in wireless networks over the past decade. It is however unfortunate that the focus of such interest is not on sensor networks because of their different goals and constraints (Korakis, Jakllari, and Tassiulas, 2003). The main difference happens to be limited energy resources in sensor networks, which does not necessarily limit the capability of devices in a wireless network (Cordeiro and Challapali, 2007).

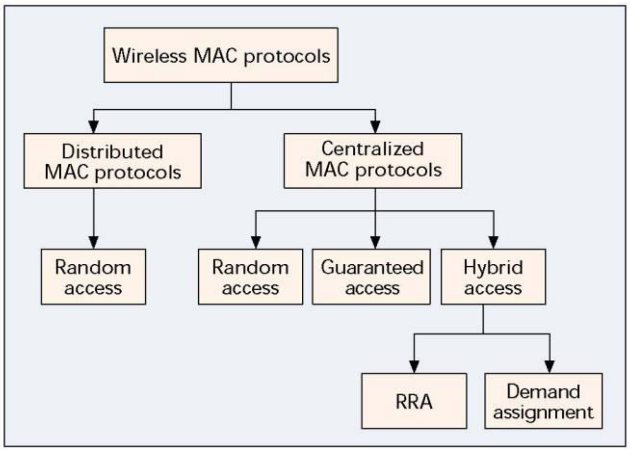

Figure-1. Classification of wireless MAC protocols.

The above figure shows how MAC protocols are classified; centralized and distributed protocols. Classification largely depends on the design of a network's architecture. The two classifications can further be sub-classified on the basis of their mode of operation. Sub-classification yields random access protocols, hybrid access protocols and guaranteed access protocols. When a node makes a transmission attempt in a random access protocol, submission of data is always a success. On the other hand, collision occurs when multiple nodes make transmission attempt. Even so, such collisions are resolved by the nodes in line with rules as defined by contention resolution algorithm (CRA). The first protocol designed for packet radio networks happen to be ALOHA, which is a perfect example of random access protocol. Its operation is as follows; a node with data transmits the data and re-transmits the same data after a random period should the earlier transmission collide with another data. This protocol has a maximum throughput of 18 percent. If the protocol's medium is slotted and data transmission is attempted at the beginning of the slot, the vulnerable data transmission period is halved, which in effect doubles system's efficiency. This slotting version in ALOHA is what is referred to as S-ALOHA as acknowledged by Yahya and Ben-Othman (2009).

3. ISSUES OF MAC

Studies in multiple accesses have been limited to basic networks incorporating several transmitters with one destination. As such, it definitely does not present the self-organizing wireless sensor networks known to have several dynamic pairs of transmitters and receivers. To create extension of MAC operation for multi-destination networks, researchers explored the problem of contention-based access that relate to wireless networks using two fixed receivers and employed conflict algorithms to determine bounds on maximum stable throughout (Nguyen, Katz, Noble, and Satyanarayanan, 1996). The Group time-division multiple access (TDMA) algorithm was employed as a time-division mechanism in a network with two destinations for the purpose of separating groups of nodes containing packets of data destined for different locations. Transmission scheduling idea is not new even though how it is used in this context. Depending on traffic need, each group is allocated time. Analysis of TDMA was undertaken with focus on throughput properties and best time allocation was ascertained as a function of loads offered independent of any underlying multiple access protocols in each group of users. The same analysis can be undertaken in multi-destination networks with arbitrary topology (Ali *et al*., 2006). The assumption with a fixed pair of transmitter and receiver is that it contrasts the dynamic and independent design of sensor networks where all nodes are able to transmit and receive packets of data as source-destination pairs for the purpose of relaying the same (Maheshwari, Gupta, and Das, 2006). Assuming that only one transceiver for each node exists; simultaneous packet transmission and reception by any node within a network must be ruled out. This calls for the need to create a mechanism that activates nodes to function as transmitters or receivers (Demirkol, Ersoy, and Alagoz, 2006). The need to create such a mechanism cannot be avoided. This is because the problem of achieving best channel access schedule for multi-hop networks and network partitioning into activation sets is NP-complete and requires practical solutions (Tang and Garcia-Luna-Aceves, 1999). We introduce in this paper these issues based on limited knowledge of network connectivity map to partition nodes into disjoint transmitter-receiver sets. Instead of creating problem-free schedules like in link scheduling, we may consider a room for multiple transmissions for each receiver and rely on one MAC protocol to resolve any problems that may not be avoided.

4. SENSOR NETWORK-BASED MAC PROTOCOLS

The unique operating environment coupled with the platform has been appreciated by many researchers who have proposed several MAC protocols that are specially designed for sensor networks. Due to space limitations, this paper cannot address all the protocols. Therefore, this paper presents discussions that relate to such protocols. There exist two types of MAC network protocols; scheduled and unscheduled (random) protocols. Scheduled protocols are designed to recognize

ARPN Journal of Engineering and Applied Sciences

neighboring sensor nodes for the purpose of making communication orderly (Van Hoesel, Nieberg, Kip, and Havinga, 2004; Ye, Silva, and Heidemann, 2006). Majority of scheduling methods have sensor nodes organized in line with TDMA. In this setting, one sensor node makes use of slotted time. This setting reduces collisions and message re-transmission (Rajendran, Obraczka, and Garcia-Luna-Aceves, 2006). Unscheduled protocols are designed to make use of energy efficiently by allowing sensor nodes to function independently, in effect eliminating complexities (Cano, Bellalta, Sfairopoulou, and Barceló, 2009). Although collisions and idleness leading to energy loss may occur, there is no sharing of information. Not all unscheduled MAC protocols operate this way and the below discussion focuses on classifying the MAC protocols on the basis of their large-scale organization of sensor nodes or lack of the same.

4.1 Contention-based MAC

This type of MAC protocol is based on Carrier Sense Multiple Access (CSMA) or Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). Its design allows for sensing before transmitting data (Jung, Hwang, Sung, and Hwang, 2009). Sensing provides room for detecting if the medium is busy (carrier sense) (Choi, Lee, and Lee, 2013). Good examples of this type of MAC protocol are Sensor-MAC, T-MAC, Directional-MAC, TEEM, UMAC and BMAC.

Sensor-MAC or S-MAC: Inspired by 802.11, S-MAC is an energy efficient RTS-CTS protocol designed for WSNs. It operates in four different ways; periodic listening and sleeping, collision avoidance, overhearing avoidance and data transmission (Raymond, Marchany, Brownfield, and Midkiff, 2009).

The nodes are activated after a sleeping period and listen to ascertain whether or not there is data addressed to them. In case of none, they initiate communication on their own (Demirkol *et al.*, 2006). This simply means that the sleeping period is local and synchronized between the nodes. Every active period has a fixed size of 115ms with variable sleeping period. It is the length of the sleeping period that determines the duty cycle of S-MAC. Nodes exchange synchronization information at the beginning of every active period.

Transfer of data can occur after the SYNC period for the remaining active period using RTS-CTS. One advantage of S-MAC is elimination of energy waste as a result of sleep schedules (Raymond and Midkiff, 2008). Even with energy-saving capability, S-MAC does not fulfill simple implementation, scalability and cannot tolerate changing network environment. S-MAC must also maintain numbers of neighboring schedules as size of network increases otherwise it incurs overhead due to repeated rounds of re-synchronization. Furthermore, a node with more data monopolizes the wireless radio channel. The latter prompted modification of S-MAC protocol for the purpose of eliminating the need for some nodes to remain awake longer than others. The modified version (S-MAC-layer) has the capability to increase energy efficiency and prolong a wireless sensor network life span. Another version of S-MAC that allows low-duty cycle operation was also proposed with the aim of reducing control overhead, low latency and traffic adaptive wakeup (H. Kim and Shin, 2008). For all these to happen, the version coordinates sleeping of the nodes.

Directional MAC or D-MAC: is an improved version of Slotted ALOHA algorithm. In DMAC, the slots are assigned to sets of nodes on the basis of data gathering tree. During reception period, all the nodes have transmission period. DMAC has the advantage of having very good latency (Huang, Shen, Srisathapornphat, and Jaikaeo, 2002). However, it does not incorporate collision avoidance methods. In effect, collision occurs when several nodes with the same schedule transmit data to the same node (Dai, Ng, & Wu, 2006).

Timeout -MAC or T-MAC: From above, it is clear that S-MAC does not function well when there is fluctuation in traffic load (Van Dam and Langendoen, 2003). This problem was addressed by introduction of T-MAC protocol that time out value to end a node’s active period. A node that hears nothing within the time out period instantly goes to sleep.

T-MAC has the advantage of using only one fifth of energy that S-MAC uses. However, both provide for same performance. Just like with S-MAC, T-MAC has the same scaling and complexity problems that S-MAC has (Busse, Haenselmann, and Effelsberg, 2006). The shortened active period in T-MAC however reduces the ability to snoop on neighboring traffic.

Traffic Aware Energy Efficient MAC (TEEM): TEEM is another improved version of S-MAC protocol. It features two very important modifications. Unlike S-MAC, TEEM has all the needs switch off their radios when no data is about to be transmitted in a network (Suh & Ko, 2005). Secondly, it eliminates communication of different RTS control even when transmission of data is about to occur. In TEEM, the listening period is made up of Syndata and Syncnodta. This means that the initial part of the listening period has data and no data in the other part. Both parts are however useful for synchronization. Every node listens in the initial Syncdata to ascertain whether or not there is data to be transmitted. In case there is no data, it sends a sync data to the Syncnodata part (Staub, Bernoulli, Anwander, Waelchli, & Braun, 2006).

Urgency -MAC or U-MAC: This is an improved version of S-MAC protocol. Unlike S-MAC, UMAC has several duty-cycles, duty-cycle tuning and selective sleeping after transmission. There is no assigning of the same duty-cycle for nodes; each node is assigned different periodic listen/sleep schedules that have different duty-cycles (Ko, Shankarkumar, and Vaidya, 2000). In this setting, the tuning duty-cycle capability reflects on different traffic loads on each node in a network. The variation corresponds well with diversity of tasks performed by a specific node in addition to its location. The selective sleeping functionality saves energy (Barroso, Roedig, and Sreenan, 2005).

Berkeley Media Access Control (B-MAC): Unlike the other versions, B-MAC makes use of clear channel assessment (CCA). It allows for packet backoff, which provides for channel arbitration, link layer acknowledgement for reliability and low power listening (LPL) (Polastre, Hill, and Culler, 2004). B-MAC makes independent decisions, which allows for optimum use of energy, latency, throughput and fairness or reliability. In using low energy, it uses adaptive preamble sampling scheme for the purpose of reducing duty-cycle and at the same time minimizing idle listening (an adaptive rate scheme). B-MAC supports fly re-configuration in addition to providing network devices with bi-directional interfaces, which leads to optimized performance (Raymond and Midkiff, 2008).

4.2 Time Division Multiple Access (TDMA) -based MAC

Even though random access provides for high flexibility and low latency for applications that have low traffic loads, deterministic scheduling still remains the best way to eliminate sources of energy waste. With proper scheduling, only one pair of transmitter-receiver remains active at every transmission period. This reduces collisions and eliminates idle listening and overhearing. The use of TDMA is considered as a natural for use in sensor networks. This is because radios can be switched off at idle time for the purpose of conserving energy. However, maintenance of accurate synchronization between sensors requires deterministic TDMA scheduling to have a large overhead. In addition, latency increases linearly with total number of sensors sharing the same channel. This is because TDMA assigns separate timeslots to every transmitting sensor (Marinkovic, Spagnol, & Popovici, 2009).

EYES MAC: TDMA-based E-MAC protocols divides time into time slots, which nodes transfer data without necessarily having to contend with the medium or having to address energy-wasting collisions that emanate from transmission. This setting allows a node to assign only one slot to itself and controls the slot. Furthermore, that same node has reserved time after the time frame length, which consists of different time slots (Guduru, 2011).

Every time slot is again divided into three parts; communication request (CR), traffic control (TC) and data part. In the CR part, other nodes can send a request to another node that controls existing time slot. Nodes with requests pick random start time in the short CR part to be able to make their own requests.

Lightweight MAC (L-MAC): This protocol borrows from E-MAC. L-MAC protocol considers a network's physical layer properties. Through this, the protocol minimizes the number of transceiver switches, which makes it possible for sleep interval for sensor nodes to adapt to amount of data traffic (Watfa, Selman, and Denkilkian, 2010).

In his course of its time slot, a node transmits data made up of two parts; control message and data unit. The control message is of a fixed size and is useful in different ways. It contains time slot's controller ID, indicates the distance of the node to the gateway in hops, which allows for simple network routing. It also addresses the intended receiver and reports on the length of data unit.

Advanced-MAC (A-MAC): This is a TDMA-based MAC protocol designed for low rate and reliable data transmission, which prolongs network lifetime. It is an adaptation of L-MAC protocol. In comparison to conventional TDMA-based protocols that depend on central node manager for allocation of time slot for nodes in a clutter. A-MAC protocol employs distributed technique, a scenario where nodes select their own time slots by collecting information in their neighborhood (Kim, Kim, Kim, Choi, and Lee, 2005). The protocol has a power down feature to which automatically reverts when no data transmission activity is available.

The protocol features several frames, with each frame consisting of several time slots. Every node transmits a message at the start of its time slot, a message that serves two purposes; the message acts as the synchronization signal and also as neighbor information exchange (Lau and Chan, 2006). The controlled node uses this message to inform its neighboring nodes which one will engage in the following data session. The identified node therefore remains in listening mode so as to be able to receive data. This led us to conclude that the other nodes automatically switch to power down mode for the duration of the current time slot. Unlike with L-MAC, A-MAC allows a node to submit data to multiple locations.

Furthermore, the protocol's coordination allows TDMA to attain higher throughput with high traffic load. Even though the protocol is very effective in eliminating energy waste that occurs due to collisions during communication, the protocol has several issues. First, it is difficult to change cluster frame length and time slot assignment, which leads to poor scalability. Generally, TDMA-based protocols need to have strict synchronization, which also leads to high expenditure on hardware and high data latency. Latest research has however led to development of other high breed protocols such as Z-MAC and G-MAC.

5. COMPARISON BETWEEN SCHEDULED & UNSCHEDULED IN MAC PROTOCOLS

When it comes to savings on energy, scheduled MAC protocols try to save the same through coordination of sensor nodes by making use of a common schedule. Most scheduled MAC protocols have elements of TDMA because their design encourages increased energy consumption (Ergen, Di Marco, and Fischione, 2009). Through scheduling, MAC protocols determine which sensor nodes need to utilize network channel at any given time, in effect limiting or eliminating collisions, idle listening and overhearing. All non-active sensor nodes go to sleep mode until a time when they have data to transmit or when ready to receive a message.

However, the advantages that scheduled MAC protocols provide for tend to be costly. The cost is in terms of increased messages and maintenance of schedules. Additional sensor nodes in a network have to wait while learning before joining a schedule to use a channel (Jang, Lim, and Sichitiu, 2012). Furthermore, there delays are bound to occur between sensor nodes goes to sleep and when neighboring sensor nodes re-assign resources of those nodes that go asleep. In effect, Yahya and Ben-Othman (2009) highlighted that some resources remain unused, which leads to further delays in packet loss.

Scheduled MAC protocols must also function properly in situations where sensor nodes are in incorrect state. Segmentation of MAC state can also lead to conditions in which collisions cancel out benefits that the protocols provide for (Kleunen, Meratnia, and Havinga, 2011). Scheduled protocols also have a serious problem when it comes to synchronization, which can occur through a periodic beacon, which in effect increases transceiver utilization or in some cases using increased precision oscillators, which again leads to increased sensor nodes cost.

Scheduled MAC protocols must also address the effect of additional latency and reduced throughput. In a normal situation, a sensor node can only access a wireless channel for a fraction of allocated time, which in a TDMA-based MAC protocol a sensor node can access the channel depending on timeslot length (Djukic and Mohapatra, 2009). This means that only one sensor node can transmit in that period with any unused time going to waste. Although such waste can be minimized by reducing the length of time slot, decreased maximum message length without fragmentation is bound to occur. Those sensor nodes that need to transmit messages at a higher rate that the allocated time slot can manage have to coordinate with the other sensor nodes on a schedule in order to gain access to extra time slot. Every sensor node therefore queues messages until a time when it has the opportunity to transmit such messages (Rashid, Embong, Zaharim, and Fisal, 2009). A number of scheduled MAC protocols try to overcome limitations on throughput and latency by sharing information in messages.

Scheduled MAC protocols compared with unscheduled MAC protocols have the advantage of being simple in design. Unscheduled MAC protocols do not only consume a lot of resources during processing; they do not share or maintain state, have small memory footprint and decrease messages that a node transmits. In addition to these, any additional sensor nodes added to a network do not join any node group and therefore start participating immediately. The disadvantage with unscheduled MAC protocols however is that they have higher rate of collisions, idle listening and overhearing (Yahya and Ben-Othman, 2009). This is because sensor nodes do not participate in coordination of transmissions. Addressing these challenges requires that unscheduled protocols use such other techniques as channel reservation messaging and channel sensing. However, channel reservation messaging can easily offset any benefits obtained by organizing sensor nodes. Another great advantage of unscheduled MAC protocols is that they give room for sensor nodes to adapt quickly to any changes in traffic conditions. This is because channel reservation technique can easily bring up fine granularity, which sensor nodes can adapt to quickly (Sala, Limb, & Khaunte, 1998). Furthermore, unscheduled MAC protocols have the capacity to remove delays between resource allocation and resource utilization, something that is very common with scheduled protocols. Removal of such delays allows for faster adaptation to any changes in network conditions. However, fairness is a major issue with unscheduled MAC protocols. This was addressed by Kredo and Mohapatra (2007) as the lacking of mechanism capable of equalizing channel usage.

6. CONCLUSIONS

Advances made in technology have made it possible for research and development of wireless communication systems that have gone a long way in reducing communication costs. Such developments have also opened up more channels including multimedia communication. Networked systems have not only cut down communication costs and made it possible for various types of communicating; the systems have made it possible to have faster communication.

Both scheduled and unscheduled MAC protocols developed for use in network channels play a critical role in data transmission and reception. Despite of this however, serious operation challenges still exist in their sensor nodes, challenges that affect smooth flow of data. Further research is therefore still very necessary for the development of protocols that provide for efficiency at reduced cost.

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