Energy Conservation MAC Protocols with Low Duty Cycling for WSN: A Review

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ABSTRACT

The energy constraints in the wireless sensor network are under too much consideration. Since WSN is based on relay system and therefore each node participate in complete communication process either as a source, forwarding nodes or as a receiver. This paper presents critical reviews on recent development in various MAC protocols for saving energy in wireless sensor network by modifying duty cycle. These protocols are based on the work done on the Medium Access Control layer of TCP/IP protocol suit.

General Terms

Low power listening, Wake-up schedule, synchronization

Keywords

LPL, PION, CCA, RTS, CTS, SIFS, DIFS

1. INTRODUCTION

A wireless sensor network consists of tiny nodes operated on low power battery. These nodes have to perform many tasks such as sensing environment for information extraction, network establishment and propagating the information. For all these operations, sensor node requires power from its limited battery.

There is much concern over Battery utilization in the sensor nodes having very little backup. Sensor network focuses on the two major areas for preserving energy which are networking sub system and sensing sub system. For the network sub system, nodes are engaged in management of routes, links, sending and receiving of data. For the sensing subsystem nodes generally reduce the amount of energy expensive samples. Protocols that are used for energy conservation can be categorized according to their characteristics into three major groups which are Data Driven, Mobility Based and Duty Cycling mentioned in survey paper [1].

Data Driven:- This approach is based on the reduction of data in the network. It mainly focuses on the model used to send data for conserving energy, in which source and sink nodes are used and decide how to collect data and forward them to the sink. The sensed data is compared with predicted data at sensor nodes and if the difference is within an application dependent tolerance, then it is assumed that the model is valid. If difference is greater than tolerance limit then sampled data is send as it is and model is updated. Redundant data are removed by certain procedures like In-network processing, Data prediction and Data compression. One more category is important for this heading i.e. efficiently data acquisition technique which deals with the sampling of data by using following methods adaptive, hierarchical and Model Driven active sampling. It concern over data reduction through in-network processing, Data compression and data prediction. There is another suitable technique to reduce the energy consumption such as implementing cross layer design for application, data representation, routing and MAC. However detail studies should be done in approximate representation of sensors reading with sophisticated data structure.

Another technique is prediction based but it requires large computing and storage unit which makes it costly affaire. The need of large centralized computing resources in energy efficient data acquisition protocols makes it complex system. To reduce the complexity of this approach a new area of distributed approach is investigated. Comprehensive sensing, dual prediction with adaptive sampling in a seamless architecture etc. are some more areas to investigate. Hierarchical sampling is based on characteristics of sensing environment so there is requirements of specific application based transceivers. These transceivers are costly and tightly bounded with application. Model-based active sampling has some limitation such as preplan of network data acquisition, workless in fault oriented network, no outlier detection etc.

Mobility Based approach:-This approach concentrates over the resolution of the problem of stationary sink where data traffic is very high causing depletion of energy with high rate in the neighborhood nodes of sink. Changing the position of sink node helps in uniform distribution of energy consumption.

Mobile Sink solves the problem of hot spot near sink node but increases complexity of implementation for example there should be extra algorithm is required for the sink node movement with the suitable speed and sojourn time at the site in addition of routing the data to the sink node is another area for investigation. Energy efficient techniques are required to timely discover the mobile node by the stationary nodes keeping low probability of missing contacts with mobile node.

Duty cycle:- The sleep period is most favorable period where remarkable amount of energy be saved. The nature of sensor network environment is unpredictable and therefore most of the time energy is wasted during ideal listing of the sensor. A proper scheduling for sensor node sleep wakeup activity is required which can effectively save energy and also provide good throughput without noticeable delay. Among all the type of techniques, duty cycle is most favorable approach for investigation because it is applicable where redundant sensor nodes are deployed and a set of few numbers of nodes required for communication. Rests of the nodes which are not in the communication process go to sleep. A proper synchronization is required for the good performance in communication.

Number of sensor nodes is optimized for the communication which is researched under topological control category. Two approach have been reviewed which are location and connectivity driven. GPS enabled location driven approach is not suitable for the highly dense deployment of sensor nodes. Sensor nodes become expensive as well as bulky. Also bad weather condition creates problem for the proper operation of GPS.

Power management scheme is another technique in Duty cycling which emphasis on the active state of sensor node. Sleep wakeup protocols discussed above have some limitation such as requirement of extra radio, proper scheduling in sleep-wake up timings. The problem can be further reduced by using embedded clocks in asynchronous approach.

MAC protocol is one of the areas for power management where improvement is required, because of the dense deployment of nodes; there is too much energy consumption in the process of communication, collision, retransmission, ideal listening etc. TDMA, Contention Based and Hybrid approaches are used to avoid unnecessary energy consumption with some flaws. Fixed slot allocation in TDMA is preferably not suitable in highly dynamic environment of sensor nodes. Also energy is wasted during collision and retransmission in the contention based approach. Hybrid approach uses advantages of both of these approaches.

2. LOW DUTY CYCLE MAC PROTOCOLS

As we have observed that various techniques are employed to save energy in different schemes of energy conservation protocols. In this paper we mainly focus over MAC scheme with low duty cycling, since it has large impact on the overall energy conservation. A good MAC protocol adapt with changes in topology, environmental effect, node density etc. MAC protocols are classified in the following categories, Contention based, Schedule based and Hybrid (Slot). The protocols are investigated based on the following three criteria:-

– Number of physical channel (or nature) used:- Single, Double (Data + tone and Data + Control) and Multiple (FDMA and CDMA)

– The degree of organization (or independence) between nodes:- Random, Slots and Frames, and

– Notification method:- Listening, Wakeup and Schedule

In contrast to WLAN protocol, MAC protocol are designed for sensor network usually tradeoff performance (Latency, throughput, fairness) for cost (energy, efficiency, reduced algorithmic complexity). The sources of overhead as Ideal Listening, Collision, Overhearing, Protocol Overhead, and Traffic Fluctuations are much prevailed in contention based MAC protocols. This energy consuming overhead are minimized in Scheduled based (TDMA) approach. But TDMA pay some cost in the way like Schedule broadcasting and reduced capability to handle traffic fluctuation between mobile nodes.

2.1. Contention based MAC Protocol

In contention based protocol, there are nodes contending for the channel to send the data. So there are major challenges to save energy during unnecessary collision, overhearing and idle listening. CSMA/CA is good example for collision avoidance. Also it adapts to avoid overhearing. IEEE 802.11 is based on CSMA where distributed inter frame spacing (DIFS) is employed by sender which is a duration, for which sender wait for checking medium to free. If medium is free then receiver send the clear to send (CTS) signal after waiting for short inter frame spacing (SIFS). If collision or packet lost occurs then sender waits and uses binary exponential back-off function and then sends data again. **Figure 1** show IEEE 802.11 MAC approach with one sender, receiver and other nodes. Sender uses DIFS and sends RTS as mentioned above then receiver clears that it can receive data. During RTS-CTS mechanism a Network Allocation Vector (NAV) is set by other nodes using the signal which is transmitted by sender containing information of communication duration. Other nodes overhear and acquainted with the information and delay their communication, also this information is strengthened by receiver at the time of CTS. After the transmission and reception of Data, receiver sends acknowledgement to confirm the data reception and then next Contention Window (CW) is started. In this way the collision is eliminated on the expense of energy consumed during overhearing.

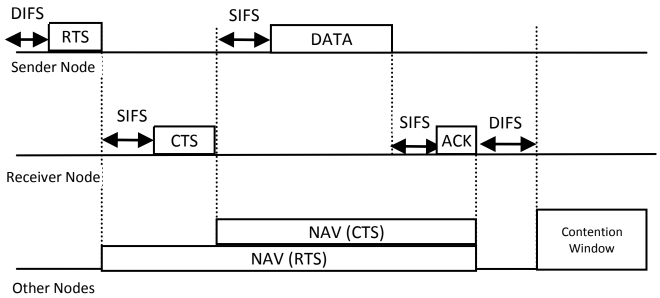

Figure 1: IEEE 802.11 MAC approach

2.1.1. B-MAC [2]

The IEEE 802.11 consumes much energy during ideal listening and it is inappropriate for low duty cycle. The protocol [2] proposed by Joseph Polastre, Jason Hill and David Culler is ultra low power operation interface, effective collision avoidance and high channel utilization. B-MAC (Berkley-MAC) uses adaptive preamble sampling scheme to reduce duty cycle and minimizes ideal listening. B-MAC is design of versatile, configurable interface MAC protocol. B-MAC configures itself according the current work load. B-MAC is motivated by the needs of monitoring application. It realizes other application and services like target tracking, localization, triggered event reporting and multi-hop routing. It uses clear channel assessment (CCA) and packet back-off for channel arbitration, link layer acknowledgments for reliability, and low power listening (LPL) for low power communication. It also provides network services like organization, synchronization and routing. Noise Floor Estimation method of B-MAC help in finding a clear channel on transmission and it determine whether the channel is active during LPL or not.

The node's life time is determined by its overall energy consumption which is calculated as:-

$$E = E_{rx} + E_{tx} + E_{listen} + E_d + E_{sleep}$$

Where E = total energy consumption

E_{rx}, E_{tx}= Energy consumption in reception and transmission

E_d= energy of sampling data

E_{sleep} =energy during sleep

For the calculation of energy consumed in sampling the following formula is used

$$t_d = t_{data} \times r$$

$$E_d = t_d c_{data} V$$

Where t_{data} = time duration for data TX/RX

t_d= time utilized in data transmission with rate r

c_{data} = current used for sampling data

V= voltage required for sampling

The energy consumed during transmission is calculated as:-

$$t_{tx} = r \times (L_{preamble} + L_{packet})t_{txb}$$

$$E_{tx} = t_{tx} c_{txb} V$$

Where t_{tx}= time duration of data transmission

$L_{preamble}$ = length of preamble signal

L_{packet} = length of data

t_{txb} = time of one byte data transmission

c_{txb} = current required to transmit one byte data

V= voltage required for transmission

The bound limit is used over total time the node will consume for receiving packets and the limit of energy consumption E_{tx} calculated as

$$t_{rx} \leq nr \times (L_{preamble} + L_{packet})t_{txb}$$

$$E_{rx} = t_{rx} c_{rxb} V$$

Where n = number of neighbors of sender

In the B-MAC protocol ideal listening time t_{listen} is reduced when it samples and no activity is present at that duration. In order to reliably receive the packets, the LPL check interval time t_i must be less than the preamble time as:-

$$L_{preamble} \geq [t_i/t_{rxb}]$$

With the information of check interval and associated preamble length, it is easy to calculate time spent in sampling channel. The total listening time is calculated using single channel sampling time and the frequency of sampling as:-

$$t_{listen} = \left(t_{r_{init}} + t_{r_{on}} + t_{rx/tx} + t_{sr}\right) \times \frac{1}{t_i}$$

$$E_{listen} \leq E_{Sample} \times \frac{1}{t_i}$$

Where $t_{r_{init}}$ = time for initializing radio

$t_{r_{on}}$= time for starting radio

$t_{rx/tx}$= time for switching from RX/TX

t_{sr}= time for sampling radio

E_{listen} =energy consumption during sleep

E_{Sample} =energy consumption in single LPL radio sample

t_{listen} = time required during listen period

At last the node can sleep in the intervals left all these operation calculated as:

$$t_{sleep} = (1 - t_{rx} - t_{rx} - t_d - t_{listen}) \times \frac{1}{t_i}$$

$$E_{listen} = t_{sleep} c_{sleep} V$$

Where t_{sleep} = sleep period for sensor node

E_{listen} = Energy consumption during sleep

Now the life time of single sensor node which is dependent on total energy consumed E and the battery capacity is calculated as:-

$$t_l = \frac{C_{batt} \times V}{E} \times 60 \times 60$$

Where t_l= life time of sensor node

C_{batt} = battery capacity

B-MAC can perform better in case of one hop to base station optimization and balanced tree configuration of sensor nodes deployment. Also optimization requires in the system services application for the long term usability of B-MAC. This optimization is also proposed in WiseMAC [3] where preamble is considerably reduced in size which saves transmission and reception cost.

2.2. TDMA based MAC protocol

This section discuss scheduled based protocol category which are fully collision free because in such protocols slot is allotted before the beginning of transmission. In such protocols energy efficiency is attained by transmission schedule, which avoids collision at receiver end and switching at low power radio when there is no data intended for it.

2.2.1. TRAMA-Traffic Adaptive Medium Access Control[4]

It is one of the fine scheduled based protocols. The election algorithm is used to select sender in competition of channel reuse. TRAMA [4] by V. Rajendran, K. Obraczka, and J. J. Garcia-Luna-Aceves uses identifiers of the nodes, one and two hop away, the current time slot, and traffic information that specify that which node intends to transmit to other nodes for collision free transmission. The protocol refers random-access slots for signaling and schedule-access slots as transmission slots. Timestamp mechanism is used for node synchronization. To get two hop information of the node a signaling slot is used in which contention based mechanism applied which may cause collision. Schedule Exchange protocol (SEP) is used by nodes to announce its schedule, traffic based information with neighbor for better channel utilization. Node uses state of the queue for announcement. Slots are pre-computed in the interval [t, t + schedule interval] for the node having highest priority its two hop neighbors. These slots are used by node as a transmitter and receiver and if the nodes do not have enough packets to transmit then it give up the slots. These vacant slots are further used by other nodes that have data to send. Nodes announce the schedule using schedule packets containing bitmap which is used to identify the neighbors ordered sequentially. This bitmap is a quantity which is equal to the total number of one-hop neighbors of the node. Bitmap is helpful in broadcast and multicast transmission. Schedule summary is transmitted with data packets which minimizes the data loss. It consists of schedule timeout, numSlots and bitmap corresponding to the winning slots in the current interval. With this information the intended receiver updates its schedule information and resynchronizes itself. Schedule packet format is shown **Figure 2** Change over slot is a slot after which all winning slots go unused. These unused winning slots accumulate at the end before the last winning slot, which is used for announcing next schedule. This maximizes the sleep duration.

The Adaptive Election Algorithm is used to identify the states of node which are Transmit (TX), Receive (RX) and Sleep (SL). These states depend upon the Absolute winner and the announced schedules from its one hop neighbors. From the particular node's point of view an Absolute Winner is (a) node itself (b) a node from the two hop neighbor of the node and (c) a node lies in the node's one hop neighborhood. TRAMA keep set of possible contender within one hop for channel into set known as Possible Transmitter Set. A node uses extra slot for transmission without collision only if it has highest priority in the neighbor's two hop neighborhood.

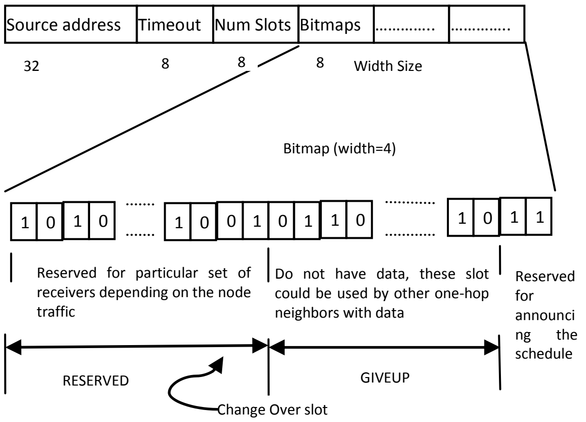

Figure 2: TRAMA Format of schedule packet

TRAMA is more adaptive with respect to sensor network based applications; it supports unicast, broadcast, and multicast functionalities.

2.2.2. ATMA [5]

The bursty nature of traffic in sensor network is under reviewed and found the solution using the protocol known as ATMA (Advertisement based TDMA protocol)[5] by Surjya Ray, Ilker Demirkol and Wendi Heinzelman. This protocol is similar to slot selection protocol TRAMA with 99% packet delivery guarantee. The number of signal packet transmission is set to 7 in TRAMA which result in longer delay and higher energy consumption.

The ATMA uses the concept of S-MAC protocol, which divides the frame into SYNC, advertisement and data periods. Advertisement and SYNC periods are contention based and data period is divided into slots. Since frame size is much larger than the drift period therefore contention based SYNC and advertisement exchange without any problem.

Advertisement period is divided into small slots which depend on clock resolution. The ADV packet contains receiver ID and selected data slot period. Each node chooses the slot number and initializes the timer. When timer reaches the zero the ADV packet is transmitted and waits for acknowledgement from the intended receiver. Successful reception of A-ACK from the intended receiver confirms that all the neighbors of the receiver is aware of which slot is used. Receiver deferred its ACK packets when it observes that selected slot is already occupied by another transmission. When sender wants to send ADV packets and found that another transmission is running then it delayed its transmission with frizzing timer to avoid collision. Reducing the number of ADV packets transmission for individual packets during busty traffic saves much energy. Only single ADV/A-ACK is required for reserving single slot in transmission of 'n' consecutive data packets. Data period is divided into slots which are enough longer than ADV slots.

2.2.3. Adaptive-TDMA based protocol[6]

It is a good option in which collision avoidance is assured by assigning nodes on different sub channels divided in time.

Adaptive TDMA-based MAC protocol [6] by T.-H. Hsu P.-Y. Yen is also named as bit-mapped-assisted Round Robin (BMA-RR). The variable slot size of this protocol is much suitable in sensor environment against fixed slot in LEACH [7] protocol. This slot assignment or TDMA schedule broadcasting is done by cluster Head.

Non Cluster head nodes send the control messages to cluster head for more requirement of slots which is further processed by cluster head. This process is divided into two different phases

- Cluster set-up phase
- TDMA broadcasting phase.

In the cluster setup phase, TDMA based protocol is using LEACH [7] technology to elect cluster head and the cluster head send ADV message using n- persistent CSMA technique which contain Head ID. In response of this message, non cluster head sensors send JOIN-REQUEST message which contain their node ID and ID of cluster Head. After completion of above process the cluster head sets up TDMA based schedule. The cluster head broadcast the time slots to all nodes in the cluster during which all the nodes reached in steady state phase. Steady state phase and setup phase together form one round and each round consists of several sessions with duration 'S'. Session 'S' is divided between four periods which are control period, announcement period, transmission period and idle period. Control period is used by nodes, which are willing to send the data to cluster head. This provides schedule for each node and announces the schedules to all the other nodes in the announcement period. The distribution of slots among nodes is done by round robin strategy. In the transmission period, the node uses time slots to send and receive data and rest of the nodes turn off their radios and goes to sleep to save the power. If the nodes have no data to send and receive then they reaches to idle period. In next session, the same period is repeated again.

To accomplish the task of scheduling sensor nodes in different slots, there are three arrays for slots management. First is job array, which holds number of requests of sensor nodes, second is schedule array which checks that sensor nodes have data for sending or not. If node has data to send then value of corresponding sensor node in job array is decreased by one and its value is increased in schedule array. Third is slot array which is used to hold the slot sequence of sensor nodes request.

Now the power is utilized by various nodes in different periods of the session.

$P_t\ mW$ =Power consumption during transmission

$P_r\ mW$ = Power used in receiving

P_i = Idle power.

T_d Seconds = Time required in sending the i^{th} data,

T_c Seconds = Time for Control information which is used by cluster

T_{ch}= The time for sending and receiving control packets.

The energy consumption by cluster setup phase is given by formula

$$E_{setup} = P_t T_{ch} + P_r T_c (N-1) + (N-1) P_t T_c + (N-1) P_r T_{ch} + P_t T_{ch} + (N-1) P_r T_{ch}$$

Where $P_t T_{ch}$= Total energy consumed by cluster to broadcast the ADV message cluster head for sending schedule to the node.

$P_rT_c(N-1)$ = The energy consumed by non cluster head nodes for receiving ADV messages.

$(N-1)P_tT_c$= Energy is used for sending Join Request to cluster head by non cluster head nodes.

$(N-1)P_rT_{ch}$= Total energy for receiving Join Request by cluster head and receiving Schedule by non cluster head nodes

Energy consumption at each non cluster head node during a single session is calculated by

$$E_{sn} = P_tT_c + (N-2)P_tT_c + P_rT_{ch} + P_tT_d$$

For the j source node, if it send TD_{num} Data then energy consume by it is done by formula

$$E_{sn\_TD} = (P_tT_d)TD_{num}$$

For the single session the energy consumed by j node is

$$E_{sn-j} = E_{sn} + E_{sn-TD}$$

During the transmission, each non source node keeps off their radio when they are idle and their energy consumption for single session is calculated by

$$E_{in} = P_iT_c + (N-2)P_iT_c + P_rT_{ch}$$

And the energy consumed by cluster head during a single session is calculated by formula

$$E_{ch} = cP_rT_c + (N-1-c)P_iT_c + P_tT_{ch} + n_iP_rT_d$$

Energy consumption is due to receiving c packets by cluster head from member nodes during control period and stays idle for (N-1-c) control slots, where $n_i$is total number of packets transmitted during i^{th}session. Energy consumption during i^{th} session is calculated by

$$E_{si} = \sum_{j=1}^{c} E_{sn-j} + (N-1-c)E_{in} + E_{ch}$$

The total energy consumption in steady state period is calculated by

$$E_{total} = \sum_{i=1}^{k} \mathrm{E_{si}}$$

Each round consist of k sessions and therefore total energy consumption during each round is

$$E_{round} = E_{setup} + E_{total}$$

The BMA-RR sends more number of control packets for the use of idle time slot efficiently than traditional TDMA, E-TDMA and BMA MAC protocols. In this protocol we achieve following two things, one is to conserve energy on nodes with low data traffic and second is to decrease transmission latency and increase data throughout with heavy data traffic.

2.3. Hybrid Slot based MAC Protocols

2.3.1. SMAC-Sensor MAC [8]

SMAC is described in the paper [8] by Wei Ye, John Heidemann, Deborah Estrin which focuses on four measure issues of wasting of energy such as overhearing, control packet overhead, collision and idle listening. In this protocol, long messages are broken down into short packets and send into burst, since those nodes having large message size take more time than others. In idle listening condition sensors are in sleep mode to save the energy. This contention based protocol is similar to PAMAS [8] because both of them avoid overhearing but have little difference in the use of band signal, which is present in PAMAS but not in SMAC. In SMAC protocol, various assumptions are made for example in the network and application there are large number of sensor network deployment to manage latency, periodic listen and sleep which is synchronized among the nodes through broadcasting of schedules. These schedules are maintained by neighbors in their tables. There are two types of nodes, one is synchronizer, which decides the schedules for sleep and wakeup, another one is follower which follows the schedules provided by synchronizer. In case of ambiguity node follow both the schedule of synchronizer and follower. The medium access mechanism is same as IEEE 802.11 using RTS and CTS. Also network is in flat topology i.e. there is virtual clustering mechanism. Synchronization is achieved through SYNC packets containing address of node and its schedule for sleep. **Figure 3** shows the conditions for SYNC packet transmitted by sender in timing relationship diagram, First sender wants to send only Sync packet, second sender sends RTS packet only and third sends both SYNC and RTS. CS is abbreviated as carrier sense.

Collision avoidance is based on IEEE 802.11 RTS-CTS mechanism and each data packets contain information for remaining time of communication in NAV field abbreviated as network allocation vector. Sender responsibility

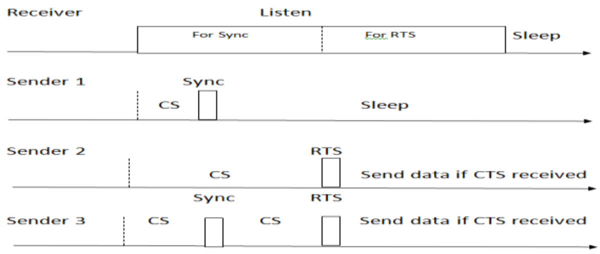

Fig 3: Timing diagram conditions for sender transmission

is to sense carrier first before sending data packets and if medium is busy then nodes go to sleep for random amount of time. unicast packets follow the following order of process RTS-CTS-DATA-ACK and there is no need of RTS and CTS for the broadcast packets. Also NAV information is enough for preventing nodes from overhearing of neighbor nodes messages which is also considered as important issue in wastage of energy.

A message passing is a technique in which data packet is send in the small fragments and wait for acknowledgement of each fragments. The technique is something different than IEEE 802.11 RTS-CTS technique. During fragment transmission, SMAC reserves channel for all fragments and if any of the fragment fails to reach or corrupted during communication than the transmission of fragment increase the duration of reservation through the ACK which helps the nodes to involve in fewer contention.

With all the delay of IEEE 802.11, there is one more delay in SMAC i.e. sleep-delay which is due to sleep of the receiver. A complete frame of time consist of Listen and Sleep period and considering that packets are arriving with equal probability the average sleep-delay on the sender is

$$D_s = {T_{frame}}/{2}$$

Where D_s = sleep-delay

T_{frame} = Frame length

$$T_{frame} = T_{listen} + T_{sleep}$$

Where T_{listen} = time period for listening

T_{sleep} = time period for sleep

As compare with non periodic sleep protocols,

The energy save is

$$E_s = \frac{Tsleep}{Tframe} = 1 - \frac{T_{listen}}{T_{frame}}$$

Here conclusion is that if listen period is short as compare to other protocols then it saves much energy. For the heavy load condition, there is much energy consumption in S-MAC than MAC802.11, since S-MAC requires synchronization and for which it sends more number of SYNC packets.

2.3.2. RMAC[10]

RMAC (routing enhance duty cycle)[10] by Shu, D.; Saha, A.K.; Johnson, D.B is similar approach as used in S-MAC with wisely utilization of data period in duty cycle. For the communication with the multi-hop away destination, it uses a PION signal which propagates to destination through many intermediate nodes. For the PION signal, RMAC uses data period of duty cycle as shown in the **Figure 4**. During sleep period data communication take place and involve those nodes which are agreed for data relay and rest of them go to sleep. PION contains all the details of RTS (source address, next hop address and time of communication) and additional cross layer routing layer information like final destination address. Data transmission is like a pipeline process as shown in **Figure 4** which performs into the sleeping period of the duty cycle. In the sleeping period, nodes which have confirmed for data relay are wakeup at the right time to forward the data frame. The exact time of wakeup is calculated as:-

$$T_{wakeup}\ (i) = (i-1).(durDATA + SIFS\ + durACK + SIFS)$$

Where durDATA = time to send single data frame

durACK = time to send Acknowledgement

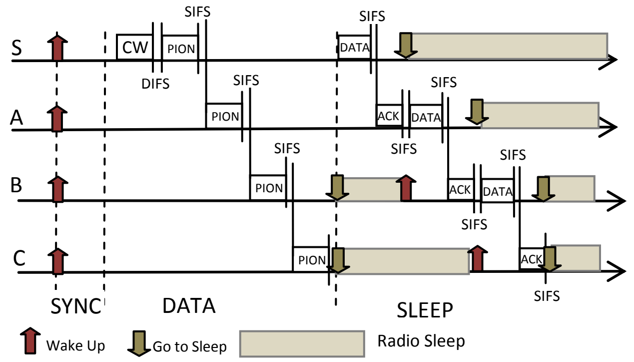

Figure 4: RMAC Overview

Setting of network allocation vector (NAV) is also important aspect of this protocol and it is done for three segments of time

(a) Confirmation PION Segment: [now, now + durPION]

(b) Data Segment: [$t_{datastart}$,$t_{dataend}$]

(c) ACK Segment: [$t_{ackstart}$,t_{ackend}]

There are circumstances when frame is lost and therefore affecting schedules of downstream nodes which is handle by upstream nodes, through restricting themselves to retry PION transmission in the same operating cycle. The retransmission takes place in next duty cycle. Node follows next hop duty cycle if it has different schedule then the nodes at upstream itself for the sake of resolving ambiguities and synchronization.

2.3.3. P-MAC [11]

This protocol supports data forwarding with help of cross layer approach. P-MAC [11] protocol by Fei Tong 1, Rong Xie 1, Lei Shu 2 and Young-Chon Kim divides the network into virtual grids where nodes become member of corresponding grid according to the distance from the sink. S-MAC is known for energy efficient sensor MAC protocol but it has one disadvantage i.e. packet latency. Routing protocol is required by RMAC to process its function and it degrades the performance of MAC layer. P-MAC protocol forwards data packet from higher grades to the lower grades and then to sink of grade zero. It uses variation of RTS/CTS handshake mechanism for forwarding the data packets to the sink. First process is to initiate grade division and schedule assignment in the network by the sink. Nodes associate themselves with their logical grades according to the distance from the sink node. Grades increase from lower to higher i.e. from sink to rest of the network. Nodes within same grade have same schedule. But the schedules are staggered in two different adjacent grades. The schedule is divided into three periods send data, receive data and sleep. If nodes in the higher adjacent grade are in send data period then the nodes are in adjacent layer must be in receive data period. Nodes in same grade contend for medium but the nodes in adjacent grades cooperate. Data transmission has been shown **Figure 5**. NAV is not required in P-MAC like in IEEE 802.11 because after the contention, winner will receive data and rest of them will go to sleep.

Duration of each period is calculated as

a) SEND/RECEIVE DATA ($T_{S/R}$)

$$T_{S/R} = 2CW + 2DIFS + 2CIFS + durRTS + durCTS + durDATA + durACK$$

b) SLEEP period (T_{SLEEP})

$$T_{SLEEP} = sleep\_factor.T_{S/R}$$

Where $sleep\_factor$ is a positive integer.

The whole cycle is calculated as

$$T_{cycle} = \left(sleep_{factor} + 2\right).T_{S/R} = \tau.T_{S/R}$$

Where τ = cycle coefficient.

The proper function of P-MAC is shown in **Figure 5.**

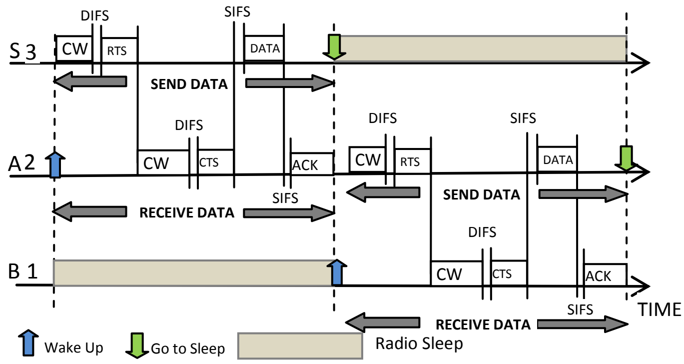

Figure 5: P-MAC integrated with routing, node S has data to send

Schedule is chosen by node i when it is already associated with grade using some criteria like:

a) The node will reach in RECEIVE DATA: if $i \,\%\, \tau = 0$ after $T_g - i.durGRADE$ time.

b) The node will reach in SEND DATA: if $i \,\%\, \tau = 1$ after $T_g - i.durGRADE$ time.

c) The node will reach in SLEEP: if $i \,\%\, \tau \geq 1$ after $T_g - i.durGRADE$ time.

d) SLEEP duration is:

$time = T_{SLEEP} - (i\%\tau - 2).T_{S/R} = (\tau - i\%\tau).T_{S/R}$

Where T_g= time to finish GDSA process.

P-MAC designed in such a way that it keeps minimum overhead and maintaining superiority of duty cycling with considering cross-layer optimization.

2.3.4. *IH-MAC[12]*

This is also a category of the MAC protocols, in the paper [12] intelligent hybrid MAC (IHMAC) by Mohammad Arifuzzaman, Mitsuji Matsumoto, Takuro Sato perform well in high traffic load with improved channel utilization without compromising energy efficiency; it combines the features of CSMA, broadcast scheduling and link scheduling. It uses broadcast scheduling and link scheduling dynamically according to traffic conditions. IHMAC protocol classifies the packet according to delay requirements and they are queued with priority specified by application layer. SYNC packets are used for synchronizing schedule among the nodes which are neighbors to it in the same virtual cluster. Given **Figure 6** explain the concept of synchronization schedule which is similar to SMAC but different in the use of virtual clustering in which all the nodes follow the same schedule, therefore all the nodes in the network are not required to have same schedule.

Frame slot is shown in **Figure 6** is assigned by keeping priority to the node which has critical data and if there is no such type of node than this opportunity goes to the owner of slot. Owner is decided by clock arithmetic. In case of multiple values through the calculation there is competition among different owners for medium access. Another type of slot known as rendezvous slot is used by node to send messages to their neighbors. This slot is calculated on the basis of system requirements such as network delay, load etc. The state diagram IHMAC is shown in the **Figure 7**, node goes in sleep state for the predetermined time value after that it goes to wakeup state and listen the channel. If node has data to send than it goes to CSMA/CA state and competes for channel access.

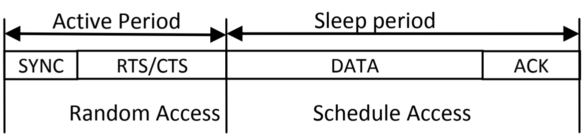

Fig 6: Random slot frame for IHMAC protocol

If it loses the contention then it goes to sleep state after setting the time for the next wakeup period. Parallel communication is also used within two hop network since collision occurs at receiver end. It helps the sender to send data to both the nodes which are in transmission and not in transmission range.

It also sends data to those which are not coming into the range of other sender transmission. For the parallel transmission IHMAC uses the NAV concept of IEEE 802.11, which block the sender for time period mentioned in NAV (network allocation vector), but in this protocol blocking is only done after looking for the possibility of parallel communication. For the data queued in the buffer, node convert some of its owned slot in to rendezvous slots and informed the neighbors about number of slots used. It also specifies the communicating nodes identity so that all the nodes should keep their radio in sleep mode. IHMAC also save the power of nodes by adjusting the transmission power dynamically using following calculation:

$$P_{desired} = \frac{P_{max}}{P_r} \times Rx_{thresh} \times C$$

Where $P_{desired}$ = the power which is adjusted using power received

P_r = power received from receiver at the transmitter side P_{max} = Maximum power for transmission Rx_{thresh} = minimum signal strength necessary for the proper communication C = constant.

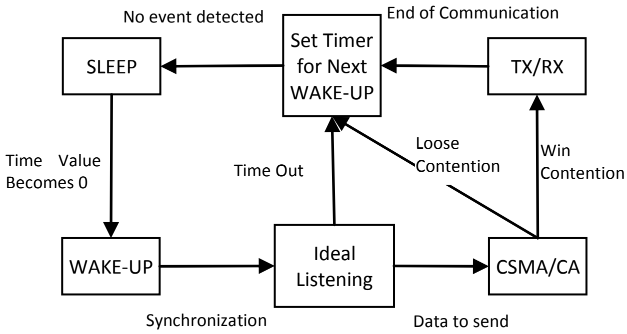

Fig 7: State diagram of IHMAC protocol

For the Data transmission, three different priorities are followed which are critical data, owner and non owner data in decreasing order. Three types of power are used for sending packets such as SYNC, RTS, CTS, DATA and ACK.

As compared to SMAC, IHMAC is use energy more efficiently. When comparing to other protocols such as TMAC, QMAC the IHMAC overshadow all of them in heavy traffic condition but in light traffic condition IHMAC performance is degraded and it becomes same as above three protocols.

3. CONCLUSION

Among all the categories of energy conserving protocol, MAC protocol with low duty cycle is most investigated filed and also demanding a lot of attention for research. There are various approaches for MAC implementation, discussed above which compared in table shown below in **Table 1.** The MAC protocols approach discussed above follow the following basic strategies TDMA, FDMA, CDMA and CSMA/CA. TDMA is contention free most effective in static environment but it is limited in scalability hence not suitable for dynamic environment. FDMA is also a contention free but limited by its bandwidth requirements and complex circuitry for the operation. CDMA is best in security and contention free but complex in computation overhead. CSMA/CA is best in scalability, flexible in nature, simple to implement but requires extra signaling overhead. Recently, researchers are more concentrated over the traffic condition in sensor network which is nondeterministic and they are using combination of MAC techniques in pair. Adaptive TDMA, variation in use of duty cycle periods, cross layer design approach are some important area where investigation is required.

Table 1: Comparative chart of the tables

Protocol	Organization	Notification	Advantages	Disadvantages	Remarks
B-MAC[2] 2003	Random	Listening	Low power, collision avoidance, reconfigurable, simple, adaptive n/w environment	Contention is more dense N/W, Long preamble energy consuming	X-MAC (fragmented short Preamble)
TRAMA[4] 2003	Frames	Schedule(per node)	Collision free, traffic adaptive,	Fix number of retransmission is 7, less energy efficient	ATMA is better than TRAMA
ATMA[5] 2010	Frames	Listening + Schedule	Reservation of slot is based on nature of traffic,		
TDMA-based-MAC[6] 2011	Adaptive (Frames)	Schedule	Demand based slot allocation, Ideal state energy conservation, improved throughput	Control overhead is high during high load traffic, tradeoff between throughput and energy consumption	
S-MAC[8] 2002	Slot	Listening	Collision and overhearing avoidance, Maintain Synchronization	End to end latency increases, synchronization overhead, not suitable for variable load	T-MAC performs well in variable load.
RMAC(PION)[10] 2007	Slot	Listening + Multi-Hop PION	Contention displacement, Improved end to end latency, multi hop TX during single duty cycle	Loss of PION signal causing significant energy consumption	P-MAC is better in energy efficiency
P-MAC [11] 2011	Slot	wake-up scheduling, pipeline scheduled	Reduced Latency, grade division, independent of routing mechanism	Grades area calculation is not present	
IH-MAC [12] 2013	Slot	Listening + Schedule	Combine broadcast scheduling and link scheduling dynamically, parallel TX, TX power adjustment	Less energy efficient in low traffic	

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