Wireless Sensor Network MAC Protocol: SMAC & TMAC

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Abstract—**Wireless sensor networks is an emergent technology which has made Ambient Intelligence a reality. It consists of several tiny nodes connected to each other in Ad hoc environment and coordinate with each other to form a network. It has wide range of applications, potential in areas such as intruder alert and tracking, environmental monitoring, industrial process monitoring, and tactical systems. However, as they are spread in areas with difficult terrain and to achieve full coverage of area there are large number of wireless sensors used, it is difficult to replace their batteries once exhausted. Energy conservation is needed especially at MAC layer level. Various MAC protocols with different objectives have been proposed for wireless sensor networks. SMAC is one of the base protocol which with slight modifications results in various protocols. SMAC is having static sleep schedules while TMAC is having dynamic sleep schedules. In this paper, we first outline the basics of Wireless sensor network then we discuss the properties of MAC layer succeeding with a section outlining the reasons of energy wastes in WSN. Two Protocols discussed in this paper i.e SMAC and TMAC are presented subsequently with their advantages and disadvantages. Finally, before concluding, an article on various design process related to SMAC and TMAC as per WSN is included.**

Keywords— **Wireless Sensor Network, Ambient Intelligence, MAC Layer, Energy Wastes, SMAC, TMAC**

1. Introduction

Before proceeding with the Wireless Sensor Network we need to understand the need and conditions which paved the way to the invention of Wireless Sensor Network. Normally the systems we use in our work places consist of PCs, Laptops, Mainframes, Smartphone's and Tablets etc. These systems are built on the concept of "Human – System" Interaction. In this type of system human interacts with the system for information processing. This whole setup is indirectly connected to Physical environment. Physical environment is read by user and user interacts with system. On the other hand there are setups where system interacts with Physical environment and adjusts itself. Both the scenarios are depicted in figure 1 and 2.

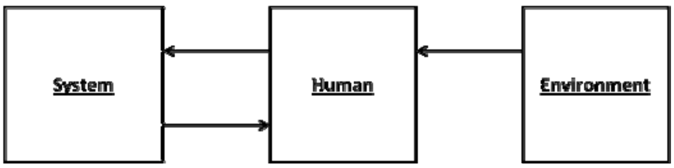

Fig 1 System Human Interaction

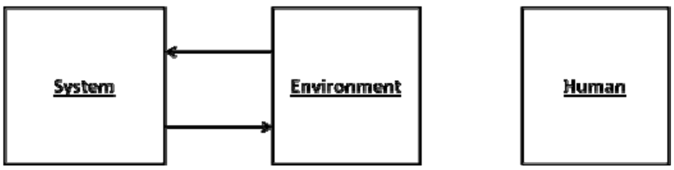

Fig 2 System Environment Interaction

As we can observe from Fig 1.2 that system itself is capable of interaction with environment and this leads to what we call it as "Embedded System". Example can be washing machines, microwave oven, chemical process plant or a temperature regulating unit in a Blast furnace. As the technology is advancing our capability to provide this sense to big machines has also created a desire to impart it to small devices and things related to our daily life. As rightly coined term by [1], this technology is known as "The Ambient Intelligence". Ambient means surrounding which implies providing intelligence to the surrounding. Exactly what is meant by this can be understood by following example. Imagine if our surrounding understands us. When we reach our home and door opens automatically when it senses us. Lights are switched on when we enter the room and music is played as per the person's personal choice. This is the ultimate combination of "User – System – Physical Environment".Now going one step further, what if these sensors which are sensing us also communicates with each other and form a network. This type of network has many applications. Their application may range from military services, medical to disaster relief operations. Basically for this imagination to become reality we need to develop devices which are very small but have the following capabilities:

- Processing power for onboard processing
- Transmitter and Receiver
- Power Supply
- Sensors to interact with Physical environment

Now, going into detail of the Wireless Sensor Network, we have tiny devices called nodes which are spread in an area in a particular pattern or in random fashion. They are capable of interacting with each other and transmitting the data to one another. Generally, this kind of network has a "sink" or base station where all the information gathered is transmitted. This sink, is in turn, connected to the remote computer or device monitoring the whole system as shown in Fig 3. This remote computer can be a server or mainframe. These devices along with opening a new world of opportunity and applications also create lots of new challenges for the researchers. Deepak Ganesan et al. [2] presents various challenges faced in sensor networks like (a) supporting multi-hop communication while limiting radio operation to conserve power, (b) data management (c) geographic routing challenges, and (d) monitoring and maintenance of such dynamic, resource-limited systems along with solution to these various challenges.

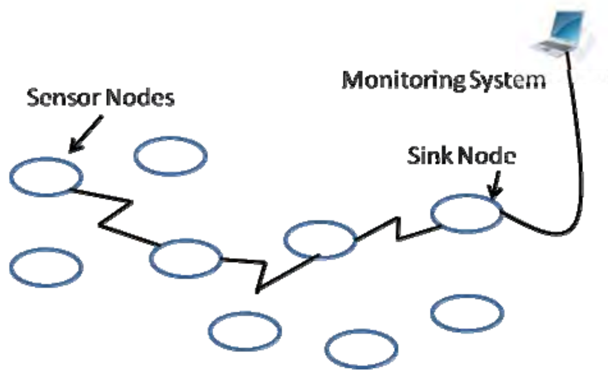

Fig 3 Wireless Sensor Network

These tiny devices have power supply on board and it is generally irreplaceable due to terrain constraints and small size. This makes power conservation an important aspect of WSN. Then as these are connected in Ad hoc fashion dyeing of nodes may make certain area of network isolated which will result in inaccessible network clusters which will finally lead to defeat of the sole objective of Wireless Sensor Network. Keeping these in mind section II discusses various works done in this field, section III discuss the MAC Layer related design considerations, Section IV presents SMAC and TMAC, two popular MAC protocols with their advantages and disadvantages. Section VI finally concludes this research paper.

2. Survey Methods

Ilker Demirkol et. al. [4] identifies the change needed in conventional MAC protocol to be suited for WSN for energy efficiency and reviews some MAC protocols elaborating their merits and demerits. The common sources of energy waste are collision, control packet overhead, idle listening, overhearing and overemitting. Communication patterns viz., broadcast, converge cast, local gossip and multicast are reviewed and their application in various types of scenarios is discussed. MAC protocols like S-MAC, T-MAC, WiseMAC, TRAMA, SIFT, D-MAC and DSMAC are reviewed with their respective working, merits and demerits. At last underlying technologies like TDMA, FDMA and CDMA are briefly explained in context with MAC layer of WSN.

Wei Ye et. al. [5] in this paper has proposed S-MAC, a medium-access control (MAC) protocol designed for wireless sensor networks. As we know Wireless sensor networks has limited power supply in form of batteries and it is used for computing and sensing devices. In author's words, a network of these devices will integrate for a common application such as fire detection in forest etc. Sensor networks are to be deployed in an ad hoc fashion, with individual nodes remaining largely in sleep mode for long periods of time, but then becoming suddenly active when something is detected [5]. These characteristics of sensor networks and applications makes traditional wireless MACs such as IEEE 802.11 less suited for the job. Instead a new protocol needs to be developed. It has to be innovative in almost every aspect: energy saving and auto-configuration are primary goals, while per-node fairness and latency are less important. S-MAC uses three innovative techniques to reduce energy consumption and support auto-configuration. Nodes periodically sleep and thus reduce energy consumption. Virtual clusters are also formed to auto-synchronize on sleep schedules. SMAC draws some similarity with PAMAS like radio is turned off and it is dissimilar to PAMAS in terms of in channel signalling. Finally they have evaluated the implementation of S-MAC over a sample sensor node, the Mote, developed at University of California, Berkeley. The experiment results show that, on a source node, an 802.11-like MAC consumes 2–6 times more energy than S-MAC for traffic load with messages sent every 1–10s [5].

Zahra Rezaei et. al. [9] tries to find the answer to the most important question in WSN, "how to prolong the network lifetime to such a long time?" Since WSN uses batteries which are irreplaceable generally, the vital challenge is to keep the network alive as WSN follows an ad hoc pattern which makes it necessary to keep nodes alive for network sustainability. They discuss the reasons for energy wastes in WSN. To overcome this challenge they propose two methods, one by using various duty cycle schemes and second by proposing several MAC protocols following different technology like CSMA/CA, TDMA and hybrid. CSMA/CA consists of S-MAC, T-MAC and U-MAC. TDMA and hybrid µ-MAC, DEE-MAC, SPARE-MAC, Z-MAC and A-MAC. Merits and demerits of these MAC protocols are also enumerated and reviewed.

Divya Jain et. al. [6] studies a Wireless Sensor Network comprising of number of nodes distributed over an area to collect information. The sensor nodes communicate among themselves through the wireless channel and forward the collected data to its one-hop distant neighbouring node. These nodes are normally battery operated. But as these nodes are placed in such conditions that charging or replacing battery of these nodes are nearly impossible, energy consumption becomes a major factor. In this paper they propose creating a network once with Sensor-MAC (SMAC) and again with Sensor-MAC with sleep schedule. After simulating these networks in different topologies, network of SMAC-L, is found to give better results in life time and energy consumption when compared to network of SMAC.

Rajesh Yadav et. al. [7] reviews WSN containing sensor nodes that are generally unattended after their deployment in hazardous, hostile or remote areas. To maintain the network life, battery needs to be replenished which is not possible. So, it is necessary to conserve the battery. In this study, characterstics of ideal MAC protocol are discussed. Energy wastage scenarios are also studied. MAC protocol parameters, needed to evaluate different MAC protocols like Energy Consumption per bit, Average Delivery Ratio, Average Packet Latency and Network Throughput. MAC protocol is divided into two categories viz. contention based and schedule based. Along with that several MAC protocols are presented with their working, advantages and disadvantages. Protocols presented are PAMAS, S-MAC, Optimized MAC, TRAMA, Wise MAC, B-MAC and D-MAC.

Michael I. Brownfield et. al. [8] proposes a new MAC protocol GMAC, based on gateway duty rotation. As we know, Wireless Sensor Networks provide a valuable merit to autonomously monitor remote activities. The limited resources produces new challenges in front of MAC designers to adequately support network services while conserving limited battery power. In this study an energy adaptive WSN MAC protocol, Gateway MAC (GMAC), which implements a new cluster-centric paradigm to effectively distribute cluster energy resources and extend network lifetime, is proposed. As per the new protocol suggested by the authors G-MAC's centralized cluster management function offers great energy savings by leveraging the advantages of both contention and contention-free protocols [8]. Further, in their words, a centralized gateway node collects all transmission requirements during a contention period and then schedules their distributions during a reservation-based, contention-free period. With minimal overhead, the gateway duties are efficiently rotated based upon available resources to distribute the increased network management energy requirements among all of the nodes [8].

Wei Ye et. al. [10] already addressed several MAC issues ranging from energy waste points in WSN to proposal of MAC protocols and also implementing them on the Mote, developed at University of California, Berkeley in [39]. Now, in this proposal they have extended their work on following points.

- The scheme of periodic listen and sleep reduces energy consumption by skipping idle listening. The use of synchronization to form virtual clusters of nodes on the same sleep schedule. This schedule leads nodes to minimize additional delay.
- The use of in-channel signalling to put each node to sleep when its neighbour is transmitting to another node. This method is inspired by PAMAS but does not require an additional channel. It also helps in getting rid of overhearing problem.

- Applying message passing to reduce application-perceived latency and control overhead. Per-node fragment-level fairness is reduced since sensor network nodes are often collaborating towards a single application.
- Evaluating an implementation of our new MAC over sensornet specific hardware.
- This paper includes significant extensions in the S-MAC protocol design, implementation and experiments:
  - o Support for traffic-adaptive sleep schedules.
  - o Measurement and evaluation of the trade-offs on energy, latency and throughput.

Deepak Ganesan et al [2] review the set of challenges in sensor networks. They point out the key challenges in sensor networks like: (a) supporting multi-hop communication while limiting radio operation to conserve power, (b) data management (c) geographic routing challenges in networks where nodes know their locations, and (d) monitoring and maintenance of such dynamic, resource-limited systems. They also propose solution to each of the above stated issue and show how these networking components can be integrated in WSN.

3. MAC LAYER RELATED SENSOR NETWORK PROPERTIES

Increasing the network lifetime to maximum is a common objective of sensor network research, as nodes are assumed to be discarded when there battery is exhausted. Under these limitations, the discussed MAC protocol should be energy saver by reducing the key energy wastes presented in Section 3.1. Conserving energy can be best achieved by limiting the radio operation as a comparison of the cost of computation to communication in future platforms by Pottie and Kaiser [3] reveals that

3000 instructions can be executed for the same cost as the transmission of one bit over 100m. As communications methods are used to portray the exact behaviour of sensor network traffic which will be the basis of MAC layer protocol design since this traffic will be handled by given MAC protocol it is mandatory to understand and study different communication patterns. Various possible communication patterns are outlined in Section 3.2. Thereafter, the characteristics that must be present in a MAC protocol to suit a sensor network environment are presented in Section 3.3.

3.1 Reasons of Energy Waste

Ilker Demirkol et al. [4] and Wei Ye et. al. [5] describes the various reasons of energy wastes. Divya Jain et al. [6] have shown the simulation based on NS2 for energy losses under various scenarios for SMAC protocol. There are severalreasons for the eneregy wastes as described below. Firstly, if a node which is receiving data receives more than one packet simultaneously, these packets are called “collided packets”. Even if they collide partially all packets that cause the collision are discarded and the re-transmissions needs more energy consumption [4]. Other reason contributing to energy waste is overhearing, which means that a receiver gets the packets that are actually meant for other nodes. Thirdly, another reason contributing for energy waste occurs in form of control packet overhead. As we know that overheads are control packets needed to deliver a particular message or to maintain the transmission. Protocol having minimum number of overheads or header packets betters the bandwidth and energy consumption. Another big source of energy waste is idle listening, i.e., listening to an idle bandwidth to receive possible traffic. Final reason for energy wastage is overemitting, which comes in to role play when a packet is transmitted by transmitter when receiver is not ready. Above facts are needed to be considered to design MAC protocol which will be energy efficient.

3.2 Communication Patterns

Ilker Demirkol et al. [4] defines three types of communication patterns in wireless sensor networks: broadcast, convergecast, and local gossip. First we will see the Broadcast type of communication pattern which is generally used by a node generally termed as base station or sink to transmit some information to all sensor nodes of the network. Broadcasted information may include requests of sensor query-processing architectures, program updates for sensor nodes, control packets for the whole system [4]. In another type of communication pattern termed as local gossip, the sensors that detect an activity talks and share information with each other locally. In local gossip, sensor sends information to its neighbouring nodes which are within its range. Extension to above scenario, the sensors that detect the activity, needs to further transmit what they receive to the information centre. That communication pattern is called convergecast. In this, sensors which are receiving information from neighbouring nodes transmit their findings to a specific sensor. The destination node could be a sensor head, server managing the sensor network or base station. Another type of pattern defined in [4] is multicast which is generally the process of cluster head nodes communicating with some of their cluster members.

3.3 Properties of a Well-defined MAC Protocol

MAC protocol plays the important role in Sensor Network as major problem of battery consumption can be easily controlled if a good MAC protocol is designed [7]. However there are few more attributes other than energy efficiency which are needed to be considered. Efficient energy utilisation is needed to increase the network lifetime. Other important attributes are how sensor network reacts to changes in size of network and how it adapts itself to the changing dynamics of environment. These changes done to either topology or quantity of nodes or overall dimensions of network is changed it should not affect the normal working of sensor network.

MAC protocol which is efficient should adapt to these characteristics. Other major protocol characteristics important from IP based network viewpoint take backstage in sensor network. These features are delay, throughput and bandwidth efficiency etc.

4. Proposed MAC layer protocols

In this section, a two important MAC protocols defined for sensor networks are described briefly by stating the essential behaviour of the protocols wherever possible. Moreover, the advantages and disadvantages of these protocols are presented.

4.1 Sensor-MAC (S-MAC)

Basic concept of SMAC is periodic sleep listen schedules which are handled locally by the sensor network. Nodes which are adjacent form clusters virtually and they share common schedule. This means that if two nodes are side by side and fall in two different clusters they wake up at listen schedule of both clusters. This also results in more energy consumption as nodes wake up to two different schedules. The schedules are also needed to be communicated to different nodes of virtual cluster which is accomplished by SYNC packets and time in which it is sent is known as synchronization period. Figure 4 represents a sample sender-receiver communication. CS helps in collision avoidance. CS stands for carrier sense method of collision avoidance. In addition to it, unicast data packets transmission is done using RTS/CTS. A new and innovative feature of SMAC is message passing through which a long message is sent in burst by dividing it into small messages. This helps in energy saving by using common overhead. However, this concept of sleeping schedule may also result in high delay termed as latency which will be significant in case of multi-hop routing algorithms, as each node in between will have their own sleep schedules. This is known as *sleep delay*. This disadvantage can be overcome by using adaptive listening technique, and thus the overall delay can be improved as proposed in TMAC explained next. In that technique, the overhearing node wakes up for a small duration at the end of the transmission. So, if this node is the next-hop node, it can take the data immediately from the transmitting/passing node.

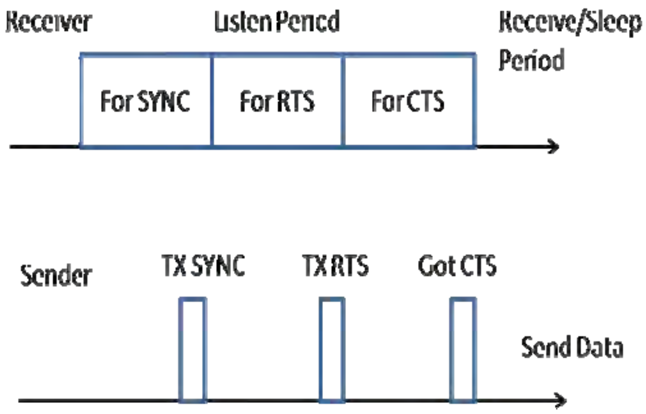

Fig 4 Sensor MAC Protocol

Advantages: The battery utilisation is increased implementing sleep schedules. This protocol is simple to implement, long messages can be efficiently transferred using message passing technique.

Disadvantages: RTS/CTS are not used due to which broadcasting which may result in collision. Adaptive listening causes overhearing or idle listening resulting in inefficient battery usage. Since sleep and listen periods are fixed variable traffic load makes the algorithm efficient.

4.2 Timeout MAC (TMAC)

Timeout T-MAC [7] is the protocol which is derived from S-MAC protocol in which the non sleep and sleep periods are fixed. In TMAC the sensor node deviates to sleep period if no event has occurred for a time ‘Tact’ as shown in Fig.5.

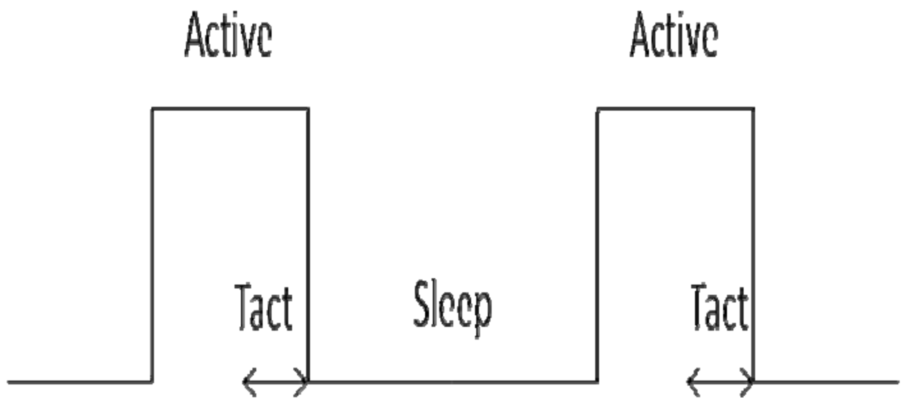

Fig 5 TMAC Protocol

There are many such events like data receiving, start of listen or sleep period etc. Minimum idle listening period is the time 'Tact'. The interval Ta is greater than sum of the contention time, length of an RTS packet, turn-around time and the length of the CTS packet. This whole scenario results in energy consumption which less in TMAC as compared to Sensor S-MAC protocol. However, this is adjusted against high delay or latency which T-MAC protocol has as compared to the S-MAC protocol.

Advantages: TMAC can easily handle variable load due to dynamic sleeping schedule.

Disadvantages: TMAC's major disadvantage is early sleeping problem in which nodes may sleep as per their activation time and data may get lost especially for long messages.

5. Conclusion

Although there are various MAC layer protocols proposed for sensor networks, however, there is not one protocol which is accepted as a standard. One of the reasons behind this is the MAC protocol choice will be application-specific, which means that there will not be single standard MAC for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware. Major area which needs attention is the extension of network life which is dependent on utilisation of battery with as much efficiency as possible. Major usage of battery is at the MAC Layer level where radio module is utilised. As it has been shown by various researches that radio transmission needs more power as compared to processing of same amount of data. MAC Layer protocols needs to be developed efficiently. SMAC is one of the basic MAC protocol which conserves energy by providing sleep schedules so that all the nodes of a particular area are not active at all times. Only those nodes are activated which are needed to maintain full accessibility of network. However, SMAC has static sleep schedules that is schedule do not change according to need or changing environment which leads to sleep delay. This particular problem is overcome using dynamic sleep pattern or scheduling as in case of TMAC protocol, which is a derived from SMAC protocol. In TMAC according to change in pattern of network like inclusion of new nodes, deactivation of exhausted node, network will adapt itself and have a variable sleep schedule which will increase the battery utilisation. However a new problem creeps in i.e of early sleeping in which if a node sleeps before it completes the transmission, increases latency. In future, an advanced form of these protocols may be realized with emphasis on early sleeping and delay sleeping with improved delay i.e. latency. Strength of SMAC is its low power consumption and for TMAC it is better sleep schedule. A combination of these positive aspects of both the protocols may be realized in a single protocol with eradication of disadvantages present in both of them. This will improve efficiency of Wireless Sensor Network in terms of Energy consumption etc.

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