International Journal of Engineering & Technology, 7 (4.6) (2018) 577-582

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Performance Evaluation of MAC Layers with Routing Protocols in Wireless Sensor Networks

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Abstract

Enormous innovations in Wireless communication shaped an outstanding enhancement in the arena of Wireless Sensor Networks (WSN). Today, WSN has transformed as an inevitable technology, controls virtually all the applications like ecological monitoring, Security and application that save our lives and possessions. Unlike conventional wired Network, WSN has its own unique characteristics which make WSN distinctive and more feasible. WSN is an infrastructure-less network, utilizes a large range of sensor nodes which are deployed in a specific geographical area of interest to sense and gather information. This information are forward to the base station with the help of routing protocol. Due to Ad-hoc nature of Wireless Sensor Networks, Medium Access Control (MAC) Layer plays a vital role in enables multiple nodes to stake a shared channel securely with slightest collusion and interference. MAC protocol benefits to increase network trustworthiness and efficiency by defining and regulating traffic in every specific channels inside the network. In this paper, we present a performance evaluation of different MAC Layer protocols like 802.11, ALOHA, CSMA, MACA and TDMA with various routing protocols like AODV, DSR, FSR and ZRP in Wireless Sensor Network. This paper compares performance parameters like Throughput, End to End Delay, Packet Delivery Ratio and Battery consumption. This analytical studies opens up with research direction and focuses on key challenges in selecting routing protocol and MAC layer to improved Network efficiency and reliability.

Keywords: *Wireless Sensor Networks; MAC layer; Routing Protocols.*

1. Introduction

Incredible advancement in micro electro Mechanical System favored a fabulous growth in Wireless Sensor Networks (WSN). WSN is an Ad-hoc network, works with organization and collaboration of hundreds to thousands of Wireless sensor nodes. These sensor nodes are deployed in an explicit topographical range of attention to observe physical or environmental conditions such as temperature, sound, vibration, pressure or pollution [1, 2]. These sensed data are dispatched in form of packets to the destination with the help of multi-hop communication. WSN follows the principles of multi-hop communication, hence each and every wireless sensor node has to participate deliberately for both transmission of data or act as relay to transmission of data. Routing protocols and MAC layers play a vital role in Sensor communication. Routing protocols are responsible in recognizing and conserving the routes in the network [3].Routing algorithms plays a major role in data communication from source node to destination. A routing protocol sends and receives packets containing routing information to and from other nodes. It enables the nodes to select a specific route in network. Selection of specific route between source and destination is done by different routing algorithms.

A routing protocol conveys the route information first among immediate neighbors, and then throughout the network. This comforts the nodes to gain awareness of network topology. Unlike conventional Wired or Mobile network, Sensor network have its own limitations. Number of Sensor nodes typically used in any application is enormous and has to measure to several orders of magnitude which requires a wide-ranging scalable solution. WSN works with very short range of communication where transmission range varies as low as from 3 to 30 m. Sensor nodes are equipped with limited processing and memory capacity. Power Another major design issue of WSN is that each Sensor nodes are equipped with low powered battery, limited range of sensing, computational, storage and communication resources. The batteries are irreversible or rechargeable. As Wireless Sensor Nodes are equipped with very low battery power, extensive utilization of computational power can potentially reduce the battery life of a Wireless Sensor [4]. Life time of a WSN depends on the Life time of Sensor nodes. After the deployment of sensor devices it is impossible to charge or replace battery present in the network. Sensor nodes data rate flow is very low range from 1 – 100 kbps. Sensor nodes are not addressed with global unique IDs also. These major constraints in WSN make conventional algorithms and protocol less effective. Most reliable and secure WSN communication requires seamless routing protocol and MAC layer protocol. Medium access control protocols for wireless sensor networks are intended to improve energy efficient. Most of the MAC Layer protocols trails the procedure of Sleep mode (i.e.) occasionally turn off the radio receivers of the sensor nodes in a synchronized mode. In recent years many MAC protocols were proposed to improve energy conservation in sensor nodes. Majority of these protocols works with the principle of Contention based or Time schedule based technique in sharing the local medium. Despite many MAC proposals, no perfect proposal came up as a major contender for resolving issue related with energy efficiency.

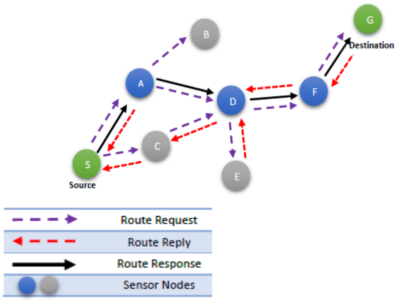


Fig .1: Wireless Sensor Networks

Conventional routing protocols along with MAC Layers have severe impact when used with energy and computationally constrained Wireless sensor networks. Thus, the exceptional uniqueness and constraints of sensor node present made design issue of Routing protocol and MAC protocol for WSN is more challenging [5].
The remainder of this paper is organized as follows. Different MAC Protocols like 802.11, CSMA, MACA and TDMA are explained in section 2. In Section 3, we introduce different routing protocols like AODV, DSR, FSR and ZRP. Simulation setup and parameters are explained in Section 4. A comparative study of routing protocols & MAC layers were discussed in the session 5. Finally, we conclude by describe future research directions in Section 6.

2. Overview of MAC Protocols

MAC protocol enables multiple nodes to share a common channel safely with minimum collusion and interference. MAC protocol regulates the traffic in every specific channel in a network which improves the reliability and network efficiency. MAC Protocol works in Data Link layer of ISO-OSI layers. Data link layer is subdivided into 2 segments. MAC Layer and Logical Link Control. End to End delay incurred in MAC Layer waiting for access to the transmit channel. Access time is dependent on MAC Scheme employed. Different MAC Protocols like IEEE 802.11, Aloha, CSMA, MACA and TDMA are explained in the reminder of this section.

2.1. IEEE 802.11

MAC Layer protocol IEEE 802.11 is a foremost protocol which is equipped and integrality with the principal of contention based mechanism to avoid data packet collision within the network. IEEE 802.11is a well define standard for Wireless Communication maintains specific principles for Physical and MAC layers. To prevent data collision, IEEE 802.11 uses techniques like carrier sensing and randomized back-offs [10]. Power save mode follows the principle of turning idle node to sleep. Sensor node will be transit from active mode to idle mode. From idle mode to sleep mode. This procedure benefits the sensor node to conserve its battery power. IEEE 802.11 follows the principle of maintaining a clock value to verify the modes of a node. In general there are 4 modes like Transmit, receive, Idle and sleep mode. A sensor node can be in any of these modes. Energy conception varies in each mode. IEEE 802.11 follows synchronization clock to maintain and discover modes of a sensor node. However, IEEE 802.11 doesn't work efficiently in multi-hop network due to its limitation in clock synchronization, neighbor discovery and network partitioning. Power consumed during waking up a sleeping node have to be monitored and managed properly to preserve energy loss.

2.2. ALOHA

Norman Abramson in the year 1970s proposed a network reliable model to fix channel allocation issues for wired network [14, 15]. Pure ALOHA is the first version of ALOHA with random access protocol characteristics developed for a wired network. The channel kept open for access of users with data. User can transmit data whenever available. If exist any data collusion retry sending the same data later. When repeated collusion occurs, wait for an exponential random time and retransmit. Pure ALOHA uses same frame length. A node cannot generate a frame while transmitting or trying to transmit. In ALOHA a node simply transmits a packet when it is generated (pure ALOHA) or at the next available slot (slotted ALOHA). Should the transmission be unsuccessful, every colliding user, independently of the others, schedules its retransmission to a random time in the future. This randomness is required to ensure that the same set of packets does not continue to collide indefinitely.

2.3. Carrier Sense Multiple Access (CSMA)

CSMA is among the most widely used technique to reduce collisions in wireless networks. It is based on the exchange of RTS (Request To Send) and CTS (Clear To Send) mini packets prior to data transmission. In CSMA/CA, the transmitter starts by sending a RTS packet to the receiver. As RTS packets are small in size, the probability of them colliding is low. When the receiver receives a RTS, it replies by sending a CTS packet. The role of the CTS is to reserve the channel around the receiver so that interfering nodes in the receiver's vicinity refrain from transmitting so as not to collide with the active transmission. Although the RTS/CTS procedure efficiently reduces collisions in traditional wireless networks, it has some drawbacks in wireless sensor networks. First, data packet sizes are also usually small in sensor networks so that their collision probability is in the same order as for RTS packets. Therefore, its use does not improve but often even deteriorates performance. In addition, the use of RTS/CTS increases the energy consumption of the protocol. Finally, RTS/CTS packets can only be used for unicast transmissions. When a user generates a new packet the channel is sensed and if found idle the packet is transmitted. When a collision takes place every transmitting user reschedules a retransmission of the collided packet to some other time in the future (chosen randomly) when the same operation will be repeated. In accordance with common networking lore, CSMA methods have a lower delay and promising throughput potential at lower traffic loads, which generally happens to be the case in WSNs. However, additional collision avoidance or collision detection methods should be employed.

2.4. Time Division Multiple Access (TDMA)

TDMA-based protocols nodes are often required to form a cluster [11], [12], [13]. The system time is divided into time slots. Each of the nodes has assigned its own time slot, and may access the shared medium only in this time Slot. It allows avoiding collisions, idle listening, and schedules sleep of the transceiver, without additional overhead. However, such an approach provides a number of drawbacks. The difficulty for the cluster to dynamically change its frame length and time slot assignments, in the event of node changes or node inclusions, contributes to poor scalability and poor mobility. In addition, effective slot assignment in multi-hop networks is also challenging. Moreover, demands of the cluster existence result in a complex inter-cluster communication. Furthermore, the TDMA-based protocol requires high quality time synchronization since the clock drift may lead to disastrous consequences. TDMA allows several users to share the same frequency channel by dividing the signal into different time-slots. It has a natural advantage of collision free medium access. It supports low duty cycle operation: a node only needs to turn on its radio during the slot that it is assigned to transmit or receive. However, it includes clock drift problems and decreased throughput at low traffic loads due to idle slots. The limits with TDMA systems are synchronization of the nodes and adaptation to topology changes (i.e. insertion of new nodes, exhaustion of battery capacities, and corrupted links due to interference). The slot assignments, therefore, should be done with regard to such possibilities. However, it is not easy to change the slot assignment within a decentralized environment for traditional TDMA, since all nodes must agree on the slot assignments.

2.5. Multiple Access Collision Avoidance (MACA)

Multiple Access Collision Avoidance [16] Improves CSMA/CA by adding a random back off time before the transmission of RTS packet to avoid collisions resulting from synchronized forwarding by multiple neighbors. Usually, the back off time is picked according to a uniform distribution which, as per [17] and [18], is not the optimum choice. MACA aim at reducing collisions by equally trying to protect all packets. In sensor networks, however, packets have different importance. For example, in surveillance applications, all nodes detecting an intrusion send an alert to the sink which generates peak traffic around the intrusion region. In this case, it is more important to protect the first packets so that they reach the sink rapidly. MACA is a MAC protocol used in wireless LAN data transmission to avoid collisions caused by the hidden terminal problem and to simplify exposed terminal problem. It is inspired by the mechanisms of CSMA/CA, but does not implement carrier sensing (which leaves the name MA/CA or simply MACA) [19].

In this scheme, the node that needs to transmit a message sends a small RTS message to the receiver. The receiver immediately replies with a small CTS message to the sender. After receiving the CTS, the sender will transmit the data message. Both the RTS and the CTS messages carry the length of (or time to transmit) the data message as well as the names of sender and receiver [20]. Meanwhile, any node hearing the RTS must remain silent during the time needed for the other nodes to exchange CTS message and data packet. Any node hearing the CTS must remain silent until the data transmission is complete [21].

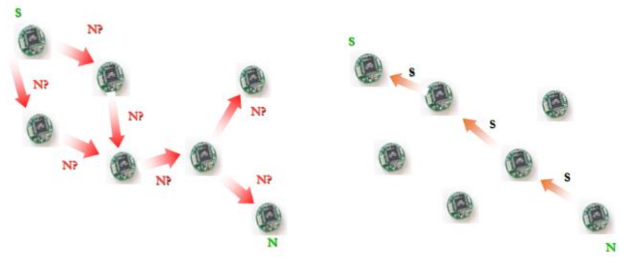
3. Overview of routing protocols

Routing protocols are specific algorithm designed to perform the way the routing within sensing region. A routing protocol shares the route information primarily with first-hop neighbors, and then spreads the route information throughout network. This time period can be called as learning time in the network; by this process all sensor nodes gain knowledge of the entire topology of the network. In this session, different routing protocols like AODV, DSR, FSR and ZRP are discussed.

3.1. Ad hoc On Demand Distance Vector (AODV)

Ad hoc On Demand Distance Vector (AODV) Routing Protocol uses on demand approach to discover and identify a specific route. When a node requires sending data, AODV uses route discovery using control messages like route request (RREQ) and route reply (RREP) to find the route to destination.

In AODV protocol neighbour nodes stores the route information of its next hop neighbour. This enables AODV to evaluate the shortest distance and safe path. To discover a path source node broadcast a route request message to its immediate neighbour. Neighbour in-turn sends the route request packet to its neighbour. This process continues until the destination is reached. When the Route Request (RREQ) packet reaches the destination, destination node writes back with Route Reply (RREP) and window size for data transmission. Once the data packet is transmitted the route information will be cleared. AODV protocol discovers and identify route only when nodes require sending or receiving data. During error while transmission or link failure a route error (RERR) message will be generated and send it to the source node to find alternative path. The main advantage of AODV protocol is route is discovered and identified on demand. AODV faces severe drawback as intermediate nodes may forward to unreliable routes if the source sequence number is very old and the intermediate nodes have a higher, but not the related to latest destination sequence number [10].



Broadcasting RREQ Message RREP Message from Destination

Fig.2: Ad Hoc On Demand Distance Vector Routing Protocol

3.2. Dynamic Source Routing Protocol (DSR)

Dynamic Source Routing Protocol is an on-demand routing protocol which has built to reduce bandwidth utilization in wireless Network. Dynamic Source Routing Protocol is similar to AODV protocol used in Wireless Mesh Network. DSR differs from AODV by performing source routing instead of using the route information of neighbouring nodes. Source routing means all the route information are maintained in the adjacent nodes. DSR follows two phases during routing Route Discovery and Route Maintenance. Route Discovery is used to discover the path to reach the destination. Route Maintenance is used to switch to different path during route failure. Route Reply is used by destination to write back to the source that the intended packet has reached the destination.

3.3. Fisheye State Routing Protocol (FSR)

Fish eye is a proactive and hierarchical routing protocol. FSR uses the technique followed by a fish eye. Fish eye normally observers and focus with high detail on the object very close to its focal point. When the object distance increases from the focal point the detail decreases. The same principle is used in Fisheye State routing. FSR maintain topology map at each node. FSR will not flood or broadcast to evaluate the route. Instead, nodes maintain a link state table based on updated information from the neighbour.

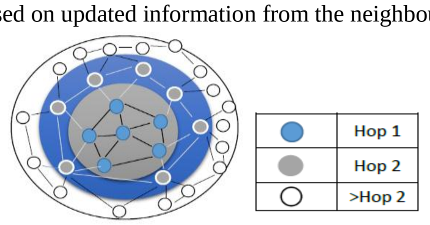
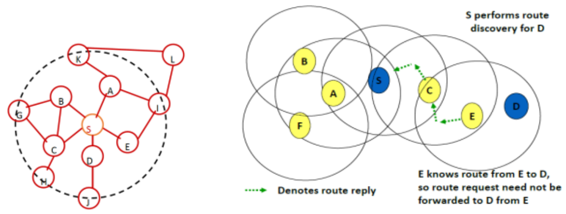


Fig. 3: Fish Eye State Routing Protocol

A full topology map will be stored in each node of the network. The topological map will be utilized to route discover and route maintenance. Shortest path will also be evaluated using topological map [22].

3.4. Zone Routing Protocol (ZRP)

The zone routing protocol is a combination of reactive and proactive routing protocol. ZRP takes the advantages of both reactive and proactive routing protocols.



Intra Zone Routing Protocol Inter zone Routing Protocol

Fig.4: Zone Routing Protocol

Major drawback of Proactive routing protocol is excess bandwidth is utilized while maintain a routing information. However, in reactive routing protocol initiates unwanted delay in the network by increasing route request and route reply wait time. Reactive routing protocol causes major energy conception by broadcast route request and route reply. The Zone routing protocol admits these problem network delay and excess energy utilization. In Ad-Hoc network if network congestion is most likely to occur, the path will be changed or packets will be diverted to nearby node. In ZRP route information is maintained only with sensor nodes which stay on the routing zone. In ZRP A sensor node discovers and identify its zone through a proactive scheme called Intra zone Routing Protocol (IARP). For nodes outside the routing zone, Inter zone Routing Protocol (IERP) is responsible for reactively discovering routes to destinations. The major difference of IERP is identifying and maintain a route record of nodes exist in the Routing Zone. This will reduces the unnecessary broadcast of route request to identify the nearest neighbor.

4. Simulation Setup

QualNet 5.2 Network Simulator tool is used to evaluate the performance of different Ad hoc routing in Wireless sensor networks. In this simulation, we have tested routing protocols with 10, 25, 50, 100, 200 node density. The nodes are deployed randomly in a terrain of 200 X 200 m2. CBR is used as data traffic application with multiple source and destination. The parameters used in the simulation are summarized in the table below:

Table 1: Simulation Setup

Parameters	Values
Routing Protocols	AODV, DSR, FSR, ZRP
MAC Layers	IEEE 802.11, ALOHA, CSMA, MACA, TDMA
Packet Size	512 bytes
Terrain Size	200 x 200 m^2
Nodes	10, 50, 100, 150, 200
Node Placement	Random
Data Traffic	CBR
Simulation Time	3000 Sec
Simulator	Qualnet 5.2

5. Comparative Study

In this session, comparative study on different routing with MAC layers were made based on performance characteristics in wireless sensor networks. Performance metrics like throughput, End-to-End Delay, packet delivery ratio are compared with variable node density like 10, 50, 100, 150 and 200. Performance analysis is made using QualNet 5.2 on AODV, DSR, FSR and ZRP routing protocols with MAC Layers like IEEE 802.11, ALOHA, CSMA, MACA, TDMA.

5.1. Performance evaluation of Routing protocols with MAC Layer based on Throughput:

Performance evaluation of routing protocols AODV, DSR, FSR and ZRP were modelled with MAC protocol with varying node density. The figure 5.1 represents average throughput of different routing protocols. In a WSN, throughput is measured in terms of successful delivery of data packet within the threshold time. The data may use different routes and passes across multiple intermediate nodes to reach the destination [7]. Throughput is measured using number of bits of packet received per unit time. Normally throughput is measured as bits per sec.

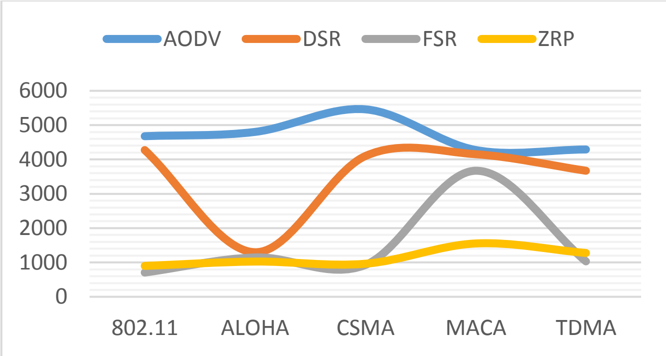


Fig. 5: Comparision of Throughput

5.2. Performance evaluation of Routing protocols with MAC Layer based on End to End Delay:

In this session, comparison of different routing protocol is performed based on End to End delay. Figure 5.2 represents the graphical representation of delay in second. Average End-to-End delay is a metrics used to measure the performance with time take by a pack to travel across a network from a source node to the destination node. In WSN, sensor nodes switch between an active (on) and a sleeping (off) mode, to save energy. Such Scenario pays a greater latency in the sensor network. Each sensor node with sensed data has to wait for the neighbor sensor node to turn it to active mode from sleep mode [10]. End to end delay evaluates latency when data send by sensor nodes and received by destination node. An end to end delay includes all possible delay caused during route discovery, retransmission delay, queuing delay and relay time.

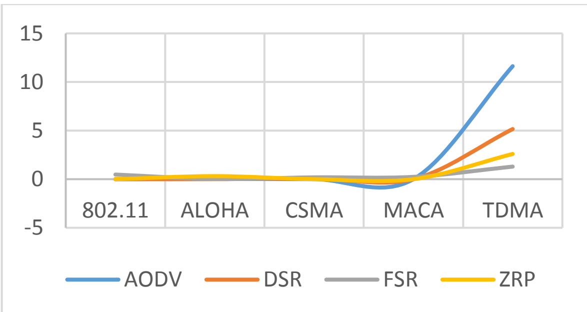


Fig. 6: End to End Delay

5.3. Performance evaluation of Routing protocols with MAC Layer based on Packet delivery Ratio:

Comparison of different routing protocol based on varying node density with MAC layer has been done. In this session packet delivery ratio has be calculated. Packet delivery ratio is a performance metrics used to evaluate total packets properly delivered. It is the ratio of total amount of data packets received at the destination to total packet transmitted at the source.

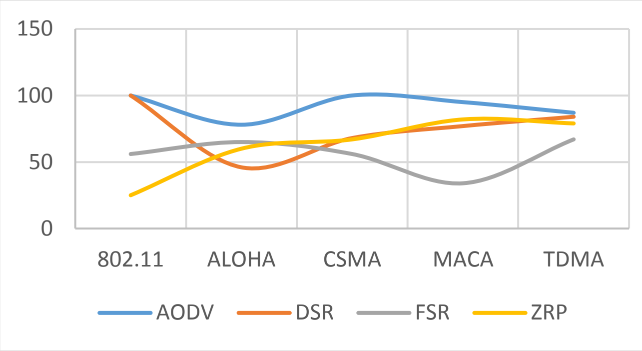


Fig. 7: Packet Delivery Ratio

To evaluate the packet delivery ratio, the packet send from the source and the packet received at the destination should be recorded. Source node transmits the information to destination with sequenced packet with sequence number. If a packet fails to reach the destination either by discard or by congestion control mechanism, the source node retransmit the packet based on retransmission timer algorithm. However, number of retransmission increase the transmission overhead and cause very low packet delivery ratio. When number of source and destination increases the transmission complexity also increases. It is the duty of a routing protocol to manage packet routing with shortest and reliable path. Packet delivery ratio is calculated by dividing the number of packet received by destination through the number packet originated from source [9].

5.4. Performance evaluation of Routing protocols with MAC layers based on Battery consumption :

Sensor nodes are equipped with limited battery resource and it's very crucial to manage energy resource effectively. In this session battery utilization of sensor nodes were calculated. Fig. 5.4 shows battery consumption of sensor nodes. In the figure T represents Transmission mode, R represents Receive mode and I represent idle mode. It's found all sensor nodes utilize higher energy resource during Idle than transmission or receive mode. FSR utilizes higher energy resource compared with all other routing protocols.

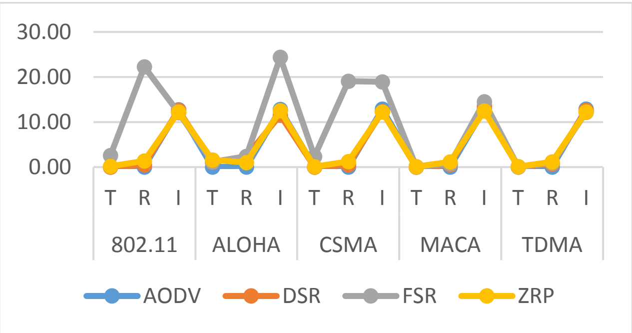


Fig. 8: Battery Consumption of Sensor Nodes

6. Research directions

In recent years, many researchers has proposed several MAC Protocols to diminish the energy depletion and to improve network proficiency. However, none of those protocol has come up as a contender and perfect resolution for energy efficiency. The following aspects has to be considered while design a proficient MAC protocol for the wireless sensor networks. Although there are various MAC layer protocols proposed for sensor networks, there is no protocol accepted as a standard. One of the reasons for this is that the MAC protocol choice will, in general, be application dependent, which means that there will not be one standard MAC for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware. TDMA has a natural advantage of collision free medium access. However, it includes clock drift problems and decreased throughput at low traffic loads due to idle slots. The difficulties with TDMA systems are synchronization of the nodes and adaptation to topology changes when these changes are caused by insertion of new nodes, exhaustion of battery capacities, broken links due to interference, the sleep schedules of relay nodes, and scheduling caused by clustering algorithms. The slot assignments, therefore, should be done with regard to such possibilities. However, it is not easy to change the slot assignment within a decentralized environment for traditional TDMA, since all nodes must agree on the slot assignments. In accordance with common networking lore, CSMA methods have a lower delay and promising throughput potential at lower traffic loads, which generally happens to be the case in wireless sensor networks. However, additional collision avoidance or collision detection methods should be employed.

6.1. Energy Efficiency*:*

Wireless sensor nodes are designed with limited battery and computational resource. One of the major design issues in WSN is preservation of the energy accessible at each sensor node. In any case, energy is a very critical resource and must be used very sparingly. Extensive usage of complex computational protocols and transmission time will deplete the battery power faster. Sensor nodes have to limit the transmission and computation to prevent ultimate utilization of energy resource. It is often found very difficult to change or recharge batteries for these sensor nodes. Cost of recharging the batteries of Sensor node are very equal with replacing them with a new one. Hence, an effective routing protocol and MAC layer protocol has to be designed to improve energy efficiency and improve network life time. In such scenario, algorithm has to be designed to reduce packet broadcast during learning curve and to update the route.

6.2. Throughput:

Throughput requirement varies with different applications. Some of the sensor network application requires selection the information with fine sequential determination. In such sensor applications it is better that sink node receives more data.

6.3.Latency:

Latency requirement basically depends on the application. In the sensor network applications, the detected events must be reported to the sink node in real time so that the appropriate action could be taken immediately.

7. Conclusion

Existing MAC Layer procedures with routing protocols adopt that the nodes are pre-programmed to send the data to the sink to performing offline query dispensation. In WSN model, an implicit hypothesis is fashioned about the nature and competencies of the sensor nodes. This approach faces two major weaknesses. First, the Sensor node behavior is preprogrammed and cannot be amended after distribution. Second, WSN overall lifespan is declined because of energy wastage due to all-encompassing communication overhead. It is fascinated most exhaustive research work and determination has concentrated only on designing the MAC Layer protocols and Routing protocol for sensor network. However, there is no protocols plays as major contender to resolve the issue related with energy preservation. Hence, energy conservation in WSN with MAC Layers and routing protocol pays an important research area. Future perspectives of this work are focused towards modifying one of the above routing protocols such that the modified protocol could minimize more energy for the entire system.

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