A Survey on Adaptive Duty Cycle Control with Queue Management in Wireless Sensor Networks

S. Logeshwari
PG Scholar,
Department of ECE,
Muthayammal Engineering College,
Tamil Nadu, India

N. Saranya
Assistant Professor,
Department of ECE,
Muthayammal Engineering College,
Tamil Nadu, India

J. Neeraja
PG Scholar,
Department of ECE,
Muthayammal Engineering College,
Tamil Nadu, India

Abstract-Wireless sensor network attracted wide range of applications and provide a bridge between virtual and physical world. Sensor nodes are generally stationery and mainly depends on battery, so energy consumption plays an vital role in wireless sensor networks. Energy consumption plays important role in protocol stack To save energy in wireless sensor network, several MAC protocol have proposed. The selection of MAC Protocol depends on the application. MAC protocols reduce the energy consumption by controlling the duty cycle. Adaptive duty cycle control with queue management controls the duty cycle through queue management and achieve high performance at high traffic. In this paper several MAC protocols have been discussed and compared the same protocol with the advantages and disadvantages.

Keywords- **Wireless Sensor network; Medium Access Control; Energy; Delay**

I. INTRODUCTION

A sensor network is an infrastructure comprised of large number of sensor nodes used to monitor the environment. In addition to sensing it is also used in control and activation. The basic components in a sensor network: (1) an assembly of distributed or localized sensors; (2) a network which is internally connected; (3) a central point of information clustering; and (4) a set of computing resources at the central point. The computation and communication infrastructure associated with sensor networks is often specific to this environment and rooted in the device and application-based nature of the networks. Today's sensors can be described as ''smart'' inexpensive devices equipped with multiple onboard sensing elements, they are low-cost low-power multifunctional nodes that are logically homed to a central sink node.

The complexity of wireless sensor networks which generally consist of a data acquisition network and a data distribution network monitored and controlled by a management center. The study of wireless sensor networks is challenging in that it requires an enormous breadth of knowledge from an enormous variety of disciplines

II. MEDIUM ACCESS CONTROL

The wireless channel exhibits a broadcast nature where the transmission of a sensor node can be received by multiple sensor nodes surrounding it. This nature results in each sensor node sharing the wireless channel with the nodes in its transmission range. Since the communication has to be performed through this broadcast wireless channel the design of Medium Access Control (MAC) protocols is of crucial importance in WSNs.

The MAC protocols ensure communication in the wireless medium such that the communication links between nodes are established and connectivity is provided throughout the network[5]. The channel should be access in such a way that the collisions which occur when two closely located nodes transmit at the same time are minimized or eliminated.

III. ENERGY CONSUMPTION

The low cost requirements and the distributed nature of the sensor nodes constrain the energy consumption of all the layers. Hence the energy efficiency is of primary importance for the MAC layer protocol design. The MAC layer protocol should ensure that nodes transmit their information with minimum energy consumption. The sources of energy consumption in WSNs are due to Idle Listening, Collision, Protocol Over Head, Transmit and Receive Power.

The sensor and the processing circuitry consume negligible amounts of power when compared to the radio. Accordingly the major sources for energy consumption during a communication attempt can be classified as follows.

A. Idle Listening

Idle listening refers to the cases where the radio is operated and no useful data are retrieved from the channel. One of the major sources of idle listening is leaving the radio on during long idle times when no sensing event happens. This may result in overhearing. When a node receives a packet that is not destined for itself, it wastes energy while receiving this packet. All the sources of idle listening in WSNs should be minimized in the MAC layer design.

B. Collisions

These occur when two or more closely located sensor nodes transmit packets to the same receiver at overlapping times. The overlapped information causes the receiver not to receive either of the packets leading to packet collision. Collisions constitute a major source of energy consumption in WSNs. Since the half-duplex nature of the wireless channel prevents collision detection, collision avoidance techniques are usually exploited by MAC protocols.

C. Protocol Overhead

Another major source of energy consumption is the control overhead of the communication protocols. In order to coordinate communication in wireless channel, MAC protocols require control packets to be transmitted. Although these control packets provide robust operation of MAC protocols they need to be minimized to improve the energy efficiency.

D. Transmit Vs. Receive Power

Transmitting and receiving a packet constitute the major sources of energy consumption in WSNs. However depending on the hardware architecture transmitting or receiving may dominate the energy consumption[3].An important way to save energy in WSNs is by turning off the transceiver circuitry. The radio of a sensor node can be operated in sleep mode where all the circuitry related to the radio is switched off. This is especially desirable when a node has no packets to transmit or receive during a specific period.

IV. CSMA MECHANISM

Most of the MAC protocols proposed for WSNs rely on a conventional medium access scheme that has been introduced for WLANs. This scheme is the carrier sense multiple access (CSMA) mechanism. Many of the MAC Protocol used in WSNS use CSMA mechanism In contention-based protocols, CSMA is used for basic data communication. Similarly in reservation-based protocols slot requests are generally performed through CSMA. CSMA as its name implies relies on carrier sense.

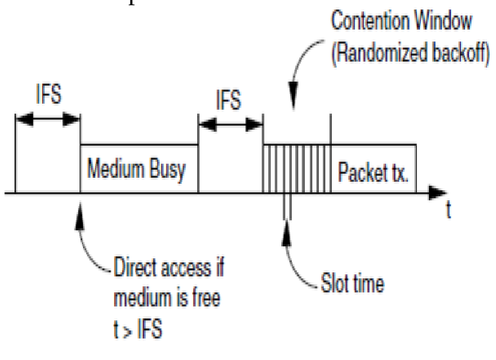

Fig.1. Basic CSMA Protocol

Carrier sense refers to nodes listening to the channel for a specific amount of time to assess the activity on the wireless channel. In other words CSMA is a listen-before-transmit method[8]. The functionalities of the basic CSMA are shown in Fig.1. A node, first, listens to the channel for a specific time which is generally referred to as the interframe space (IFS). Then the node acts based on two conditions:

• If the channel is idle for the duration of the IFS, the node may transmit immediately.
• If the channel becomes busy during the IFS, the node defers transmission and continues to monitor the channel until the transmission is over.

In basic CSMA the transmitter node has no way of knowing that a packet has been successfully transmitted. It is possible that a packet may be corrupted because of wireless channel errors or collides with another packet. In order for a node to be informed about its transmission an acknowledgment mechanism is incorporated into CSMA. When a node receives a packet from the transmitter node, it waits for a smaller amount of time than the IFS, i.e., SIFS < IFS, and transmits an acknowledgment (ACK) packet back to the transmitter[6]. On reception of the packet, the receiver sends ACK message to receiver.Absence of ACK message indicates that the error in packet transfer.One of the major shortcomings of the CSMA mechanism is its susceptibility to hidden terminal collisions.

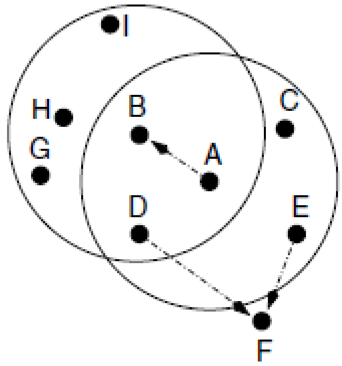

Fig. 2. Hidden Terminal Problems

The hidden terminal problem is shown in Fig. 2. Node A is transmitting a packet to node B, nodes C, D, and E can hear this transmission and defer their transmission attempts. However, nodes G, H, and I, which can hear B but not A, are not aware of this transmission since they cannot sense the transmission of node A. Hence, if one of these nodes starts transmitting a packet, this packet may collide with the packet that is being sent by node A, at node B. This phenomenon is known as the hidden terminal problem.

If the data packet being sent is long, then the probability of hidden terminal collision is high. In order to solve this problem the CSMA/CA scheme has been introduced in wireless networks, where CA stands for collision avoidance. In this scheme nodes send small packets to reserve the wireless channel prior to data transmission. The operation of CSMA/CA is illustrated in Fig.3. The process of exchanging four messages in CSMA/CA is generally referred to as four-way handshaking.

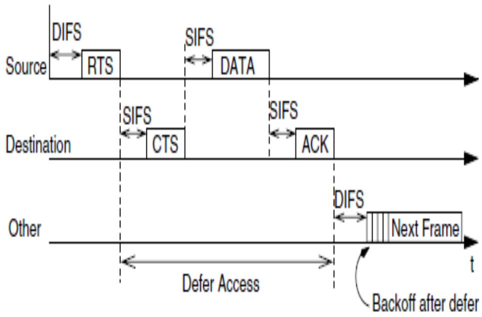

Fig.3. Basic CSMA/CA Mechanism

The difference between CSMA and CSMA/CA is the transmission of two reservation packets in the latter mechanism. The channel reservation in CSMA/CA is performed through two small packets, i.e., request to send (RTS) and clear to send (CTS). These packets are generally smaller than the actual DATA packets.

V. CONTENTION BASED MAC PROTOCOLS

One of the fundamental classes of MAC protocols is the contention-based protocols which rely on controlled contention between nodes to establish communication links. Contention based protocols provide flexibility since each node can independently perform contention decisions without the need for message exchanges. Instead each node tries to access the channel based on the carrier sense mechanism. Contention based protocols provide robustness and scalability to the network. On the other hand the collision probability increases with increasing node density.

A. S-MAC

The CSMA/CA technique has the disadvantage of requiring nodes to continuously sense the channel for inactivity. To save energy consumption in wireless sensor network duty cycle operation is introduced.Using this operation, the activity of a node is scheduled according to a specific amount of time called the *frame* which is shown in Fig.4. A node sleeps for a specific amount of time and listens to the wireless channel for the rest of the frame. The ratio of the listen interval and the total duration of the frame is denoted as the *duty cycle*. During the sleep interval the radio of the node is switched off to save energy. In the meantime the particular node is also detached from the network.

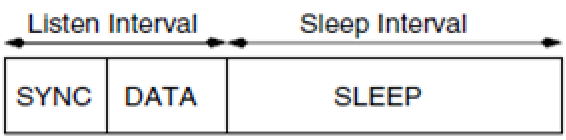

Fig.4. Listen and Sleep Intervals of MAC

S-MAC is a distributed contention-based MAC protocol which relies on coordinated sleep schedules to decrease the energy consumption while trading off throughput and latency[1]. While the protocol is based on the CSMA/CA scheme periodic sleep and listen cycles are introduced to reduce idle listening. The operation of each node is maintained during frames. Each frame consists of two intervals, listen and sleep, as shown in Fig.4.

The listen interval is further divided into two intervals called SYNC and DATA. The main idea behind S-MAC is to construct virtual clusters of nodes that sleep and wake up at the same time. This goal is performed through periodic synchronization messages abbreviated as SYNC messages. The SYNC portion of the listen interval is reserved for the exchange of these messages. Then nodes try to find their intended receivers during the DATA interval.

S-MAC ensures that nodes which are in the transmission range of each other, synchronize according to a single sleep schedule. This is performed by exchanging periodic SYNC messages. The structure of a SYNC message is shown in Fig.5. and consists of the ID of the sender node and the remaining time until the sender switches to sleep mode.

During protocol initialization a node listens to the channel for a specific amount of time long enough to receive any SYNC packets sent by its neighbors. If no SYNC packet is received during this interval the node determines its own sleep schedule and broadcasts a SYNC packet. This particular node is referred to as the synchronizer. The nodes which receive this packet follow the sleep schedule of the synchronizer.

The sleep schedule consists of the remaining time until the node will go to sleep. Since all the nodes are informed about the duty cycle and the frame size this information is sufficient for other nodes to synchronize. However inaccuracies in the clocks of a sensor node prevent actual time values being broadcast. Instead a node broadcasts the remaining time to switch to sleep.

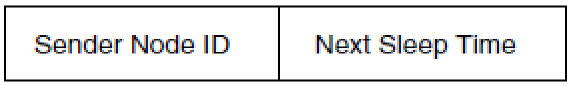

Fig.5. Structure of the S-MAC SYNC Packets

If a node receives a schedule from a neighbor before choosing its own schedule, it follows this neighbor's schedule i.e. becomes a follower. Furthermore the follower waits for a random delay and broadcasts this schedule. S-MAC does not aim to globally synchronize the network such that a single schedule is followed throughout the network. Instead the nodes in close proximity are synchronized. As a result it might happen that a node receives a neighbor's schedule after it has selected its own schedule[10]. In these cases this node is referred to as the *border node* as shown in Fig. 6. Border nodes adapt to both schedules and wake up at the listen intervals of these two schedules. However, it is expected that a node adopts multiple schedules very rarely since every node tries to follow existing schedules before choosing an independent one.

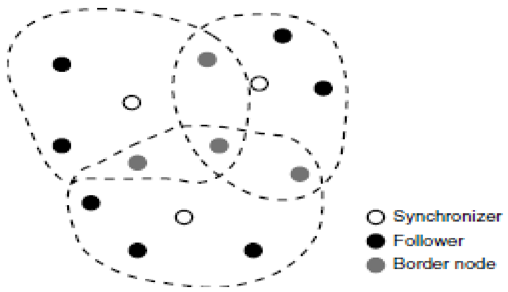

Fig. 6. Virtual Cluster of S-MAC Protocol

B. B MAC (BERKELEY MAC)

Energy consumption is the main performance metric that drives novel medium access protocols being developed for WSNs. Duty cycle operation requires sleep–wakeup schedules to be formed such that nodes in close proximity are active at the same time. This operation has two drawbacks in terms of energy inefficiency. Nodes need to send periodic messages firstly. All the nodes need to be active during the listen period to wait for a possible incoming packet secondly.Even when there is no traffic, nodes consume energy at a rate at least equal to the duty cycle-MAC has been designed to provide a core MAC protocol that is simple and reconfigurable by higher level protocols. An optional link level ACK mechanism is provided without any RTS–CTS message exchanges.

The CSMA mechanism can be configured by higher layers by changing the backoff durations. B-MAC is based on two mechanisms: sleep–wake scheduling using low-power listening (LPL) and carrier sensing using clear channel assessment (CCA). Both of these mechanisms improve the energy efficiency and channel utilization.

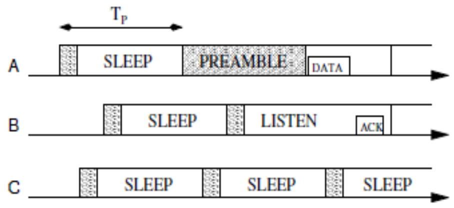

Fig.7. Preamble Sampling

Furthermore, B-MAC has been implemented in Tiny OS and provides simple interfaces for the higher layer services to easily configure the underlying MAC operation. This enables rapid development of cross-layer solutions, which require the basic functionalities of a MAC protocol. Through the provided interfaces, the higher layer protocols can toggle the CCA and ACK services.

The drawbacks of the fixed duty cycle operation of S-MAC and its derivatives can be addressed by removing the requirement of *schedule* for each node. Accordingly, all the nodes in the network do not need to wake up and sleep at the same time. Instead, each node can determine its sleep and wakeup schedule without any synchronization with the other nodes. This however requires transmitters to synchronize with their intended receivers when they have a packet to send. In other words, a transmitter needs either to *wake up* its intended receiver or wait for the intended receiver to wake up and send its data. This necessity is solved through preamble sampling, which is also referred to as LPL. A preamble message is send before each packet to *wake up* the intended receiver with the goal of minimizing the "listen cost" associate with the fixed duty cycle protocols is the main idea behind LPL. Accordingly, each node periodically wakes up, turns on its radio, and checks for activity on the channel. During this small period, if activity is detected on the channel, the node will be in the receive mode. However, if no activity is detected, then the node switches back to sleep state.[4]

The operation of LPL is shown in Fig.7.for three nodes: transmitter node is A, receiver node is B, and neighbor node is C. In this method, each node in the network determines its sleep schedule. The sleep schedule frame length is determined as *TP*.The node wakes up for a short amount of time at each TP secondto detect the activity of the channel. As shown in Figure 7,the wakeup time of each node is not synchronized with other nodes. When node A has a packet to send to node B, it first sends a preamble of length *TP* to wake up the node. Note that a length of *TP* is required for the preamble to wake up any node. When node B wakes up, it listens until the end of the preamble, determines that the packet is destined for itself, and does not switch to sleep state to wait for the subsequent packet. Node A then sends the DATA packet and node B replies with an ACK packet if the transmission is successful. Note that node C also wakes up during the preamble transmission. However, since the packet is not destined for itself, it switches back to sleep state without consuming more energy.

C. DSMAC

One of the basic enhancements for fixed duty cycle operation is provided through the DSMAC (Dynamic Sensor MAC) protocol . The main motivation behind this protocol is to minimize the medium access delay that may occur due to high traffic rate. The S-MAC duty cycle allows a fixed number of packet transmissions during the listen period. If a node generates (or receives) more packets than it can immediately transmit, the delay that will be experienced by the packet will increase[5]. The delay that is incurred by the MAC protocol in transmitting a packet is generally referred to as medium access delay. Static duty cycles may result in intolerable medium access delay, which builds up the packet queue.. DSMAC aims to solve this problem. The solution is to double the duty cycle in case the medium access delay of a packet exceeds a pre-specified value. In order to conserve energy, a node also checks if its energy consumption is lower than a threshold value. The sleep schedule of the DSMAC protocol, is shown in Fig.8.

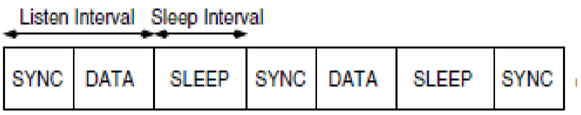

Fig.8. Listen and Sleep Interval of DSMAC

Doubling the duty cycle enables a node to receive or send more packets than the original schedule performed by other nodes. Moreover, since every other listen interval coincides with the original schedule, connectivity is still established. When a node decides to double its duty cycle, it broadcasts this value inside the SYNC packet that is sent at the beginning of each original frame. The node also includes its intended receiver in the SYNC message. Accordingly, the receiver node, after receiving the SYNC packet, adjusts it duty cycle and wakes up at the specified time. Other nodes in the virtual cluster are not affected by this operation.Doubling the duty cycle will result in reducing the medium access delay and the buffer length can be decreased[5].

D. T-MAC

T-MAC aims to solve duty cycle problem by introducing an adaptive duty cycle operation . The nodes start to listen to the channel in each listen interval but time out when there is no traffic for a specific amount of time. In this way, the duration of the listen interval is reduced in cases where there is no node in the virtual cluster to transmit a packet. The sleep–wakeup schedule of the T-MAC protocol is shown in Fig.9.

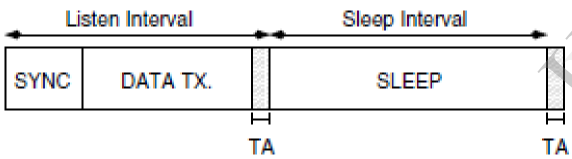

Fig.9. Listen and Sleep Interval of MAC

When there is no traffic, the listen time of the T-MAC protocol is lower than S-MAC's.*TA*,is a time out value which is an important parameter for the T-MAC protocol. This value is determined such that $TA>G+R+T$, where G is the length of the contention interval, R is the time for RTS packet transfer, and the turnaround time between the reception of the RTS packet and the transmission of the CTS packet is denoted as T. This ensures that potential hidden neighbors of the receiver nodes are aware of the transmission before switching to sleep. Although this awareness is not crucial for the communication taking place, it has implications for multi-hop awareness of the MAC protocol[8].

VI. RESERVATION-BASED MEDIUM ACCESS

Reservation-based protocols have the advantage of collision-free communication since each node transmits data during its reserved slot. Hence the duty cycle of the nodes is decreased resulting in further energy efficiency. Recently time division multiple access (TDMA)-based protocols have been proposed in the literature. Generally these protocols follow common principles where each node communicates according to a specific super frame structure.

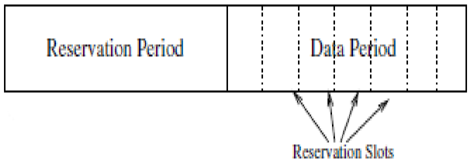

Fig.10. General Frame Structure for TDMA Based MAC Protocol

This super frame structure which generally consists of two main parts is illustrated in Fig.10. The reservation period is used by the nodes to reserve their time slots for communication through a central agent i.e., cluster head or with other nodes. The data period consists of multiple time slots that are used by each sensor for transmitting information. Among the proposed TDMA schemes the contention schemes for reservation protocols, the slot allocation principles, the frame size, and clustering approaches differ in each protocol.

A.TRAMA

The energy-efficient collision-free MAC protocol TRAMA is based on a time-slotted structure and uses a distributed election scheme based on the traffic requirements of each node. As a result the time slot that a node should use is determined such that any collisions with other nodes are prevented. TRAMA is a schedule-based MAC protocol where no central entity is required for reservations. Rather pair wise communications between neighbors are performed to schedule transmission slots for the communicating parties. Consequently each node schedules the slots during which it will transmit or receive packets[9]. Accordingly the node can coordinate when it has to sleep or remain active in the network.

TRAMA consists of four main phases:

- Neighborhood discovery: In this phase nodes need to be informed about their neighbors such that the potential receivers and transmitters can be determined.
- Traffic information exchange: During this phase nodes inform their intended receivers about their traffic information. More specifically if a node intends to send a packet to a node, it informs this particular node during this phase. Consequently by collecting traffic information from other nodes a node can form its schedule.
- Schedule establishment: Based on the traffic information from its neighbors node determines the

slots for transmitting and receiving packets in a frame. These schedules are then exchanged between nodes.

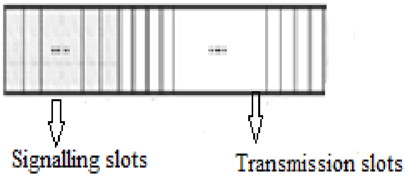

Fig.11. Frame Structure of TRAMA

- Data transmission: Based on the established schedule information the nodes can switch to active mode and start communication in the specified slot. The superframe structure of TRAMA is shown in Fig.11. The frame consists of signaling slots in the reservation period and transmission slots in the data period.[9] TRAMA operation consists of three mechanisms: the neighbor protocol (NP), schedule exchange protocol (SEP), and adaptive election algorithm (AEA). In summary:

(1) Each node gets information about its every two-hop neighbor using NP.
(2) The traffic information of each node is gathered by SEP using signaling slots
(3) Each node calculates its priority.

VII. HYBRID MEDIUM ACCESS

Contention based and reservation based protocols provide different advantages and disadvantages in the medium access performance. Since contention based protocols require significantly less overhead these protocols result in high utilization in cases where there is low contention. However when the numbers of nodes contending for the channel increases, channel utilization decreases since these nodes are not coordinated

On the other hand reservation-based protocols provide scheduled access to each node and decrease collisions. This results in high utilization when the competition is high but also in latency and overhead. Such a contrast produces a tradeoff between access capacity and energy efficiency.

Hybrid schemes in MAC protocols aim to leverage the tradeoff introduced in channel allocation by combining random access schemes with reservation based access TDMA approaches. Hybrid solutions provide performance enhancements in terms of collision avoidance and energy efficiency due to improved channel organization and adaptively to dynamic traffic load.

A. ZEBRA-MAC

In order to provide an adaptive operation based on the level of contention Zebra-MAC (Z-MAC) combines the advantages of each scheme in a hybrid MAC solution. The communication structure of Z-MAC still relies on time slots similar to TDMA-based solutions. Each slot is tentatively assigned to a node. However the difference between TDMA-based solutions is that each slot can be stolen by other nodes if it is not used by its owner. Consequently, Z-MAC behaves like CSMA under low contention and like TDMA under high contention. Similar to many reservation based protocols Z-MAC consists of a setup phase and a communication phase. The setup phase has four main components:

- Neighbor discovery
- Slot assignment
- Local frame exchange
- Global time synchronization.

Neighbor discovery is performed once by each node to gather information about its neighborhood. During this phase, each node broadcasts its one-hop neighborhood information to its neighbors[6]. At the end of multiple message exchanges each node is informed about its two hop neighborhood information. Collisions in the wireless channel affect the two-hop neighborhood of each node because of the hidden terminal problem. Slot assignment is performed by the DRAND protocol which ensures a broadcast schedule such that each node is assigned a slot that will not coincide with the slots of its two-hop neighbors. DRAND first creates a radio interference map of the network. Nodes that can interfere with each other are connected by bidirectional links in the interference map. Slot assignment is performed iteratively according to this map.

VIII. EXISTING SYSTEM

The Adaptive duty cycle control with queue management in wireless sensor networks controls the duty cycle through queue management and achieve high performance under variable traffic rates. An adaptive duty cycle control mechanism based on the queue management with the aims of power saving and delay reduction. The scheme does not require use state information from the neighboring nodes but only uses the local queue length available at the node.

Using the queue length and its variations of a sensor node a control based approach is presented and a distributed duty cycle controller is designed. Queue Threshold is fixed as 7.Queue Threshold is fixed to every node in order to increase the energy efficiency. This is because node is in sleep mode until the 8 packet is received. Real time data denotes information that is delivered immediately after collection. Periodic data denotes information that is collected regularly over Period of time.

Sleep time of node increases if queue length becomes smaller than queue threshold. Sleep time of node decreases if queue length becomes larger than Queue threshold. In the existing system no priority is given for real time data. Real time data have buffered in the queue. So the real time data gets delayed. The simulation results show that the proposed method gives increased packet delivery ratio reduced consumption of energy and reduced delay.

IX. RESULT

Number of nodes is 40and the number of source and destination is 2.Initially Queue Threshold is fixed to red color node and it remains in the sleep state until the queue threshold is reached is shown in Fig.11. The output at the sleep state is

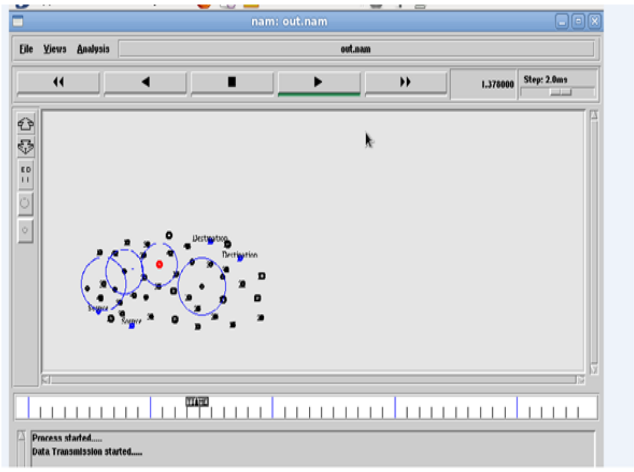

Fig.11.Sleep State

Node which is in the pink color indicate the active state and the data transmission occurs until the queue threshold become less than the fixed value is shown in Fig.12.The output at the active state is

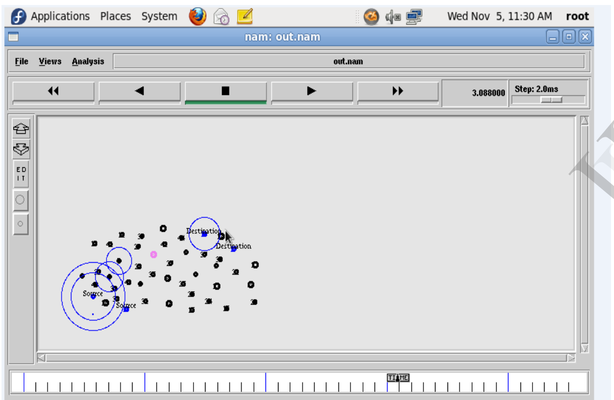

Fig.12.Active State

A.XGRAPH

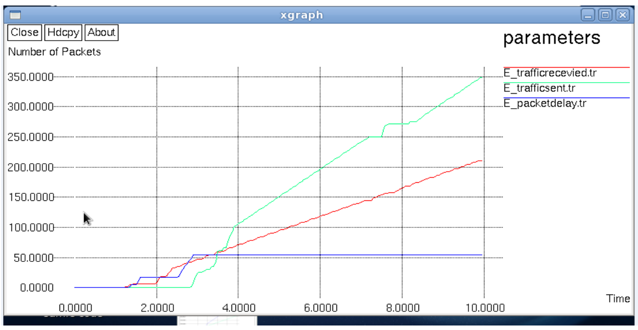

Fig.13.XGRAPH

Graph is obtained between energy of the send packet, received packet and delay where x-axis is taken as time and y-axis is taken as Number of packets. The result obtained shows that power consumption is less under heavy traffic and the delay is less compared to other method.

X. CONCLUSION

Adaptive Duty Cycle Control method controls the duty cycle through the queue management and the high performance under the heavy traffic is obtained. The sleep time is dynamically changed based on the queue length. This results in lower power consumption and faster adaption to changes. Adaptive duty cycle method only requires a queue length for computing the duty cycle which add good stability. The simulation results show that the proposed method significantly improves both energy efficiency and delay performance.

Designing a MAC Protocol for energy efficiency in wireless sensor network is difficult. Therefore no protocol is considered as a standard protocol. Several Adaptive MAC Protocol which is energy efficient proposed by many researchers have been discussed with their advantages and disadvantages. Selection of Particular MAC Protocol depends on the application which means no one is standard.

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