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Effect of Varying Traffic Load on MAC Protocols for WSNs

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Abstract— In the current decade, wireless sensor networks are emerging as a peculiar multi-disciplinary research area. Wireless sensor networks are appealing to researchers due to their wide range of application potential in areas such as target detection and tracking, environmental monitoring, industrial process monitoring, and tactical systems. However, lower sensing ranges result in dense networks, which bring the necessity to achieve an efficient medium access control protocol subject to power constraints. As medium access control has a significant effect on the energy consumption, energy efficiency is one of the fundamental research theme in the design of medium access control (MAC) protocols for wireless sensor networks. Sensor networks are expected to be deployed in an adhoc fashion, with nodes remaining largely inactive for long time, but becoming suddenly active when something is detected. These characteristics of sensor networks and applications motivate a MAC that is different from traditional wireless MACs such as IEEE 802.11 in several ways: energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important. There are plenty of MAC protocols available for wireless sensor networks in literature but SMAC is one of the most popularly used protocol designed specifically for WSN. In this paper, we would compare the performance of IEEE 802.11 MAC protocol with S-MAC protocol on different parameters like remaining energy, collision counts and distinct event delivery ratio by varying packet-inter arrival period.

Keywords— WSN, MAC, IEEE, SMAC, 802.11

I. INTRODUCTION

WSN are envisioned to consist thousands of extremely small and cheap devices that can sense the environment and communicate the data as required. Wireless sensors are generally equipped with data processing and communication capabilities. The sensing circuitry measures ambient conditions related to the environment surrounding the sensor and transform them into an electric signal. Processing such a signal reveals some properties about objects located and the events happening in the vicinity of the sensor. The sensor sends such collected data, usually via radio. The single most critical requirement for widespread adoption of such networks is power efficiency since battery replacement is not a viable option for such large wireless networks. Other challenges are the ultra-small size and per-unit device cost constraints, which are required to make such networks economically viable. These challenges necessitate advances in many different areas, some of which include sensors, radio architectures, circuit design techniques, sensor data processing and communication protocols.

1. Core Features of Wireless Sensor Networks

The design of WSN is determined by the sensor nodes characteristics and by application-specific requirements. Oftentimes, the WSN has to satisfy several constraints, suggesting the need for compromise solutions that provide balance between all of the imposed constraints. The core features of WSN are listed below.

- **Energy limitations**
  In the absence of promising energy-scavenging technologies that would provide constant energy supplies for the wireless sensor nodes, batteries are the most commonly used sources of energy. Energy is thus a scarce resource, and it presents a basic limiting factor for the node's lifetime. Thus, intelligent polices for the efficient utilization of the energy resources are needed. Communication in WSN is the most expensive operation in terms of energy. Usually, the energy required for transmission of only one bit is sufficient for the execution of about a thousand arithmetical operations. In WSN, the received signal power varies as a function of distance. This variation is caused by path loss and shadowing. The propagation of electromagnetic signals through the medium can be disturbed by various environmental factors, such as presence of obstructing objects or surface roughness which causes signal absorption, reflection, scattering and diffraction. These factors further attenuate the signal power at the receiver, influencing the reception of data packets and thereby increasing the overall energy consumption of the network.
- **Local processing**
  Data collected by the wireless sensor nodes that lie in proximity to each other may contain a high level of spatial and temporal redundancy. Local data processing (through data aggregation or data fusion) reduces the amount of data that have to be transmitted back to the data sink, thereby providing the application with high-level data representations that qualitatively satisfy the application's requirements.

- **Resistance to node failure**
  WSN are dynamic systems. Changes in the network topology may be caused by node failure due to various factors such as depleted batteries, environmental factors (fire, flood), an intruder's attack etc. The WSN should be self-adaptable, meaning that the loss of sensor nodes should not affect the overall functionality of the WSN.
- **Scalability**
  In many applications, a WSN may contain hundreds or even thousands of sensor nodes. The WSN should be scalable, meaning that the performance of these networks should be minimally affected by a change in network size. In many cases, recharging or replacing batteries is not possible, and adding new sensor nodes is the only way to prolong the lifetime of the network. In such cases, the WSN should easily integrate any new sensor nodes, with minimal degradation of functionality.
- **Deployment**
  Wireless sensor nodes can be deployed in various ways, depending on the application and the environmental conditions. They can be deployed randomly over the monitoring field, they can be attached to a specific moving object that is being monitored or they can be arranged deterministically. After deployment, the sensor nodes in most applications remain static. Depending on the deployment strategy, suitable communication protocols should be developed based on the existing network topology in order to support the WSN functionality.
- **Heterogeneity**
  WSN may consist of different types of nodes in terms of their sensing capabilities, computation power, memory size, radio circuitry and energy consumption. The diversity of hardware components can become a gap between these devices, raising new issues in communication and network configuration.
- **Quality of Service(QoS)**
  Satisfying the application goals by meeting the QoS requirements is one of the basic principles of WSN design. Quality of service in WSN can be defined from two perspectives: Application-specific and network. The application-specific QoS refers to QoS parameters specific to the application, such as, the quality of the sensor nodes measurements, the network's coverage, the number of active sensors, delay, etc. The network's perspective of QoS refers to the problem of how the supporting network can satisfy the application's needs, while efficiently using the WSN resources such as energy or bandwidth.

2. Wireless Sensor Nodes

Recent technological improvements have made the deployment of small, inexpensive, low-power, distributed devices, which are capable of local processing and wireless communication, a reality. Such nodes are called as sensor nodes. Each sensor node is capable of only a limited amount of processing. But when coordinated with the information from a large number of other nodes, they have the ability to measure a given physical environment in great detail. Thus, a sensor network can be described as a collection of sensor nodes which co-ordinate to perform some specific action. Unlike traditional networks, sensor networks depend on dense deployment and co-ordination to carry out their tasks.

Previously, sensor networks consisted of small number of sensor nodes that were wired to a central processing station. However, nowadays, the focus is more on wireless, distributed, sensing nodes. But, distributed, wireless sensing [6] when the exact location of a particular phenomenon is unknown, distributed sensing allows for closer placement to the phenomenon than a single sensor would permit. Also, in many cases, multiple sensor nodes are required to overcome environmental obstacles like obstructions, line of sight constraints etc. In most cases, the environment to be monitored does not have an existing infrastructure for either energy or communication. It becomes imperative for sensor nodes to survive on small, finite sources of energy and communicate through a wireless communication channel.

Another requirement for sensor networks would be distributed processing capability. This is necessary since communication is a major consumer of energy. A centralized system would mean that some of the sensors would need to communicate over long distances that lead to even more energy depletion. Hence, it would be a good idea to process locally as much information as possible in order to minimize the total number of bits transmitted.

A greater number of sensors allows for sensing over larger geographical regions with greater accuracy Fig.1 shows the schematic diagram of sensor node components. Basically, each sensor node comprises sensing, processing, transmission, mobilizer, position finding system, and power units (some of these components are optional like the mobilizer). The same figure shows the communication architecture of a WSN. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. Each sensor node bases its decisions on its mission, the information it currently has, and knowledge of its computing, communication, and energy resources. Each of these scattered sensor nodes has the capability to collect and route data either to other sensors or back to an external base-station. A base-station may be a fixed node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the reported data.

Deployment of a sensor network in these applications can be in random fashion (e.g., dropped from an airplane) or can be planted manually (e.g., fire alarm sensors in a facility). For example, in a disaster management application, a large number of sensors can be dropped from a helicopter. Networking these sensors can assist rescue operations by locating survivors, identifying risky areas, and making the rescue team more aware of the overall situation in the disaster area.

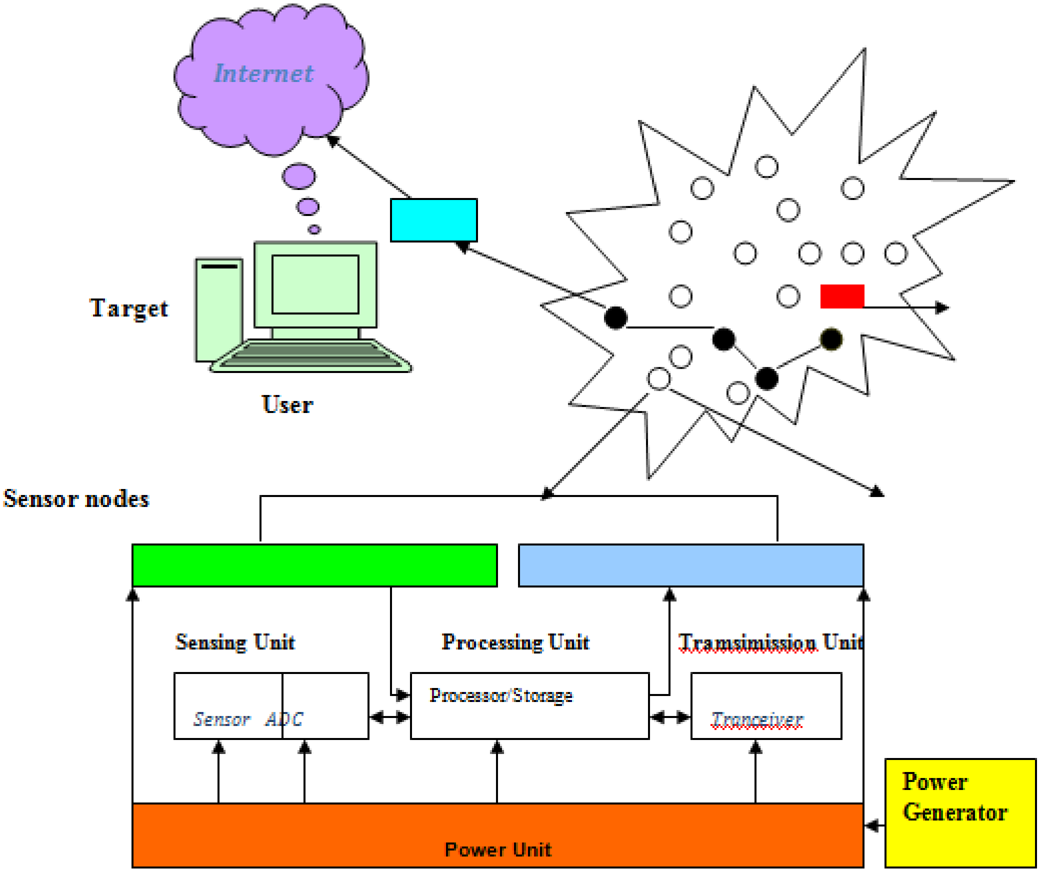

Fig 1. The components of a sensor node

II. SENSOR-MAC

S-MAC protocol was proposed by SCADDS project group at USC/ISI [15]. S-MAC is most popularly used protocol designed specifically for WSN. S-MAC is designed aiming at the requirement of saving energy of WSN according to 802.11 MAC. The main goal of S- MAC protocol is to reduce energy consumption, while supporting good scalability and collision avoidance [4]. This protocol tries to reduce energy consumption from all the sources that have been identified to cause energy waste, i.e., idle listening, collision, overhearing and control overhead.

2.1 Periodic Listen and Sleep

The basic scheme is shown in Fig. 2. Each node sleeps for sometime, and then wakes up and listens to see if any other node wants to talk to it. During sleeping, the node turns off its radio, and sets a timer to awake itself later.

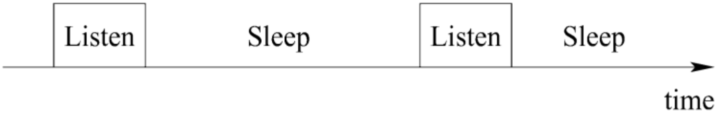

Fig. 2. Periodic listen and sleep

All nodes are free to choose their own listen/sleep schedules. However, to reduce control overhead, neighbouring nodes are prefer to synchronize together. That is, they listen at the same time and go to sleep at the same time. It should be noticed that not all neighbouring nodes can synchronize together in a multihop network. Two neighbouring nodes A and B may have different schedules if they must synchronize with different nodes C, and D, respectively, as shown in Fig. 3..

Fig. 3. Synchronization of neighbouring nodes that have different schedule

2.2 Collision Avoidance

If multiple neighbours want to talk to a node at the same time, they will try to send when the node starts listening. In this case, they need to contend for the medium. Among contention protocols, the 802.11 does a very good job on collision avoidance. S-MAC follows similar procedures, including virtual and physical carrier sense, and the RTS/CTS exchange for the hidden terminal problem [16].There is a duration field in each transmitted packet that indicates how long the remaining transmission will be. If a node receives a packet destined to another node, it knows how long to keep silent from this field. The node records this value in a variable called the network allocation vector (NAV) [17] and sets a timer for it.

2.3 Coordinated Sleeping

Periodic sleeping effectively reduces energy waste on idle listening. In S-MAC, nodes coordinate their sleep schedules rather than randomly sleep on their own. This section details the procedures that all nodes follow to set up and maintain their schedules. It also presents a technique to reduce latency due to the periodic sleep on each node.

2.4 Maintaining Synchronization

Since neighbouring nodes coordinate their sleep schedules, the clock drift on each node can cause synchronization errors. S-MAC use two techniques to make it robust to such errors. First, all exchanged timestamps are relative rather than absolute. Second, the listen period is significantly longer than clock drift rates. As mentioned earlier, schedule updating is accomplished by sending a SYNC packet. The SYNC packet is very short, and includes the address of the sender and the time of its next sleep. The next sleep time is relative to the moment that the sender starts transmitting the SYNC packet. When a receiver gets the time from the SYNC packet it subtracts the packet transmission time and use the new value to adjust its timer. In order for a node to receive both SYNC packets and data packets, the protocol divide its listen interval into two parts. The first one is for SYNC packets, and the second one is for data packets, as shown in Fig. 4.

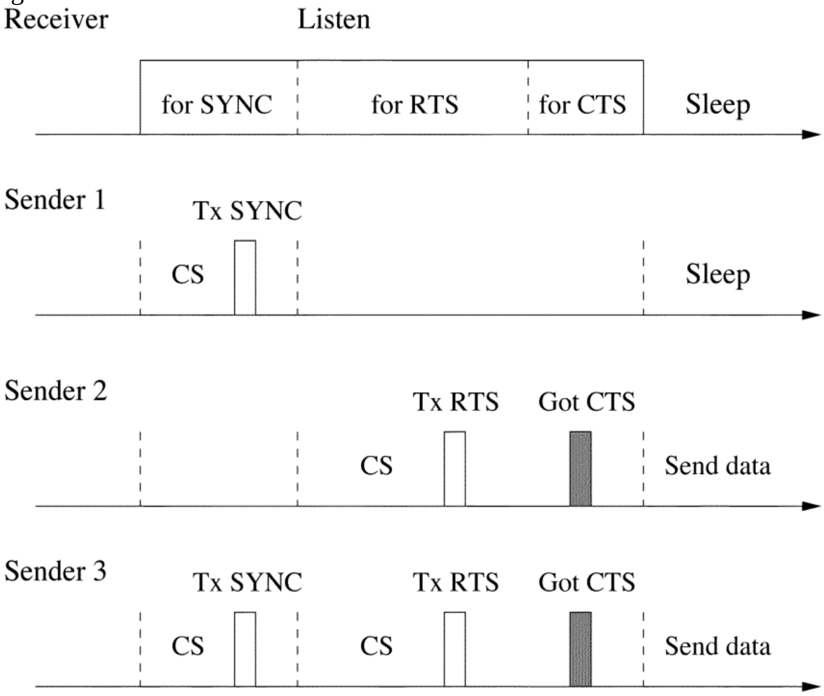

Fig. 4. Timing relationship between a receiver and different senders

III. RELATED WORK

In Ref. [4], Wei Ye et al. proposes S-MAC, a medium-access control (MAC) protocol designed for wireless sensor networks,S-MAC uses three novel techniques to reduce energy consumption and support self-configuration. To reduce energy consumption in listening to an idle channel, nodes periodically sleep. Neighbouring nodes form virtual clusters to auto-synchronize on sleep schedules. Inspired by PAMAS, S-MAC also sets the radio to sleep during transmissions of other nodes. Unlike PAMAS, it only uses in-channel signalling. Finally, S-MAC applies message passing to reduce contention latency for sensor-network applications that require store-and-forward processing as data move through the network. Finally the authors point out that the experiment results show that, on a source node, an 802.11-like MAC consumes 2–6 times more energy than S-MAC.

In Ref. [9] authors includes significant extensions in the protocol design, implementation, and experiments of S-MAC work which was published in [4]. This paper presents S-MAC, a medium access control protocol specifically designed for wireless sensor networks. Energy efficiency is the primary goal in the protocol design. Low-duty-cycle operation of each node is achieved by periodic sleeping. Together with overhearing avoidance and message passing, S-MAC obtains significant energy savings compared with 802.11-like protocols without sleeping. It is able to greatly prolong the network lifetime, which is critical for real-world sensor network applications. Periodic sleeping increases latency and reduces throughput. This paper proposes adaptive listening, which largely reduces such cost for energy savings. It enables each node to adaptively switch mode according to the traffic in the network.

IlkerDemirkol et al. [7] outline the sensor network properties that are crucial for the design of MAC layer protocols. Then, it describes several MAC protocols proposed for sensor networks emphasizing their strengths and weaknesses. This paper represents a comparison of MAC protocols investigated. Although there are various MAC layer protocols proposed for sensor networks, there is no protocol accepted as a standard. One of the reasons behind this is the MAC protocol choice will, in general, be application-dependent, which means that there will not be one standard MAC protocol for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware.

In Ref. [10], Huan Pham et al. present a new adaptive mobility-aware Sensor MAC protocol (MS-MAC) for mobile sensor applications. In MS-MAC protocol, a node detects its neighbour's mobility based on a change in its received signal level from the neighbour, or a loss of connection with this neighbour after a timeout period. By propagating mobility presence information, and distance from nearest border node.

In Ref. [11] authors present MMAC, a mobility-adaptive, collision-free MAC protocol for mobile sensor networks. MMAC caters for both weak mobility (e.g. topology changes, node joins and node failures) and strong mobility (e.g. concurrent node joins and failures, and physical mobility of nodes). Finally authors point out that this protocol adapts the time frame, transmission slots, and random-access slots according to mobility.

Zhiwei Zhao et al. [12] states that at present, most MAC protocols use the same transmission power when sensor nodes send packets. However, the deployment of the sensor nodes is asymmetrical in wireless sensor networks, which will bring more energy consumption and unnecessary collisions. This paper, proposed a transmission power control protocol for WSNs based on SMAC protocol. Power control at the MAC layer selects the minimum amount of transmitting energy needed to exchange messages between any pair of neighbouring nodes

In Ref. [13], Jian Xiao et al. present an efficient power control algorithm for wireless sensor networks. In the proposed algorithm, a transmitter sends RTS, CTS, DATA, and ACK frames with their corresponding minimum required power levels specified in its power control table. While reducing the power consumption, the proposed algorithm preserves the collision and overhearing avoidance properties of the SMAC protocol.

In Ref. [14] authors states that existing protocols such as sensor MAC (SMAC), reduce energy consumption by introducing an active/sleep duty cycle, which always leads to more control packets. These control packets waste a lot of energy. This paper proposes a novel contention-based MAC protocol (N-MAC), which is based on SMAC. This protocol utilizes preamble sampling instead of the RTS/CTS, and special offset time of the period in place of the time synchronization. N-MAC decreases the overhead of control packets and the maintenance of time synchronization.

Zhenzhou Tang et al. [18] proposed an energy efficient MAC protocol with adaptive transmit power scheme based on SMAC/AL named ATPM (Adaptive Transmit Power MAC). The proposed ATPM can calculate the distance between the sender and the receiver by measuring the received power, and then adaptively decide the appropriate transmit power level according to the propagation model and distance. Simulations have been done to evaluate the performance of the proposed new protocol, by which we can find out that ATPM can really reduce energy consumption compared with SMAC/AL. In this paper, an energy efficient MAC protocol with adaptive transmit power scheme named ATPM is proposed. ATPM can dynamically adjust the transmit power level according to the estimated distance between the sender and the receiver.

IV. PROPOSED METHODOLOGY

In this paper, we present the simulation results. The impact of varying packet inter arrival period on the energy consumption of entire wireless sensor network with NO Ad- Hoc (NOAH) routing protocol which is specifically designed for wireless sensor network under Sensor-MAC (SMAC) and IEEE 802.11 MAC protocol is analyzed. In NOAH routing protocol packet send by sender is buffered by inter-mediate sensor nodes if route to base station is known.

Table I Salient Simulation Parameters

Parameter	**Value**
Simulation area	1000m x 1000m
Routing Protocol	NOAH
No. of nodes	20
Packet size	64 Bytes
Max queue length	50
Traffic	CBR (Constant bit rate)
Routing protocol	NOAH
SMAC duty cycle	10 %
Antenna	Omni antenna
MAC type	802.11 and S-MAC
Simulation time	200 Sec
Packet inter-arrival time (ms)	800,1000,1200,1400,1600,1800,200

There are many parameters which can be used to evaluate the performance of routing protocols. Performance metrics are considered as follows**:**

- **Remaining Energy**

Fig. 5 shows the simulation graph for NOAH routing protocol under S-MAC and 802.11 MAC protocol under vaying packet inter-arrival time. From the analysis of simulation graph, it is cleared that total energy consumption of SMAC protocol is better as compare to the total energy consumption of IEEE 802.11 protocol.

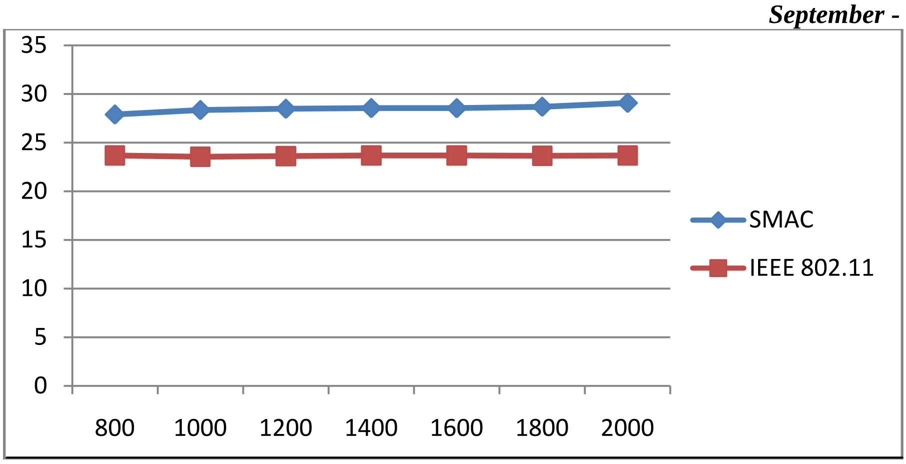

Fig 5: Remaining Energy versus packet inter-arrival time.

- **Distinct-event delivery ratio**

Fig. 6 shows the measured distinct event delivery ratio for different communication distance under IEEE 802.11 MAC and SMAC protocol. The results show that the distinct event delivery ratio of Sensor MAC increases as increase in packet inter-arrival time.

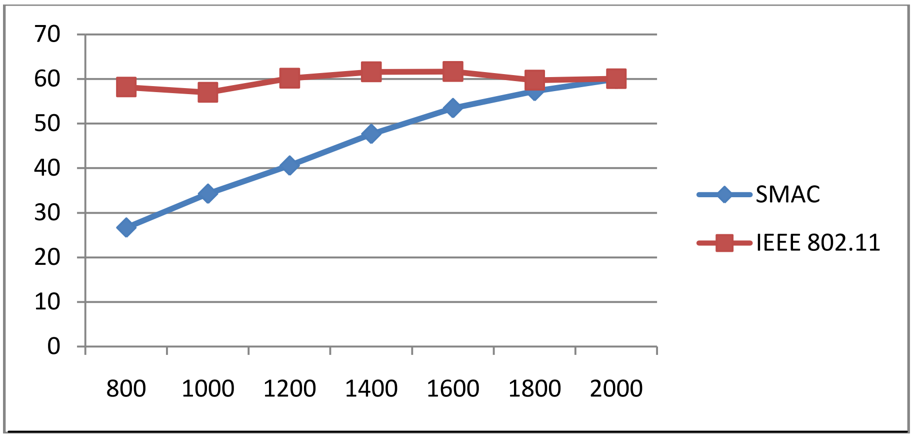

Fig 6: Distinct-Event Delivery ratio versus packet inter-arrival time.

- **Collision count**

Fig. 7 shows the measured collision counts for different packet inter-arrival time under IEEE 802.11 MAC and SMAC protocol.

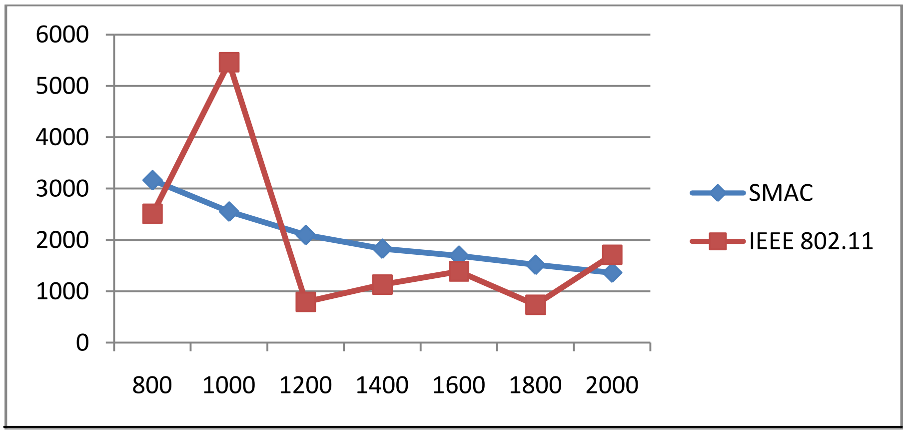

Fig 7: Collision count versus packet inter-arrival time.

VI. CONCLUSION AND FUTURE WORK

This paper compare the performance of IEEE 802.11 MAC protocol with S-MAC protocol on different parameters like remaining energy with varying packet-inter arrival period. S-MAC obtains significant energy savings compared with 802.11-like protocol as increase in traffic load by using higher packet inter-arrival time. As Simulation results show that the performance metrics of Sensor MAC far outperforms IEEE 802.11 protocol when traffic load is smaller that mean for higher packet inter arrival time that is 2000 milliseconds. As simulation results shows for heavy traffic load, 802.11 MAC consumes more energy as compared to consumed energy by S-MAC. S-MAC achieves energy savings mainly by avoiding overhearing and efficiently transmitting long messages.

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