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Energy efficient MAC-protocol with adaptive transmission power scale for WSN

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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 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 under NOAH routing protocol on different performance parameters by varying communication range of sensor nodes.

Keywords— WSN, MAC, IEEE, SMAC, 802.11

I. INTRODUCTION

The birth of wireless communications dates from the late 1800s, when M.G. Marconi did the pioneer work establishing the first successful radio communication systems have been developing and evolving with a furious pace. In the early stages, wireless communication systems were dominated by military usages and supported accordingly to military needs and requirements. Over the past few years, the world has become increasingly mobile. As a result traditional ways of networking the world have proven inadequate to meet the challenges posed by our new collective lifestyle. As a result wireless technologies are encroaching on the traditional realm of fixed or wired networks. Recent advances in processing, storage, and communication technologies have advanced the capabilities of small-scale and cost-effective sensor systems, which are composed of a single chip with embedded memory, processor, and transceiver.

WSN has a great ability of obtaining data and it can work under any situation, at any time, in any place, which makes it useful in many important fields. So, the military department, industrial circle and academic circle of many countries all over the world are paying great attention to it. It also becomes a hot issue in research at home and abroad today, and it is regarded as one of the ten influencing technology in the 21st century [1].

1. Wireless Sensor Networks (WSNs)

Wireless sensor networks have emerged as one of the first real applications of ubiquitous computing. Sensor networks play a key role in bridging the gap between the physical and the computational world by providing reliable, scalable, fault tolerant and accurate monitoring of physical phenomena. A Wireless sensor network is defined as being composed of a large number of nodes, which are deployed densely in close proximity to the phenomenon to be monitored. Wireless sensor networks (WSNs) communicate via a radio interface instead of being wired to a control station.

Sensors themselves are normally not equipped with a radio interface. Therefore, a simple signal processor and a radio are packaged together with one or more sensors into what is called a wireless sensor node.
As shown in Figure 1.1 many sensor nodes are scattered in a sensor field and each of these nodes collects data and its purpose is to route this information back to a sink [2]. The network must possess self-organizing capabilities since the positions of individual nodes are not predetermined. Cooperation among nodes is the dominant feature of this type of network, where groups of nodes cooperate to disseminate the information gathered in their vicinity to the user [3].

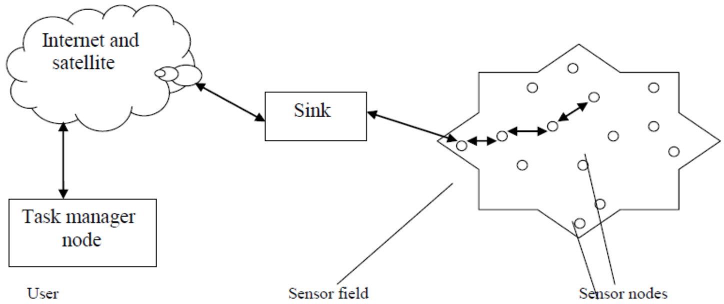

Figure. 1. Sensor nodes scattered in a sensor field

2. General Wireless Sensor Node Architecture

A WSN is composed of three main functional units: a sensing unit, a communication unit and a computing unit. General architecture of a wireless sensor node is, as shown in figure 1.2. In addition to regular sensor nodes, a WSN can contain one or more sink nodes (base stations). These sink nodes interact with wireless sensor nodes to collect sensed data and serve as a relay to the outside world. A sink node has a similar architecture to that of a regular node. The main difference is that a sink node does not have a sensing unit. A sink node is also considered, by default, to have an unlimited energy source, and therefore, there is no need to model a battery to characterize its energy consumption. However, with minor changes, the user could choose to attach a battery to the base station in the same way as for a regular sensor node.The microcontroller/microprocessor performs the data processing, thereby significantly reducing the total number of data bits transmitted over the wireless medium. The radio interface comprises the radio transceiver with power control. Increased transmission power results in smaller probability of dropped packets at the receiver, but at the same time it increases the interference with other nodes in the transmission range. Therefore, intelligent polices for power adjustment at the node need to be considered.
Different types of sensors can be attached to the node through the sensor interface. Since many sensors have analog output, an additional A/D circuit may be needed to bridge the gap between the sensor and the node.These different elements of wireless sensor nodes are as follows.

Sensing Unit

The Sensing unit consists of one or more sensors attached to a particular node. Each wireless sensor node is defined by the type of data it can collect, such as a temperature, humidity, thermal, seismic, visuals etc. Each wireless sensor senses one or more objects. A sensed object can either be a physical object such as a moving target, or it can be the environment of the sensor node, which might be the case when sensing temperature. When sensing a real object, meaningful data can be collected only if the sensed object is within the sensing range of the specific sensor. The wireless sensor can be in one of two states: active or inactive. The change between these two states is controlled by the application (running on the computing unit). When active, the sensor is constantly collecting data at a fixed sensing rate.

Communication Unit

The communication unit is in charge of relaying sensed data to the sink node and other sensor nodes when needed. The energy consumption of the communication unit depends on several factors. These include the modulation scheme, the data rate, the transmission distance and the operational mode. A communication unit can operate in several modes. The number and composition of these modes can vary from platform to platform like active, idle, and sleep. The last two modes imply constant power consumption. A constant power is also consumed during a change of operational mode. The communication energy consumption can be described in terms of transmit and receive consumptions. The transmit energy consumption depends on the transmission range and the energy consumed in the transmission circuitry. Furthermore, both transmit and receive energy consumptions depend on the message size.

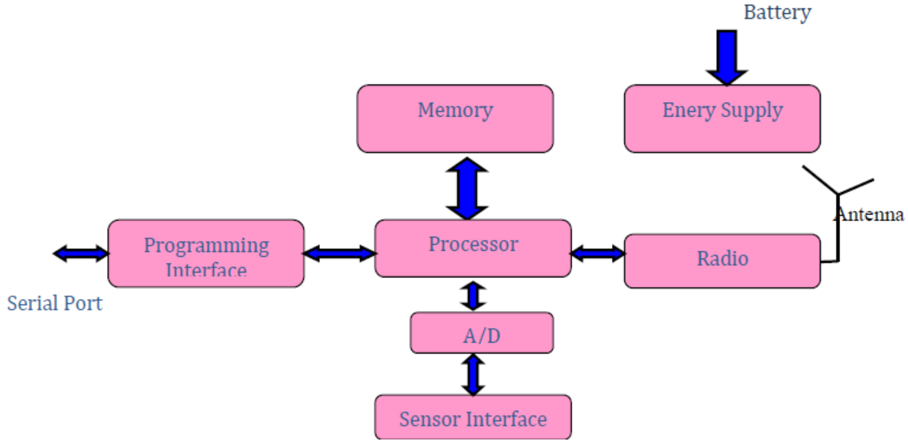

Figure 2: General architecture of a wireless sensor node

Computing Unit

The computing unit consists of a micro-controller unit, which runs the set of applications. It controls the sensing unit, performs the signal processing and executes the communication protocol. An application is attached to each sensor node. This application can request a sensor to activate or deactivate itself and can change the rate at which sensed data is collected. Another role of the application is to model any necessary processing on sensed data before sending it to other nodes in the network. It also receives and processes messages from other nodes. These messages can contain sensed data, for example when neighboring nodes aggregate their sensed data before sending a common message to the base station.
Nodes can exchange other types of messages such as messages related to collaborative reconfiguration, self-initialization or cluster formation and cluster-head election.

Battery

The battery is modeled as an energy reservoir initially with a fixed amount of available joules. The remaining energy of the battery is updated (reduced) every time whenever an activity that consumes energy occurs. These activities includes sensing, processing, transmitting, or receiving. Every time the remaining energy is updated, the node lifetime is also updated by adding the time since last update. The node lifetime is measured as the time since the node starts i.e. the node creation in the simulator or the node first activation.

Sink Node

The base station has all the components of a regular sensor node except the sensing unit and the battery. It is in charge of gathering the sensed data from sensor nodes. It also keeps track of the network lifetime. The network lifetime here is defined as the amount of time during which the network has been able to accomplish its tasks (for example collecting and relaying to the base station certain type of sensed data).

II. MEDIUM ACCESS CONTROL (MAC) MECHANISM

MAC is a good place to save energy. The medium access control is one of two sublayers that make up the data link layer of the OSI reference model. This layer is used to determine when and how nodes should access the shared medium. MAC layer takes charge of the distribution and management of the wireless channel. It plays a very important role in avoiding the collisions of nodes and distributing wireless channel, energy and other resources among contention nodes.

A. Existing MAC Protocols

One fundamental task of the MAC protocol is to avoid collisions from interfering nodes. The MAC sublayer uses MAC protocol to ensure that signals sent from different stations across the same channel don't collide. There are many MAC protocols that have been developed for wireless Voice and data communication networks.
Existing MAC protocols can be divided into two broad categories-

- Scheduled based protocols e.g. TDMA, FDMA, CDMA etc.
- Contention based protocols e.g. IEEE 802.11, CSMA etc.

Scheduled based protocol :

In this category each node gets full bandwidth for a pre-allocated time in turns or gets a permanent share of bandwidth depending upon the mechanism used for communication. Major drawback is that these are not suitable for networks whose node density changes and leads to poor bandwidth utilization.

Contention based protocol:

In this category each node contends for the medium as necessary. The major drawback is wastage of a lot of energy in idle listening.

B. Major Sources of Energy Wastage

Because of too much energy wastage, none of the above protocols mentioned above are suitable for wireless sensor networks. So it is very much clear that we need different MAC protocols for wireless sensor networks. Before discussing about the MAC protocols for WSN, take a look at the major sources of energy wastage in the existing MAC protocols [4].

The first one is collision. When a transmitted packet is corrupted, it has to be discarded, and follow-on re-transmissions that increases energy consumption. Collision increases latency as well. The second source is overhearing, meaning that a node picks up packets that are destined to other nodes. The third source is control packet overhead. Sending and receiving control packets consumes energy too. The last major source of inefficiency is idle listening, i.e., listening to receive possible traffic that is not sent. This is especially true in many sensor network applications. If nothing is sensed, nodes are in idle mode for most of the time. However, in many MAC protocols such as IEEE 802.11 adhoc mode or CDMA nodes have to listen to the channel to receive possible traffic. Measurements have shown that idle listening consumes 50%–100% of the energy required for receiving. For example, Stemm and Katz measure that the idle:receive:send ratios are 1:1.05:1.4 [5], while the Digitan wireless LAN module (IEEE 802.11/2 Mb/s) specification shows idle:receive:send ratios is 1:2:2.5 [6]. Most sensor networks are designed to operate for long time, and nodes will be in idle state for a long time. Thus, idle listening is a dominant factor of energy waste in such cases.

C. Design Considerations for MAC Protocol

To design a good MAC protocol for the wireless sensor networks, many attributes have to be considered [4]. The first is the energy efficiency. As stated above, sensor nodes are likely to be battery powered, and it is often very difficult to change or recharge batteries for these nodes. In fact, someday we expect some nodes to be cheap enough that they are discarded rather than recharged. Prolonging network lifetime for these nodes is a critical issue. Another important attribute is scalability and adaptivity to changes in network size, node density and topology. Some nodes may die over time, some new nodes may join later, and some nodes may move to different locations.

A good MAC protocol should gracefully accommodate such network changes. Other typically important attributes including fairness, latency, throughput, and bandwidth utilization may be secondary in sensor networks.

D. MAC Protocols

There are many existing MAC protocols for wireless sensor networks. In this section, a wide range of the MAC protocols is listed with their comparison [7].

- Sensor-MAC (S-MAC)
- WiseMAC
- Traffic-Adaptive MAC Protocol (TRAMA)
- SIFT
- Data gathering-MAC (D-MAC)
- Timeout-MAC (T-MAC)
- Dynamic Sensor-MAC (DSMAC)

Table I. Comparison of MAC Protocols

	Time Synch. Needed	**Comm. Pattern Support**	**Type**	**Adaptivity to Changes**
S-MAC/ T-MAC/ DSMAC	No	All	CSMA	Good
WiseMAC	No	All	np-CSMA	Good
TRAMA	Yes	All	TDMA/CSMA	Good
SIFT	No	All	CSMA/CA	Good
DMAC	Yes	Convergecast	TDMA/ Slotted Aloha	Weak

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 for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware.

III. RELATED WORK

In Ref. [2] authors present communication architecture for sensor networks and proceed to survey the current research pertaining to all layers of the protocol stack: physical, data link, network, transport and application layers.

They defined sensor network as being composed of a large number of nodes, which are deployed densely in close proximity to the phenomenon to be monitored. Each of these nodes collects data and its purpose is to route this information back to a sink. They propose that sensor network must possess self-organizing capabilities since the positions of individual nodes are not predetermined. They also propose some design factors to be taken under consideration when designing such networks. The design factors listed by the authors are fault tolerance, scalability, production costs, hardware constraints, sensor network topology, environment, transmission media and power consumption.

A. Woo et al. [8] examine how CSMA based medium access can be adapted for sensor networks. However, these approaches are not directly applicable due to the following characteristics of sensor networks:

- Network operates as a collective structure
- Traffic tends to be periodic and highly correlated
- Every node is both a data source and a router
- Node capabilities are very restricted
- Equal cost per unit time for listening, receiving and transmitting

The authors outline a CSMA-based MAC and transmission control scheme to achieve fairness while being energy efficient. They categorize media access control mechanisms into listening, backoff, contention control and rate control mechanisms. In rate control mechanism, MAC should control the rate of the originating data of a node in order to allow route-thru traffic to access the channel and reach the base station. The adaptive rate control proposed, uses loss as collision signal to adjust transmission rate in a manner similar to the congestion control in TCP.

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. Neighboring 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 signaling. 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.

Ilker Demirkol 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. Finally, authors point out open research issues on MAC layer design.

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 neighbor's mobility based on a change in its received signal level from the neighbor, or a loss of connection with this neighbor after a timeout period. By propagating mobility presence information, and distance from nearest border node, each

node learns its relative distance from the nearest mobile node and from nearest border node. Depending on the mobile node movement direction, the distances from mobile and border nodes, a node may trigger its neighbor search mechanism to quicken the connection setup time.

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.

In Ref. [12], authors proposed an energy efficient MAC protocol with adaptive transmit power scheme based on SMAC/AL named ATPM (Adaptive Transmit Power MAC). In SMAC/AL, all the nodes transmit data with a fixed power level, no matter how close the involved nodes are. 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 Ref. [13], authors evaluate some of the widely used efficient routing protocols with varying transmission range of the node. Data transmitted by a node is received by all the nodes within its communication range. We focus on the analysis of varying a range of the transmission in terms of distance. The proposed evaluation was made on routing protocols such as AODV and DSR. Results show that overall performance of DSR is better than AODV routing protocols at 125m range.

IV. PROPOSED METHODOLOGY

In this paper, we presents 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.

Simulation And Results

The performance of NOAH routing protocol under data link sublayer MAC protocol namely- IEEE 802.11 and SMAC is evaluated and analyzed. This thesis work was carried out using ns-2.34. This section of the report evaluates the performance of NOAH routing protocol under above mention MAC protocol in terms of parameters like energy consumption, Average end to end delay, Distinct event delivery ratio, throughput and number of unused nodes in the entire sensor network.

For the experiments performed, a fixed-size network consisting of 50 nodes of size 500x500 meters was manually generated and analyzed under different packet inter-arrival time. The radio speed is set at 1 Mbps and power dissipation (0.660 W in transmit mode, 0.395 W in receive mode and 0.344W in idle mode) were based on data from currently available radios. The size of each data item was set to 64 bytes.

Table I Salient Simulation Parameters

Parameter	**Value**
Simulation time	300 Sec
Simulation area	500m x 500m
Routing Protocol	NOAH
No. of nodes	50
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

.

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

1. Remaining Energy

Different changes of the entire network remaining energy measures with the time changing in algorithm. The entire network remaining energy can indicate the lifetime of the sensor networks.

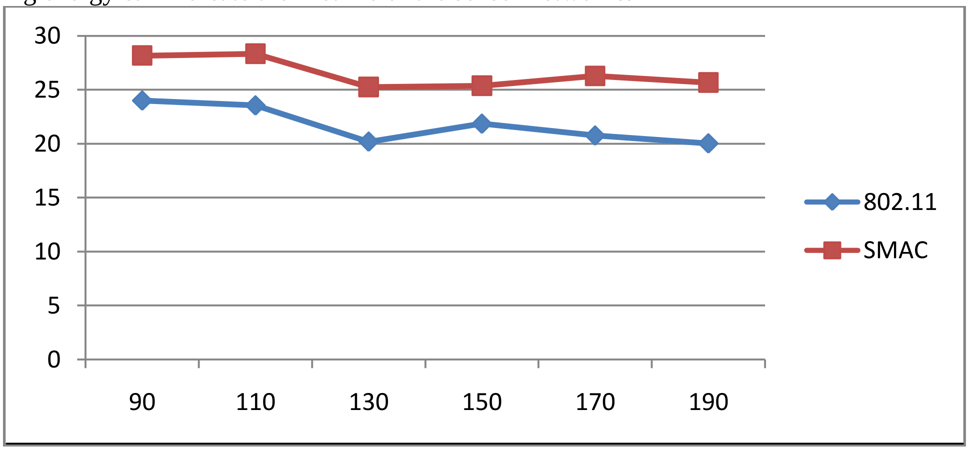

Figure 1.3 Remaining Energy versus Communication distance.

2. **Distinct-event delivery ratio**

Distinct-event delivery ratio is the ratio of the number of distinct events received to the number originally sent by sources.

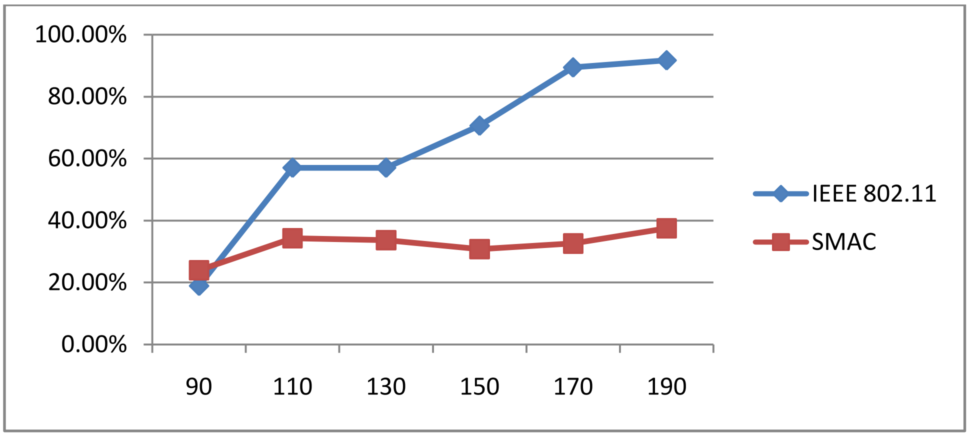

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Figure 1.4 Distinct-Event Delivery ratio versus Communication distance.

3. Collision count

Collision is the result of two devices on the same Ethernet network attempting to transmit data at exactly the same time. The network detects the "collision" and discards the packets. This metrics calculate the numbers of collision occurs in a network.

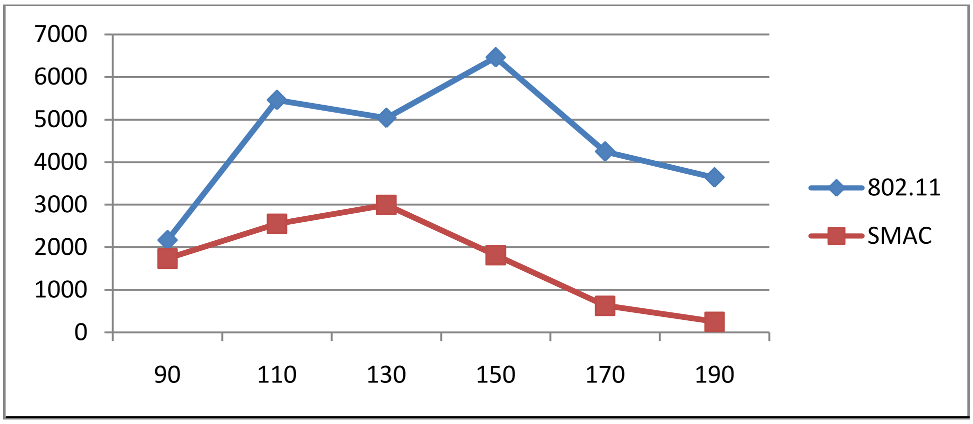

Figure 1.5 Collision count versus Communication distance.

V. CONCLUSION AND FUTURE WORK

After doing the literature review and studying S-MAC protocol in detail this thesis work concludes that S-MAC is the most popularly used MAC protocol for wireless sensor networks. This thesis work compare the performance of IEEE 802.11 MAC protocol with S-MAC protocol on different parameters like throughput and energy consumption with varying communication distance. S-MAC obtains significant energy savings compared with 802.11-like protocol. As Simulation results show that the distinct event delivery ratio of 802.11 MAC far outperforms S-MAC protocol when the communication distance is higher. But for transmission range, 802.11 MAC uses 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.

Future work include the analysis of the performance of S-MAC protocol in different modes like without periodic sleep, with periodic sleep and without adaptive listening, and with periodic sleep and with adaptive listening, on different parameters like total transmitting power, total receiving power and number of alive nodes by varying packet-inter arrival period.

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