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A Survey on Energy-Aware MAC for Wireless Network

Niranjan Kumar Ray and Ashok Kumar Turuk
Department of Computer Science & Engineering
National Institute of Technology Rourkela, Orissa-769008, India
rayniranjan@gmail.com, akturuk@nitrkl.ac.in

ABSTRACT

Minimizing energy consumption is a critical issue for any wireless network. Existing wireless network protocols use different techniques to reduce power consumption. Much research has been conducted on MAC protocols, various issues involved have mostly been presented in isolation of each other. MAC protocol plays an important role in providing fair and efficient allocation of limited bandwidth in wireless networks. This paper presents an in-depth discussion on radio energy model, energy consumption measuring and a classification of MAC protocols.

Keywords

Wireless ad hoc network, Radio energy model, Power-aware protocol, IEEE 802.11, Sleep state

1. INTRODUCTION

In wireless networks, energy consumption is a major performance metric. Lower the energy consumption longer the network life. Thus, there is an increasing interest in power saving. Energy conservation is not an issue in any particular layer of the network protocol stack; so researchers have focused on different layers to conserve energy more effectively. MAC layer involves in the function and procedure necessary to transfer data between two or more number of nodes in the network. This layer performs specific activities such as framing, physical addressing, and flow and error controls. It is also responsible for resolving conflicts among different nodes for channel access. In this paper we present the work reported on energy efficient MAC. We focused on power issue in IEEE 802.11[1] standard for wireless networks.

Energy efficiency continues to be a key factor that limits the deployability of real ad hoc [2] and sensor networks. In the context of sensor networks, researchers both from academia and industrial have proposed a variety of applications including medical diagnosis, industrial applications, environmental monitoring, and many more applications. More generally, use of ad hoc and sensor networks has been explored in areas such as homeland defense and surveillance, traffic monitoring and community networks. Energy conservative networks are becoming more popular in case of ad hoc and sensor network. Maximization of battery life is a major issue for all types of energy constrained networks. This goal can be achieved by increasing battery power and by making energy efficient networks. Despite the progress made on this direction, the lifetime of battery-powered devices continues to be a key challenge, requiring additional research into energy efficient design of platforms, protocols, and systems. Energy conservation should be an important factor in the design of efficient networking protocols for any wireless network.

We discuss some of the issues and their possible solutions. The rest of the paper structured as follows. Section 2 presents energy models and their related issues. Different energy-aware MAC protocols are described in Section 3 and conclusions in Section 4.

2. ENERGY MODELS AND OTHER RELATED ISSUES

In wireless network energy management is an important issue. The improvement in battery technology is very slow compared to advances in semiconductor technology. Lack of central coordination, difficulty to replace the battery and limited energy source in battery motivates the researchers to design an efficient energy model. This section discuss the radio energy model and other power related issues.

2.1 *Energy Model*

Energy conservation is the main target in energy-constrained communication and focused has been given to minimize the transmission energy. In wireless networks the maximum number of bits a node can transmit depends upon the total battery energy. The energy consumption of radio interface depends upon the operation mode. These modes are active, sleep, idle and transient. Power consumption in active mode is maximum and least in sleep mode. In active mode more power are consumed for transmission or reception of packets and in sleep mode least power is consumed as transceiver has nothing to do during that period. Idle mode consumes more power than sleep mode as node has neither transmitting nor receiving any network packets but is waiting for it. Transition from one mode to other mode is called transient mode operation. Transition time is normally very less but if frequent transition occurred among the node then more power will be consumed. So the total energy consume [10] 'E' by a node to transmit 'k' bit can be written as

$$E = P_{active} \times T_{active} + P_{sleep} \times T_{sleep} + P_{transient} \times T_{transient} + P_{idle} \times T_{idle}$$

where $P_{active}, P_{sleep}, P_{transient}, P_{idle}$, are the power consumption in corresponding mode and $T_{active}, T_{sleep}, T_{transient}, T_{idle}$ are the duration of time that a transceiver stays at active, sleep, transient and idle mode respectively. Further P_{active} is the summation of transmitted signal power P_{sig} and circuit power P_{ckt} . So 'E' can be represented as

$$E = (P_{sig} + P_{ckt}) \times T_{active} + P_{sleep} \times T_{sleep} + P_{transient} \times T_{transient} + P_{idle} \times T_{idle}$$

As in transient mode transceiver stays very little time and consume very less energy, so we can ignore this, then the above equation can be written as

$$E = (P_{sig} + P_{ckt}) \times T_{active} + P_{sleep} \times T_{sleep} + P_{idle} \times T_{idle}$$

Circuit power P_{ckt} is combination of mixer power consumption P_{mix}, frequency synthesizer power consumption P_{syn}, low noise amplifier power P_{LNA}, intermediate frequency amplifier power P_{IFA}, active filter power consumption P_{filt} at transmitter, active filter power consumption P_{filr} at receiver, analog to digital power P_{ADC} at receiver, digital to analog power consumption P_{DAC} at transmitter and power amplifier power consumption P_{amp}. So circuit power consumption for transmitter and receiver are expressed as

$$P_{ckt(t)} = P_{mix} + P_{syn} + P_{filt} + P_{DAC} + P_{IFA} + P_{amp}$$

$$P_{ckt(r)} = P_{mix} + P_{syn} + P_{filr} + P_{ADC} + P_{IFA} + P_{LNA} + P_{amp}$$

While the power amplifier power consumption

$$P_{amp} = \alpha . P_{sig}$$

$$\alpha = \frac{\beta}{\mu} - 1$$

β, μ are the Peak to Average Ratio(PAR) and drain efficiency of RF power amplifier respectively. The value β depends upon modulation scheme and μ value depends upon different class amplifier.

2.2 Energy Issue

Energy issues such as causes of energy waste and energy consumptions measuring are discussed here.

2.2.1 Causes of Energy Waste

The major cause of energy waste in wireless networks are collision, idle listening, overhearing and control packet overhead. Collision results in retransmission leading to wastage of energy. Listening to an idle channel for possible traffic is known as idle listening. Power consumption in ideal state is very much close to active state. Most of the energy efficient MAC protocol uses power management techniques to overcome this. Power save protocols put radio interface to sleep state to reduce idle state power consumption. The issues related to sleep state are described in section 3. When a node receives packets which is meant for other nodes is called the overhearing. Control packets are used for efficient data transmission. Excess use of control packets cost more in term of energy as well as utilization of limited bandwidth. Other cause to energy waste are, higher bit rate, long header and carrier sensing. Header compression and packet splitting are used to reduce power consumption and efficient techniques are developed for carrier sensing. It is also found that low power transmission reduces contention and consumes less power. To design an efficient MAC factors like delay, throughput, quality of service (QoS) and other factors must be considered along with energy consumption.

2.2.2 Energy Consumption Measuring

Before designing any energy-aware protocol for wireless network one have to know the energy consumption behavior of the network interface. The energy consumed by an interface depends upon its operating state. Transmit and receive states are used for sending and receiving data. The default state of ad hoc and sensor network is idle state. Stemm and Katz [3] show that idle: receive: transmit ratios are 1:1.05:1.4 while other results [4] show ratio of 1:2:2.5. Sleep state consumes very less power than any other state. Due to this most of the power save protocol put their network interface in sleep state to save energy. The table given below is some experimental power consumption measurements [5] for IEEE 802.11 (2.4 GHz) interface.

TABLE 1
POWER CONSUMPTION OF DIFFERENT STATE

Interface	transmit (watt)	receive (watt)	idle (watt)	sleep (watt)	Mbps
Aironet PC4800	1.4-1.9	1.3-1.4	1.34	0.075	11
Lucent Bronze	1.3	0.97	.84	0.066	2
Lucent silver	1.3	0.90	0.74	0.048	11
Cabletron Roamabout	1.4	1.0	0.83	0.13	2

The above table shows that in order to reduce the energy consumption, it is necessary to put network interface in sleep sate for more time than any other state.

2.3 MAC Classifications

MAC for wireless network can be broadly classified to contention free and contention based [6]. In the former method a pair of node is statically allocated to certain time, frequency or spread spectrum code to avoid contention e.g. TDMA, FDMA, and CDMA. These types are mostly applicable to infrastructure based wireless network. In other hand contention based MAC scheme are mostly applicable to ad hoc and sensor network. Further contention based schemes are classified according to their operation and application; such as power-aware, antenna based, channel based etc. Here we discuss only the power aware type ignoring other type. The next section includes the operating principles, pros and cons of some energy efficient protocol.

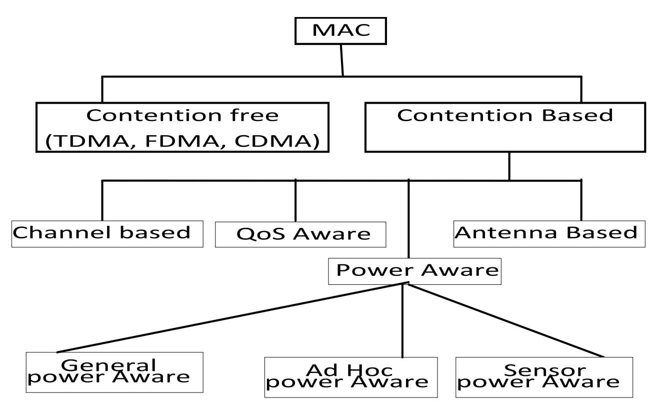

Fig. 1. Classification of MAC

3. ENERGY-AWARE MAC

3.1 General Power-Aware

3.1.1 Power Saving in IEEE 802.11:

There are two types of power management in IEEE 802.11 standard protocol [1]. First type is known as power save (PS) mode for infrastructure based wireless network and the other is IBSS PS mode which is relevant to the ad hoc model.

Power Saving in Infrastructure Wireless Network:

The nodes in PS mode consume less power compared to active mode operation. The access point buffer the MAC service date unit (MSDU) when the nodes is in PS mode and transmit them at designated time by the help of traffic indication map (TIM) and delayed traffic indication map (DTIM). The TIM identify the nodes for which traffic are pending. The amount of time spent in the PS mode is the amounts of energy save for a node. The limitation to this type is that it is not synchronous and its efficiency depends upon the access point capacity. This power saving mechanism is not suitable for ad hoc and sensor network environment.

Power Saving in IBSS:

In IBSS power save mode synchronized beacon intervals are established by the node which initiates the IBSS and is maintained in distributed fashion. It defines the fixed size length announcement traffic indication message (ATIM). All the nodes wake at the beginning of the beacon interval and wake till the end of the traffic window. Nodes participating in the traffic announcement remain awake till the end of beacon interval and the non-participator of the traffic goes to sleep at the end of the traffic window. Beacon announcements and acknowledgements are transmitted during the ATIM window to avoid contention with the data traffic. The effectiveness of power saving depends upon the value selected for the ATIM window and beacon interval. If the ATIM window is too short then not enough traffic will be announced. Like that if the window size is large then wake up time for the entire node will be more means consumption of more energy. Similarly for beacon with large interval has more traffic announcement time for which more numbers of nodes will be active after the end of the ATIM window, and there will be increased contention due to increased number of nodes trying to transmit in each interval. Power saving mechanism is the main criteria in evaluating a power save protocol, but factors like latency and throughput also be taken to consideration. Time spend in sleep state is the amount of energy save, which will be affected by the cost of state transition from sleep to wake up state, length of the beacon interval and ATIM window size as well as traffic and mobility model. Simulation results by Hagen Woesner et. al. [7] suggests that short beacon interval gives superior energy saving but it reduces the throughput. It is true for small network with light traffic load. But for network with moderately to heavily load longer beacon interval gives better results. Throughput is maximized when the ATIM window occupies about 25% of beacon interval. A general observation suggests that some throughput can be compromised in order to get higher energy saving. It is manageable if 30% or more energy is conserved at a cost of 10 % or less throughput at a moderate traffic load. Figure 2 shows the data transmission in IBSS PS mode.

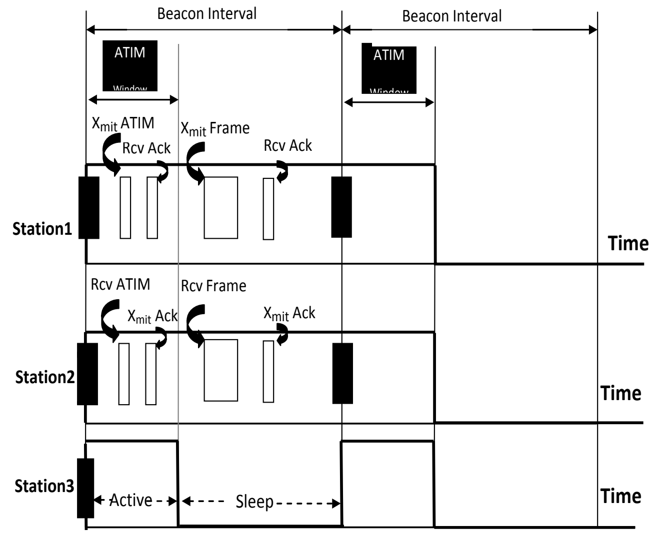

Fig.2. Data transmission in IBSS PS Mode

3.1.2 PIONO: Paging via another radio[9]

This protocol minimizes power consumption of a dual mode cellular/VoLAN device by implementing the concept of paging via another radio. The device has two interfaces to support cellular as well as wireless LAN services. The power consumption of wireless interface in idle mode operation is very much close to power consumption of transmit/receive state. In order to conserve energy the proposed technique switched off the wireless LAN interface in idle state and its cellular interface is active all time. The cellular interface is used as a paging medium to active the WLAN interface. It is assumed that power consumption of mobile hand set and cellular interface is constant. The idle mode power consumption of WLAN interface is modeled as

$$Pwlan = \frac{Pwlandoze \times Tlisten + (Pwlanlisten - Pwlandoze) \times Tbeacon}{Tlisten}$$

Where $Pwlan$ is the idle mode power consumptions. $Pwlandoze$ is the power consumption at doze state and $Pwlanlisten$ is the power required to process beacon frame. $Tlisten$ and $Tbeacon$ are the time for listen interval and time spend to process beacon frame respectively. The simulation results show that 43-65 % reduction in idle mode power consumption. The advantage of this protocol is that its power saving mechanism can be applied to 3G all-IP network.

3.2 Energy Efficient MAC for MANET

Mobile Ad Hoc Network (MANET) [2] is a collection of mobile nodes with no pre-established infrastructure, self organizing wireless nodes forms a temporary network. Ad hoc network are basically peer-to-peer multi-hop mobile wireless network, where information packets are transmitted in a store and forward manner from a source to an arbitrary destination, via intermediate nodes. Each of the nodes has a wireless interface and they communicate with each other over the radio or infrared signals. Some works on MAC layer for MANET are presented below.

3.2.1 PAMAS: Power Aware Multi-access with Signaling

Energy efficiency is the primary goal in PAMAS [8] and is achieved by using separate channels for control and data. It uses RTS/CTS mechanisms and these signals are transmitted over the control channel while data are transmitted over data channel. Node with packet to transmit sends a RTS over the control channel, and waits for CTS, if no CTS arrives then node enters a back-off state. However, if CTS is received, then the node transmits the data packet over the data channel. The receiving node transmits a “busy tone” over the control channel for the others to determine that the data channel is busy. The use of control channel allows nodes to determine when and how long to power off. If a node has no packets to transmit, then that node ought to power itself off if it found a neighbor begins transmitting. Similarly, if at least one neighbor of a node is transmitting and another is receiving, the node ought to power off because it cannot transmit or receive a packet even if it’s transmit queue is non-empty. The length of power off time is determined by different condition. It finds the duration through control channel and switch off the radio for that period. When a node waking up and access the channel over the data channel and found multiple transmission going on in such case the node uses a probe protocol to find how much time it will power off. Simulation results show that power saving range varies from 10% to 70% depending upon the network type. The author suggest that this scheme of energy saving can be helpful to other multi-access protocol without affecting throughput. The performance of power saving is affected by faster network interfaces with higher data transmission rates. PAMAS is most effective in network with high density and traffic load. Power saving ideas of PAMAS can be incorporated to other protocol without affecting delay and throughput performance.

3.2.2 EC-MAC: Energy conserving MAC

Energy conservation is the major design issue in EC-MAC [11]. The mobile nodes are controlled by the base stations. Transmission is organized by the base station in term of frames. Each frame consists of fixed numbers of slots. It was designed for infrastructure based wireless network but can be extended to ad hoc network by selecting a node to act as a coordinator in a distributed fashion. The frame consist of many phase and is started by frame synchronization message (FSM), which contents synchronization information. The request/update phase reduces the collision. New user phase which is variable in length allow new user to register with the base station. This phase is operated in contention mode using slotted aloha protocol. Down link and uplink data phase reduce turnaround time and collision. From the battery power conservation prospective, request/update phase should not operate in contention mode. The energy consumption of EC-MAC compares with other protocols and found that it gives superior power saving. The simulation results shows that at heavy traffic load its power saving is very close to IEEE 802.11.

3.2.3 Dynamic Power Saving Mechanism (DPSM)

It is a variance of 802.11 DCF power save mode discussed earlier. It uses the concept of ATIM window and beacon interval. As discussed earlier all node awake up in the start of beacon interval and those node has no traffic to receive or to send are turn to sleep mode after the ATIM window is over. The limitation of fixed ATIM window is already discussed in IEEE 802.11 PS mode. The work [7] shows that if ATIM window is fixed then performance as well as energy saving can be affected. DPSM [12] improves performance by using variable ATIM window. It allows the sender and receiver to change their ATIM window dynamically. The ATIM window size increased when some packet are pending after the current window is expired. The data packet carries the current length of the ATIM window and the nodes overhear this modify their length of the window. This allows the sender and receiver node to go to sleep state immediately after their transmission is over. The performance of DPSM is better compare to IEEE 802.11 DCF in term of power saving, however it is more complex.

3.2.4 Power Control MAC (PCM)

PCM [14] achieves energy saving without causing throughput degradation by implementing different type of transmission power. DATA and ACK packets send using minimum power while RTS/CTS packets are send with maximum transmission power. When a node sends RTS to the receiver node it transmits with maximum power P_{max} and the value included in the packet receiver measure the signal and found it as P_r . Receiver calculate the noise level of its surrounding then compute minimum necessary power level (say P_{enough}) that should be sufficient for sender. The sender receives the CTS along with maximum power level of receiver. When this transmission takes place the neighboring node hears this and defers their transmission. During data transmission same procedure are used between sender and receiver with minimum required power level that should be enough for the transmission of DATA as well as ACK. The limitation of this protocol is that it require an accurate estimation of received packet signal strength also the other factors like multipath propagation, fading and shadowing effects may degrades its performance.

3.2.5 Power Control Multiple Access (PCMA)

PCMA [15] uses two channels one for sending busy tones other for data and acknowledgement signals. The power control mechanism is used for increasing channel efficiency through spatial frequency reuse. Rather than using RTS/CTS signal it uses two signal request_power_to_send (RPTS) by sender and accept_power_to_send (APTS) by receiver to determine the minimum transmission power levels which will enough for successful packets reception at receiver. These two signals are transmitted over data channel. When it is over , data transmission as well as acknowledgement are received on the same channel. Every receiver sets up a special busy tone as a periodic pulse to avoid interference with neighboring node. Collisions are resolved by backoff strategy same as IEEE 802.11. The protocol enhanced aggregate channel utilization by more than factor two compared to IEEE 802.11.

3.3 Energy Efficient MAC for Sensor Network

Maximizing the network lifetime is a common objective for all type of wireless networks specially for sensor network. In sensor network the nodes are dead when they are out of battery. Looking to this condition the MAC protocols should be energy efficient. Other design attributes for a good sensor MAC protocols should be scalability, adaptability, Reliability, delay-predictability etc. Besides that care should be taken factors like latency, throughput, bandwidth utilization, security and fairness among nodes, etc. In this sub section we are describing some of the energy efficient MAC protocols for sensor networks.

3.3.1 Sensor-MAC

Energy conservation and self configuration is the primary goals of this protocol. The design overview of S-MAC [16] includes periodic listen and sleep. Its operation is similar to PS mode of IEEE 802.11. Listen time is fixed and depends upon the contention window and radio bandwidth. Sleep interval can be changed. Nodes exchange their schedules by periodically broadcasting a sync packet to their immediate neighbor, it uses concepts of message passing, technique to achieved energy saving and is done by minimizing the communication overhead. For collision avoidance it implements the concepts of physical and virtual carrier sensing by the help of Network allocation Vector (NAV). Figure 3 shows the massaging passing scenarios of S-MAC. Energy waste caused by idle listening is reduced by sleep schedules. Low duty cycle operation is achieved by periodic sleeping. It enables each node to adaptively switch according to traffic in the network.

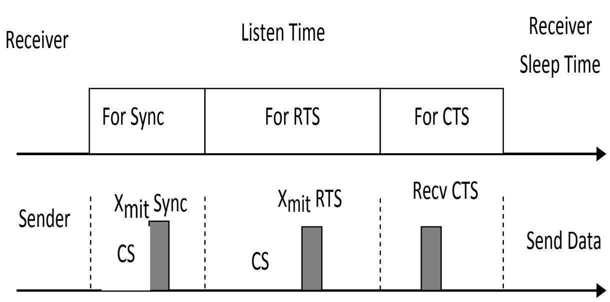

Fig.3. S-MAC Messaging Scenario

If we look at S-MAC with respect to surveillance applications, then it will be suitable when the network structure is static and there is a constant data rate. The major limitation of S-MAC is, when variation in the traffic then most of the energy of the node will be wasted in the idle state. Other limitations are sleep and listen periods which are predefined and constants which decrease the efficiency of the protocol as offered load of the network varies.

3.3.2 Timeout-MAC

Like S-MAC energy conservation is the main design issue of this protocol. Idle listening is resolved efficiently. Periodic listen and sleep scheme are used by S-MAC performs poorly in variable network traffic. It overcomes this by time out scheme. A node goes to sleep state after overhearing RTS/CTS destined for other node to conserve energy. But the nodes can miss other RTS/CTS while it is in sleep as well as it can disturb some communication while wake of. An early sleeping problem arises when the traffic through the network is mostly unidirectional like ‘node to sink’ communication. The problem here is, a node goes to sleep when a neighbor still has some message left. This is occurred in asymmetric communication pattern. T-MAC solves this problem in two ways. First method called future-request-to-send (FRTS) and second method is called full-buffer priority. In FRTS if a node over hears CTS it immediately send FRTS. The node getting FRTS knows that some traffic is pending for it so it will not goes to sleep mode. The figure 4 shows the FRTS methods for data transmission.

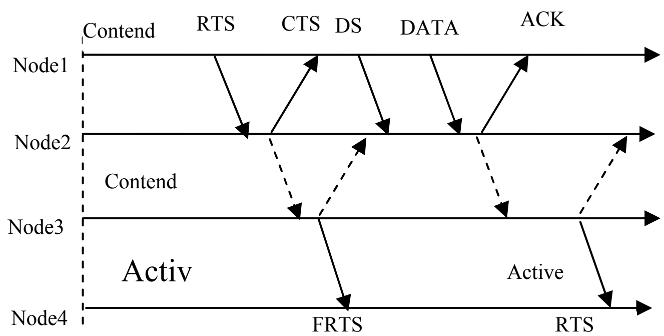

Fig.4. Future-request-to-send methods in T-MAC

The limitation with this scheme is that it increases the overhead if the network traffic is light load. When a nodes buffer is full it prefers sending rather than receiving. This is the concepts of full-buffer-priority. When a node gets one RTS signal it sends RTS to other rather than sending CTS. This technique is not ideal in high-load. Simulation results show that FRTS mechanism increases maximum throughput by approximately 75%, without consuming more energy.

3.3.3 Traffic-Adaptive MAC (TRAMA)

TRAMA [18] attempts to reduce energy consumption caused by collisions. Time is divided into random access and schedule access. In random access each node has knowledge of all 2-hop neighbors and exchange neighborhood information with each other by the help of a neighbor protocol (NP). Schedule exchange protocol (SEP) are used to transmit schedule information as well as actual data packets during schedule access time. By the help of NP and SEP nodes determine their radio state. Adaptive election algorithm (AEA) is used for this purpose. In AEA each node calculates a priority for itself and all 2-hop neighbors using a hashing function of the current slot. Node sends the data when it has highest priority in the slot. Like that If neighbors has the highest priority and the node determines that it should be the intended receiver through information acquired during SEP, it sets itself to the receive mode. It turns to sleep state to conserve energy. Distributed election algorithm is used to elect one transmitter within each two-hop distance which eliminates the hidden terminal problems [19]. The advantage of TRAMA is that it achieves less collision probability as a result more energy is conserved. In other hand calculation period of each node increases as each node calculate priorities of its two-hop neighbors in each time slot and duty cycle of the nodes increase in random time periods.

4. CONCLUSIONS

This paper presents an overview of the research work conducted on MAC layer specially looking at issue of energy efficiency in ad hoc and sensor network. We discuss the different cause of the energy waste and present how the different research paper tries to resolve the issues. We have discussed the characteristics and operating principle of different MAC protocols such as IEEE 802.11[1], PIANO[9],PAMAS[8],EC-MAC[11],DPSM[12],PCM[14], PCMA[15], S-MAC[16], T-MAC[17] and TRAMA[18]. All the above protocol is layer based but more layering of protocols creates overheads and cause more energy consumption. Therefore integration of layer is also a promising area which forces the researcher to work on cross layer design [13] issue.

5. ACKNOWLEDGMENT

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