An auto Reconfigurable Power Controlled MAC Protocol for Wireless Sensor Network

Dhara J. Patel and Rutvij C. Joshi

Abstract: Maintaining Energy efficiency is a critical issue for wireless sensor network. Life time of any sensor node directly depends on its energy efficiency. Thus, designing power efficient MAC protocol has a significant influence on the performance of wireless sensor network. In this paper we have suggest algorithm which switches the sensor node among three modes based on the power status of the sensor node and Traffic Condition. One major advantage of this protocol is that the schedule of the nodes are automatically adapted based on the network congestion and on the application traffic demand, so the network can operate efficiently in unattended conditions.

Keywords: MAC protocol, Adaptive duty cycling, Talk Time estimation, Buffering approach.

I. INTRODUCTION

Now days, Wireless sensor networking is an emerging technology that has a wide range of potential applications including environment monitoring, smart spaces, medical systems and robotic exploration. Recent advances in low power integrated circuit devices, microelectromechanical system (MEMS) technologies, and communications technologies have allowed wide deployment of low-cost, low-power sensors which can be effectively integrated to build wireless sensor networks (WSNs). In general, Wireless sensor network consists of tiny sensor nodes which are forming an ad-hoc distributed sensing and data propagation wireless network while collecting the information on the physical environment. Since to fulfill recent demand of technology, wireless sensor networks now extensively used in both military and civilian applications, that is, from battlefield surveillance system to modern highway and industry monitoring system, from the emergency rescue system to forest fire detection system, from the very sophisticated earthquake detection system to target tracking and security management.

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Each sensor node of a WSN has four basic components which are sensing unit, processing unit, radio unit, and power unit. Sensor node has the capability for sensing, simple computation, data processing, and communication with neighboring sensor nodes. With capabilities of monitoring the surroundings, the network can provide a fine global picture of the target area through the integration of the data collected from many sensors each providing a coarse local view. Single tiny sensor node is also called as mote, which are more used term in WSNs.

Recent WSN applications have noticeably different characteristics and requirements from traditional wireless applications. Single tiny node of WSN is expected to be battery equipped, and changing or recharging the power supply is usually very difficult due to cost constrain and environment conditions. Therefore, efficient energy, which is essential for prolonging the lifetime of the sensor node and eventually the wireless sensor network, is a more critical performance metric than others such as throughput and latency adopted for traditional networks. Conserving battery power is a critical issue for WSN in order to maximize its lifetime, and many researchers have been focusing on the development of power saving schemes for WSNs. They include power saving hardware and topology design, power efficient medium access control (MAC) layer protocol, network layer routing protocol, and so forth.

Communication in WSNs can be divided into several layers, where one of them is MAC layer. It is described by a MAC (Medium Access Control) protocol, which tries to ensure that no two nodes interfere with each other during communication using a proper coordination mechanism. Basically MAC protocol look out how the communication channel is shared among the sensor nodes. In general, the main design goal of typical MAC protocols is to provide high throughput, minimized latency, fairness, and QoS (quality of service). Note that most sensor nodes are battery operated and they usually cannot be recharged due to the deployment in harsh and remote environment. Therefore, the MAC protocol for WSN needs to focus on energy efficiency. In other words, the primary design issue for the MAC protocol of WSN is how to support the basic functions of MAC protocol while minimizing energy consumption of the sensor nodes to maximize the lifespan of the network. Moreover, the topology of a WSN often changes dynamically as some nodes die and new nodes are added. The MAC protocol should readily accommodate such network dynamics.

The major causes of energy waste in MAC protocol are as following:
Collision is a first source of power waste. When two packets are transmitted at the same time and collide, they become corrupted and must be discarded. Follow on retransmissions consume energy too. Collision is a major problem in contention protocols, but is generally not a problem in scheduled protocols.

Idle listening is a second source. It happens when the radio is listening to the channel to receive possible data which is not sent. The cost is especially high in many sensor network applications where there is no data to send during the period when nothing is sensed.

Overhearing is a third source, which occurs when a node receives packets that are destined to other nodes. Overhearing unnecessary traffic can be a dominant factor of energy waste when traffic load is heavy and node density is high.

Over emitting is takes place when a message is sent to the destination even though the receiving node is not ready to accept it.

Control packet overhead is last major source that consider. Sending, receiving, and listening for control packets consume energy.

Note that the major cause of energy waste in MAC protocol is idle listening. Power consumption during idle listening is almost the same as for receiving or transmitting data packets. Thus to increase sensor nodes lifetime need to reduce idle listing. One way is duty cycling approach, here the sensor nodes periodically turn off their radio and go into sleep mode, which directly shortens the idle listening period. Following MAC protocols are used earlier for power management.

SMAC [8] is a contention based MAC protocol based on fixed duty cycling techniques, a true MAC protocol, which also addresses the overheads caused by collisions, overhearing, and protocol overhead. The basic idea of this contention-based protocol is that time is divided into relatively large frames. Every frame has two parts: an active part and a sleeping part. During the sleeping part, a node turns off its radio to preserve energy. During the active part, it can communicate with its neighbors and send any messages queued during the sleeping part. Timeout- MAC (T-MAC) [8] is automatically adopts duty cycle to the network traffic. In T-MAC, when no activation event has occurred listen period ends for a time threshold TA. The time-out value, *TA*, is set to span a small contention period and an RTS/CTS exchange. If a node does not detect any activity (an incoming message or a collision) within interval *TA* it can safely assume that no neighbor wants to communicate with it and goes to sleep. On the other hand, if the node engages or overhears a communication, it simply starts a new time-out after that communication finishes.

BMAC (BERKELEY MAC) [9] is also contention based MAC protocol whose duty cycles the radio transceiver; goes again and again turn ON/OFF without missing the messages. BMAC is low power consumption protocol which uses unsynchronized duty cycling and long preambles to wake up receivers. BMAC employs an adaptive preamble sampling scheme which minimize idle listening and reduce duty cycle.

DMAC (Data Gathering MAC) is designed to solve the interruption problem by giving the active/sleep schedule of a node an offset that depends upon its depth on the tree. This scheme allows continuous packet forwarding because all nodes on the multihop path can be notified of the data delivery in progress. DMAC also adjusts node duty cycles adaptively according to the traffic load in the network by varying the number of active slots scheduled in an interval. In Wise MAC (WMAC) [11], when the sender starts the preamble before the receiver is expected to wake up rather than selecting a random time. For alerting the receiving node the preamble precedes each data packet. The nodes which are presents in the network sample are having the medium with a common period, but their relative schedule offsets are independent. If a node finds the medium busy after it wakes up and samples the medium, it regularly listen till it receives a data packet or the medium comes to the idle state. The size of the preamble in WiseMAC is initially set to be equal to the sampling period. In the Process of learning and refreshing their neighbor's the nodes sleep schedule during every data exchange as part of the Acknowledgment message. The node keeps a table of the sleep schedules of its neighbors and decides own schedule accordingly. The possibility to decrease the collisions caused by that specific start time of a wake-up preamble, a random wake-up preamble can be adopted. The wake-up preamble length gets affects by the clock drifts between the source and the destination.

ZMAC (Zebra-MAC)[12] is hybrid MAC protocol combining strength of TDMA and CSMA offsetting their weaknesses. Z-MAC behaves like CSMA under low contention and like TDMA under high contention. Unlike TDMA, it is robust to dynamic topology changes and time synchronization failures commonly appearing in sensor networks. It also handles hidden terminals with very little overhead, unlike CSMA. In ZMAC, nodes have their own fixed assigning time slot for transmission. As in CSMA, before a node transmits in a slot, it always performs carrier-sensing and transmits a packet when the channel is clear. However, an owner of that slot has priority over its non-owners in accessing the channel. The priority is implemented by adjusting the initial back off period; higher priority nodes have shorter back off periods. The goal is that during the slots where owners have data to transmit, Z-MAC reduces the chance of collision since owners are given earlier chances to transmit and their slots are scheduled a priori to avoid collision, but when a slot is not in use by its owners, non-owners can steal the slot. This priority scheme has an effect of implicitly switching between CSMA and TDMA depending on the level of contention.

X-MAC [13] (Low power listening) is a shorted preamble MAC protocol, which is an energy efficient and introduces an optimization to adaptively select sleep times for improved energy consumption and latency. X-MAC introduces a series of short preamble packets which containing target address information, thereby avoiding the overhearing problem of low power listening, saving energy on non-target receivers. X-MAC inserts pauses into the series of short preamble packets, creating a strobed preamble, which enables the target receiver to shorten the strobed preamble via an early acknowledgment, thereby achieving additional energy savings at the sender and receiver, as well as a reduction in per-hop latency.

AppSleep [14] MAC is stream oriented power management MAC protocol which provides low latency. AppSleep leverages application characteristics in order to take advantage of periods of high latency tolerance to put the network to sleep for extended periods of time, while still facilitating low latency responses when required. AppSleep also gives applications the flexibility to efficiently and effectively trade latency for energy when desired, and enables energy efficient multi-fragment unicast communication by only keeping the active route awake. AppSleep contains components to handle sleep/wake up control, time synchronization, SYNCH packet loss, and adaptive sleep. CONVERGENT MAC (CMAC) [15] is novel MAC layer protocol which improves energy efficiency and the latency by utilizing aggressive RTS, anycast and convergent packet forwarding mechanisms. It uses “aggressive RTS” equipped with double channel check for channel assessment as shown in figure 3. In CMAC there is unsynchronized sleep scheduling (or duty cycling) when there is no packet to transmit. it avoids synchronization overhead during supporting low latency. When there is no traffic, it uses zero communication CMAC allows operation at very low duty cycles. In the situation of traffic, CMAC first uses anycast for packet forwarding to wake up forwarding nodes or to quickly discover forwarder and then converges from route suboptimal anycast with unsynchronized duty cycling to route-optimal unicast with synchronized scheduling. For flow initialization it use anycast and for flow stabilization it uses convergent Packet forwarding.

RSSI and DSR based [17] MAC is based on DSR (Dynamic Source Routing) and RSSI (Received Signal Strength indication). It is based on energy efficient clustering technique and dynamic source routing algorithm (DSR) for MAC protocol on wireless sensor networks which is based on TDMA. The RSSI value, energy level and load of each node is estimated and exchanged with its neighbors. The MAC Protocol adjusts the transmission power level based on the collected RSSI value of the neighbors. If the RSSI value is greater than a certain threshold level, then the transmission power is reduced and if the RSSI value is lesser than a certain threshold level, then the transmission power is increased by the MAC protocol.

In this paper we propose new power management algorithms for MAC protocol, called AMAC (Adaptive MAC), which consistently performs well in regardless of traffic conditions in network. The propose MAC protocol switch between suggested three algorithms based on the power of node. These three algorithms are Talk Time estimation, Adaptive duty cycling and Buffering method. In Talk Time estimation algorithm based on number of transmission packets, it calculates the communication period that is also known as talk interval. To provide information of communication period beacon signals are used by the nodes.

In adaptive duty cycling algorithms nodes adapt their duty cycle based on the traffic demands and network topology. And thus due to adaptive duty cycle power is saved avoiding idle listening. In buffering algorithm first of all data packets are stored in buffer and transmit them when numbers of packets increase in predefined threshold value of buffer.

The network model considered in this paper is a multihop wireless sensor network. Assuming that there are N nodes distributed randomly in the target area. The nodes can communicate with each other or send data to the sink using omnidirectional antennas. Each sensor is able to multicast, which means a sensor can send data to several nodes concurrently but not necessarily broadcast. The destined receivers are able to receive the desired packets where discarding others.

Each node has a fixed transmission radius and sensing range. A node receives a message if and only if it is within the transmission radius of the transmitting node. Each node resides in one of the two modes: sleep mode and active mode. During the active mode, the nodes can transmit and receive data or stay idle. All sensor nodes have the same parameter values of power consumption.

II. PROBLEM FORMULATION

The increasing miniaturization of electronic components and the advances in wireless technologies has fostered research on wireless sensor networks. In one of the classic models, a sensor network consists of a large number of tiny sensor nodes deployed over a geographical area. Each node is a low-power device that integrates computing, wireless communication, and sensing capabilities. Energy conservation in wireless sensor networks is a critical issue. An efficient method to reduce power consumption consists in powering off the nodes’ wireless transceiver when communication is not needed. The key concern in wireless sensor networks is energy consumption, as sensor nodes are battery powered. The battery has limited capacity and often cannot be replaced nor recharged, due to environmental or cost constraints. Therefore, the design of a sensor network should be energy aware in order to prolong network lifetime. Here we have chose power management MAC protocol to fulfill power requirement of sensor node.

III. PROTOCOL MODEL

A-MAC protocol is Adaptive MAC protocol which dynamically adapts MAC algorithm from any three suggested algorithms based on the power remains in sensor node and traffic condition of network at given time instant.

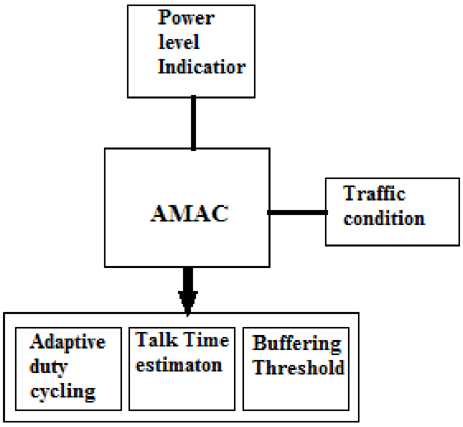

Figure 1 Model of A-MAC protocol

As shown in above Figure 1 sensor nodes choose MAC protocol based on their Battery Power status and traffic condition of the network. Thus here protocol switches among three algorithms and choose appropriate algorithm to meet traffic requirements. These three algorithms of AMAC are explained in following sections. The major advantage of AMAC protocol is that the schedules are automatically adapted based on the network congestion and on the application traffic demand, so that the network can operate efficiently and completely unattended even in very dynamic conditions.

IV. PROPOSED PROTOCOL

A-MAC protocol is basically combination of three algorithms which are talk time estimation, adaptive duty cycling and buffering approach. Based on the traffic demand and network congestion it will adopt any of the algorithms. In following subsection will see functioning of each algorithm.

A. Talk Time Estimation [2]

Sensor nodes are considered as cooperative because network is considered as multihop. Each parent node has to be physical neighbor of all its children. The clustering groups may change over time due to route changes (e.g., caused by node failures). Also, it may be recomputed periodically to better share power consumption among nodes, thus prolonging the network lifetime. However, as nodes are assumed to be static, the clusters once established remains stable for a reasonable time interval. In this algorithm, basic idea is that in typical data collection paradigm nodes can achieve low energy consumption and low latency in transferring data to the sink node if their active periods are staggered according to their position along the network. Ideally, the active part should be the minimum amount of time to allow each node to receive data from its children, and send data to its parent node. In addition, the active part should vary dynamically in order to cope with variations in the traffic pattern, network congestion or topology.

In propose algorithm, communication between a parent and its children occurs in *communication periods* (*CPs*) that repeat periodically. Each communication period is divided into two portions: a *talk interval* (*TI*), during which nodes communicate by using the underlying MAC protocol, and a *silence interval* during which nodes are sleeping. The talk interval between a node and its children is adjacent to the one between the node itself and its parent in order to reduce the energy dissipation due to state transitions. Consider a generic node *j* having node *i* as parent and node *k* as child. Let CP_m denote the m^{th} communication period, TI_{ij}^{m} the talk interval between nodes *i* and *j*, TI_{jk}^{m} the talk interval between nodes *j* and *k*, where following condition must be satisfied,

$$TI_{ij}^{m} + TI_{jk}^{m} \leq CP^{m}$$

Information regarding the communication period and talk interval is advertised by parent nodes to children by periodically sending out special packets called as *beacons*. Each beacon includes the time instant at which the next talk interval will be start, and the duration of the next talk interval. Therefore, children get idea when they have to be awake to meet with their parent nodes. Note that the protocol does not require any precise synchronization among nodes. Simple guard band mechanisms are used to avoid missing packets. Parent nodes send out a beacon at the end of every talk interval. To reduce the probability of collision with other packets, beacons are transmitted after a random delay within a beacon period, i.e. a reserved time period at the end of the talk interval.

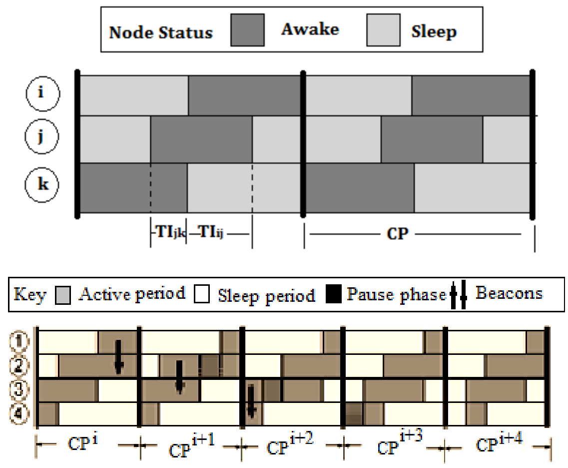

Figure 2 Communication periods between nodes i, j, k [2]

To calculate next talk interval between parent node and its child following parameters are consider. Here we assumed that, at the beginning of a talk interval a child node has all the packets it is going to send to the parent in a local buffer. During a communication period, the parent node measures the following quantities:

Packet inter-arrival time (Δ_i): The packet inter-arrival time is the difference between the time instants at which two subsequent packets are received. Where, Δ_i s is stored for all received packets.

Number of received packets (n_{pkt}): The total number of packets received in a single communication period.

These parameters refer to a single communication period, i.e. the current one. To smooth possible spikes in the estimator statistics, the estimate for the next communication period is computed using the values of the *L* previous communication periods. For this purpose each node uses two moving windows, in which it stores Δ_i and n_{pkt} related to the last *L* communication periods.

The total time required to get all packets sent by children in the next communication period is then estimated as:

$$TI_{est}^{m+1} = \overline{\Delta} \cdot n_{pkt}^{\max}$$

Where, $\overline{\Delta}$ is the average inter arrival time and $n_{pkt}^{\max}$ the maximum number of received packets. Note that using $n_{pkt}^{\max}$ is a conservative choice, to minimize the packet-loss probability. The estimate for the next talk interval is computed based on TI_{est}^{m+1} , and by recalling that the talk interval must also allow the parent node to send a beacon packet. Thus, the next talk-interval estimation is computed as,

$$TI_{rnd}^{m+1} = \left\lfloor \left(TI_{est}^{m+1} + BP\right) \div s \right\rfloor \cdot s$$

Where *BP* is beacon period and *s* is slot time. Specifically, the slot time is twice the maximum time required for a packet to be successfully delivered by the underlying MAC protocol. The talk interval estimates are expressed as an integer number of slots, and cannot be lower than one slot. This guarantees that any child has always a chance to send packets to the parent, even after phases during which it has no traffic to send.

Directly advertising TI_{rnd}^{m+1} to children as the next talk interval length might lead to some flapping of the protocol parameters. Therefore, in order to smooth the variation of the talk interval estimates, we also define two guard bands *g*1 and *g*2. The next talk interval advertised to children (TI^{m+1}) is finally computed as follow

$$\text{if } \left(TI_{rnd}^{m+1} - TI^{m} > g1\right)$$

$$TI^{m+1} = TI_{rnd}^{m+1}$$

$$\text{else } \left(TI^{m} - TI_{rnd}^{m+1} \geq g2\right)$$

$$TI^{m+1} = TI_{rnd}^{m+1} - s$$

This is the time estimation algorithm which estimates next communication period based on previous communication period.

Thus, suggested power management algorithm for sensor networks, suitable for data collection applications in which nodes have to periodically report to a sink. The main distinctive features of this scheme are: (i) it operates on top of the MAC protocol, and is not tight to any MAC in particular; and (ii) it is able to adapt the sleep/wakeup schedule dynamically, as the operating conditions change. These features are very well suited for sensor networks, which are expected to be deployed mostly at random, and have to run unattended after deployment. The only disadvantage of this method is its required more time to calculate next talk interval duration compare to other two methods. Also if traffic of network is increasing than also this protocol increases the delay of the network.

B. *Adaptive Duty Cycling [4]*

In this proposed algorithm sensor nodes adapts their duty cycle based on the traffic demands and network topology. There is no any fixed active and sleep duration of sensor nodes. Sensor nodes chose active time based on the data length required to be transmitted. After all time nodes remain in sleep duration only. So this algorithm avoids idle duration of sensor nodes which saved most of the power of nodes. Consider same network topology defined in section 1. In the given network sensor nodes adapts their active duration based on the length of data packets which need to transmit at a time. Here nodes are synchronized to avoid collision of data packets which reduced the retransmission of data packets. Also one control packet or signal required to wake up the sensor nodes from sleep period to active period. After the time out period if there is no more communication of data packets requires then sensor node goes into the sleep duration. Following figure shows the adaptive duty cycling approach for sensor node.

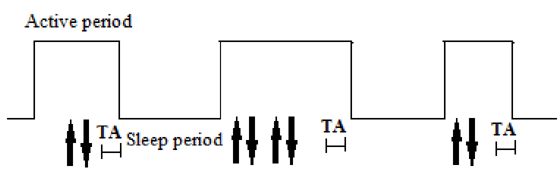

Figure 3. Adaptive duty cycle of node with TA (Time out)[4]

Here, TA is time out period, after TA time if there is no any other movement of sensor node then node goes to in sleep duration. The arrow indicates data packets transmission between nodes. From the figure it is clear that the active duration of node is change every time. In proposed algorithm sensor nodes decide their active duration based on traffic demands and position of node in the network topology. Thus, here idle listening duration of nodes reduces or in some case it's almost not available, so power is saved more. This protocol works better in high traffic conditions in network.

C. *Buffering Approach [5]*

Here we introduce the proposed buffering approach protocol which transmits data with properly adjusted buffer threshold. It redefines the timer used in adaptive duty cycling MAC and employs a novel contention window dynamically adjusted based on the buffer status. It substantially improves the energy efficiency and thus extends the network lifetime of WSNs. Major features of buffering approach MAC are as follows:

i. Dynamically adjust the threshold value of the buffer of each sensor node,
ii. Set optimal value of the threshold with respect to energy efficiency,
iii. Decide the contention window based on the buffer status in each node,
iv. Redefine the timer for active mode,
v. Modify the structure of control packet.

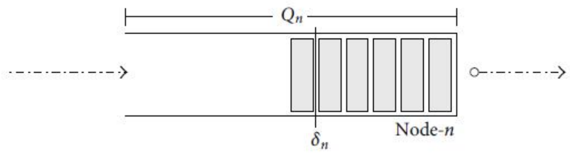

Figure 3 structure of the buffer of the node [5]

Above figure shows the structure of the buffer of a node. Q_n and δ_n denote buffer size and buffer threshold of Node-*n*, respectively. As shown in figure, data are transmitted when the accumulated data exceeds the threshold of the buffer. In this MAC the node switches to sleep mode when it does not detect any activity until the timer expires to maximize the energy efficiency. Whereas the efficiency of existing protocols degrades in some traffic conditions, MAC consistently performs well using the dynamically adjusted buffer threshold.

This MAC protocol required extra buffer to stored data packets. This protocol employs a dynamically adjusted threshold for the buffer of sensor node. It is designed to display consistent performance for various network traffic conditions. Also less control packets required. As a result, protocol can improve the energy efficiency which is one of critical issues of MAC protocol for sensor networks in addition to the QoS including fairness among the nodes, channel utilization, delay, and so forth.

V. SIMULATION RESULTS

In following section we show simulation results obtained in multi hope WSN in dynamic scenario. Firstly we have shown duty cycle for each power management algorithm based on active and sleep duration of sensor nodes. For simulations we have considered parameters such as, Talk interval slot (s) of 150 ms, Beacon period of 60 ms, Packet size (payload) of 1000 bytes, Communication period of 30 s, Moving window size (L) of 10.

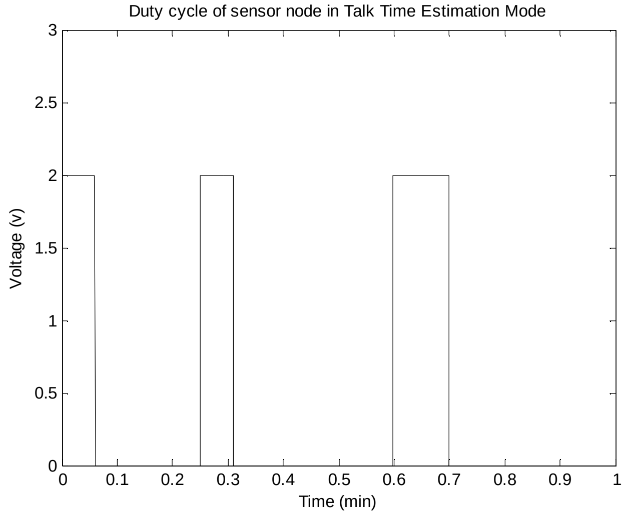

Figure 4 Duty cycle of sensor node during Talk time estimation

From figure 4 is shows that sensor nodes are remain in active for very short period of time and for other time it will remain in sleep mode. Figure 5 shows the duty cycle of sensor node in adaptive duty cycling mode. In figure also duty cycle of sensor for fixed duty cycle approach is also shown. From that it clears that unnecessary power which is waste earlier in fixed mode will be saved in adaptive cycling approach.

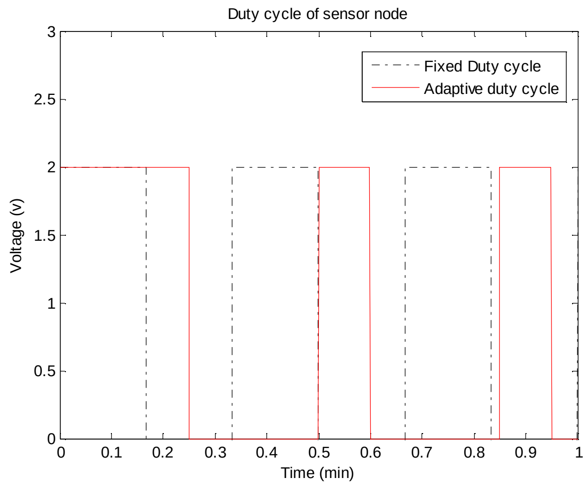

Figure 5 Duty cycle of sensor node in Fixed duty cycle approach and Adaptive duty cycle approach.

Figure 6 shows the duty cycle of sensor node in buffering approach. In buffering approach, sensor nodes transmit data packets only when buffer is full of data packets beyond the threshold level. Again after transmission of data packets sensor nodes go on sleep duration.

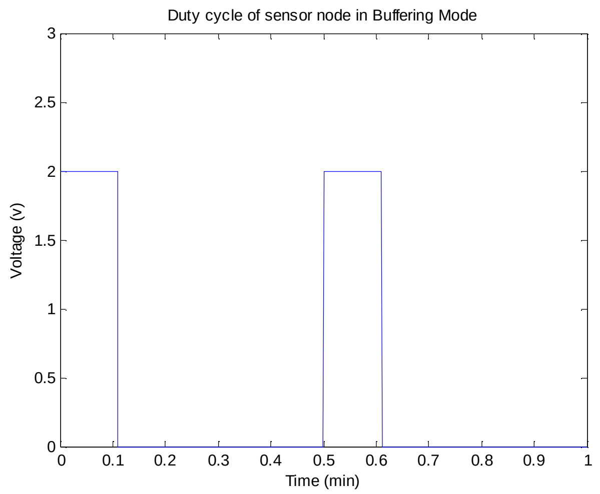

Figure 6 Duty cycle of sensor node in Buffering Mode

By comparing duty cycle of sensor node for all three algorithm it clearly shown that in buffering approach more power saved due to small duty cycle compare to all. Figure 7 shows the how sensor node adapts talk time interval based on traffic condition with communication period. It also shows the talk time period of four nodes in network which transmit data in multi hope manner.

Figure 8 and 9 shows the comparison of power consumption of network and lifetime of sensor network for all three algorithms. From figure it clears that in all mode AMAC protocol save power and transmits information without fail. Thus based on power level of sensor nodes and network congestion AMAC switched among these three algorithms.

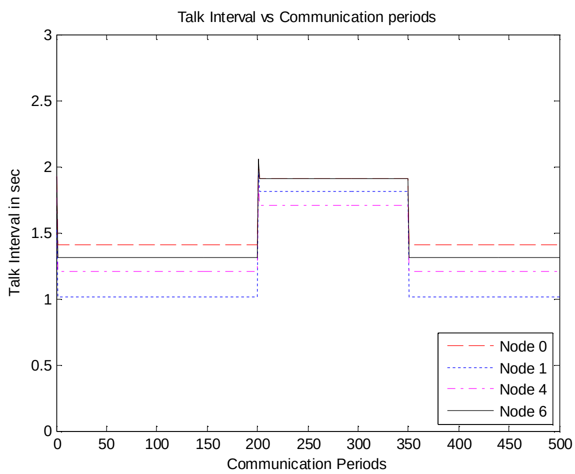

Figure 7 Adaption of talk time interval of sensor nodes with communication period

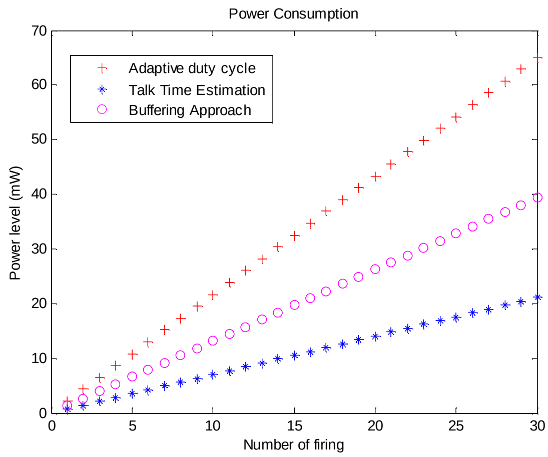

Figure 8 Power consumption of AMAC for all modes

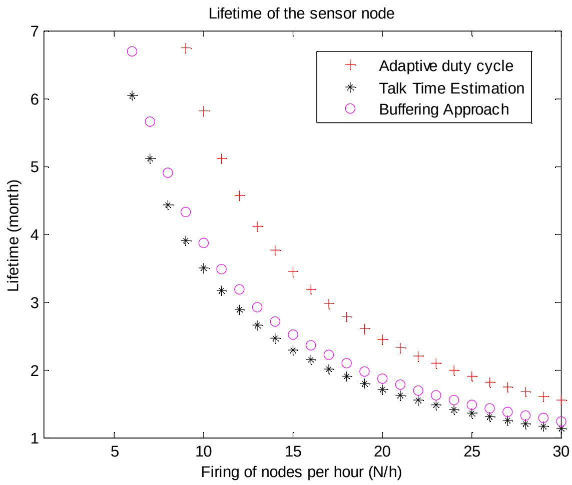

Figure 9 Lifetime of sensor network in AMAC

VI. CONCLUSIONS

Energy consumption in WSNs can be minimized by designing energy efficient MAC protocols since they have a large impact on the efficiency of WSNs. Designing MAC protocols for WSNs raises a distinctive set of challenges. In this paper we have proposed a new energy efficient MAC protocol, called Adaptive MAC (AMAC), which adapts one algorithm based on network congestion and traffic conditions.

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