Enhancing System Lifetime using Reliable MAC and Routing over WSNS

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Abstract— In the current decade, the areas of sensor design, information technologies, and wireless networks have paved the way for the proliferation of wireless sensor networks. These networks have the potential to provide practical usefulness in developing a large number of applications, including the protection of civil infrastructures, habitat monitoring, health care etc. However, the design of wireless sensor networks introduces formidable challenges. Energy is a scarce resource in the network. However, minimizing energy consumption does not neither necessarily prolong the network's lifetime, nor does it ultimately supports the QoS constraints imposed by the specific applications. The unique characteristics and constraint present many new challenges to the design and implementation of WSNs such as energy conservation, efficient data dissemination and fault tolerance. There are plenty of MAC and routing protocols available for wireless sensor networks. Efficient data dissemination is big challenges for WSNs. Directed diffusion protocol rectifies many problems of efficient data dissemination; reducing the energy consumption of WSNs nodes, robust communication thus increasing the overall network lifetime. In this paper, we evaluate the performance of data dissemination routing protocols under sensor MAC by which we can find out reduction in energy consumption through simulation studies.

Key words: WSNs, QoS, SMAC

I. INTRODUCTION

Wireless Sensor Networks are self-configured and infrastructure less wireless networks made of small devices equipped with specialized sensors and wireless transceivers. Sensing is a technique used to gather information about a physical object or process, including the occurrence of events. A sensor is a device that translates parameters or events in the physical world into signals that can be measured and analysed. A sensor, is a type of transducer that converts energy in the physical world into electrical energy that can be passed to a computing system or controller. Sensors link the physical with the digital world by capturing and revealing real-world phenomena and converting these into a form that can be processed, stored, and acted upon. The main goal of a WSN is to collect data from the environment and send it to a reporting site where the data can be observed and analysed. Wireless sensor devices also respond to queries sent from a sensor node to perform specific instructions or provide sensing samples.

The basic goals of a WSN are to:

1) Determine the value of physical variables at a given location,
2) Detect the occurrence of events of interest, and estimate parameters of the detected event or events,
3) Classify a detected object, and
4) Track an object.

Thus, the important requirements of a WSN are use of a large number of sensors, attachment of stationary sensors, low energy consumption, self-organisation capability, collaborative signal processing, and querying ability. Figure 1.1 shows the general architecture of a sensor network. As shown in figure 1.1, the three important layers

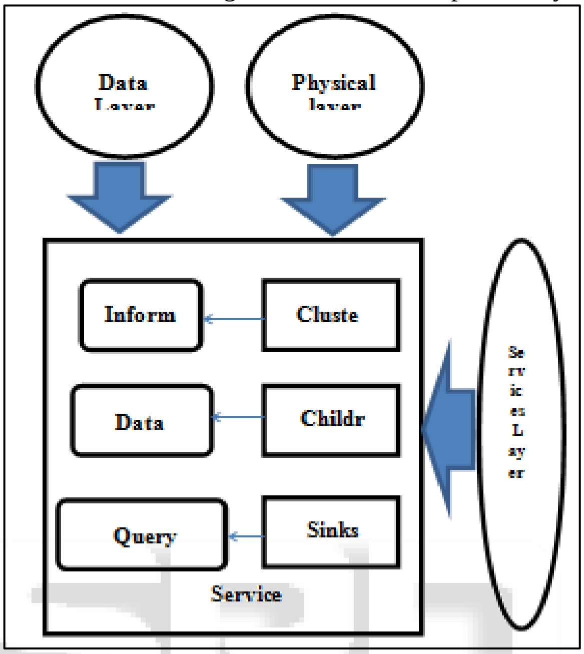

Fig. 1.1: Wireless Sensor Architecture

are the services-layer, data-layer, and physical layer. The layers provide routing protocol, data dissemination, and aggregation. The physical-layer containing the node defines itself as either a sink node, children node or parent node. Messages are modelled in the data-link layer. Broadcasting of a query is carried out by the use of sink nodes. The broadcasting can be either to the sensor network or to a designated region depending on the way the query is being used. In response to a change in the physical parameter the sensor nodes, which are close to the sensed object, broadcast this information to their neighbouring sensor nodes.

Wireless sensor networks have gained considerable popularity given their flexibility to solve problems in different application domains. WSNs have been successfully applied in the following application domains:

A. *Agriculture:*

WSNs have been used to control irrigation systems according to the humidity of the terrain.

B. *Military:*

Intrusion detection systems based on WSNs have been used by the military.

C. *Manufacturing:*

WSNs have been used to monitor the presence of lethal gasesin refineries.

D. *Transportation:*

Real-time traffic information is being collected by WSNs to later feed transportation models and alert drivers of congestion and traffic problems.

E. *Environmental:*

WSNs have been installed to monitor water deposits in mountains to detect mudslides. WSNs have been utilized in intelligent buildings to automatically control the temperature.

F. *Engineering:*

Civil engineers have used WSNs technology to monitor the condition of civil structures, such as bridges.

II. ROUTING IN WIRELESS SENSOR NETWORK

Routing in WSN is very challenging due to several characteristics that distinguish them from contemporary wireless ad-hoc networks:

- It is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes.
- In contrary to the end-to-end structure of typical communication networks, almost all applications of WSN require directing the flow of sensed data from multiple sources to a particular sink.
- Generated data traffic has significant redundancy among individual sensor nodes, since multiple sensors may generate same data within the vicinity of a phenomenon. The routing protocols should exploit such redundancy to improve energy and bandwidth utilization.
- Sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management.

A. *Classification of Routing Protocol in Wireless Sensor Network:*

Almost all of the routing protocols can be classified as data centric, hierarchical or location-based although there are few distinct ones based on network flow or QoS awareness [1, 2, 5, 9].

1) *Data-Centric Protocols:*

In many applications of WSN, it is not feasible to assign global identifiers to each node due to the sheer number of nodes deployed. Such lack of global identification along with random deployment of sensor nodes makes it hard to select a specific set of sensor nodes to be queried. Therefore, data is usually transmitted from every sensor node within the deployment region with significant redundancy. Since this is very inefficient in terms of energy consumption, routing protocols that will be able to select a set of sensor nodes and utilize data aggregation during the relaying of data have been considered. This consideration has led to data centric routing, which is different from traditional address-based routing where routes are created between addressable nodes managed in the network layer of the communication stack. In data-centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute based naming is necessary to specify the properties of data.

SPIN [19] is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy. Later, directed diffusion [6,13] has been developed and has become a breakthrough in data-centric routing.

Directed Diffusion aims at diffusing data through sensor nodes by using a naming scheme for the data. The main reason behind using such a scheme is to get rid of unnecessary operations of network layer routing in order to save energy. Directed diffusion suggests the use of attribute-value pairs for the data and queries the sensors in an on demand basis by using those pairs. In order to create a query, an interest is defined using a list of attribute-value pairs such as name of objects, interval, duration, geographical area, etc. The interest is broadcast by a sink through its neighbors. Each node receiving the interest can do caching for later use. The nodes also have the ability to do in-network data aggregation. The interests in the caches are then used to compare the received data with the values in the interests. The interest entry also contains several gradient fields. A gradient is a reply link to a neighbor from which the interest was received. It is characterized by the data rate, duration and expiration time derived from the received interest's fields. Hence, by utilizing interest and gradients, paths are established between sink and sources. Several paths can be established so that one of them is selected by reinforcement. The sink resends the original interest message through the selected path with a smaller interval hence reinforces the source node on that path to send data more frequently. Figure. 4.1 summarize the directed diffusion protocol.

Path repairs are also possible in directed diffusion. When a path between a source and the sink fails, a new or alternative path should be identified. For this, directed diffusion basically reinitiates reinforcement by searching among other paths, which are sending data in lower rates. Directed Diffusion differs from SPIN in terms of the on demand data querying mechanism it has.

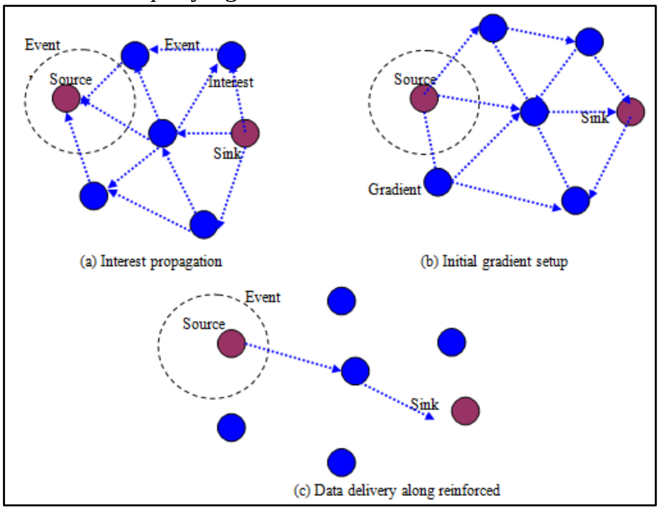

Fig. 2.1: Directed Diffusion Protocol Phases

In directed diffusion the sink queries the sensor nodes if a specific data is available by flooding some tasks. In SPIN, sensors advertise the availability of data allowing interested nodes to query that data. Directed Diffusion has many advantages. Since it is data centric, all communication is neighbor-to-neighbor with no need for a node addressing mechanism. Each node can do aggregation and caching, in addition to sensing. Caching is a big advantage in terms of energy efficiency and delay. In addition, direct diffusion is highly energy efficient since it is on demand and there is no need for maintaining global network topology.

However, directed diffusion cannot be applied to all sensor network applications since it is based on a query-driven data delivery model. The applications that require continuous data delivery to the sink will not work efficiently with a query-driven on demand data model. Therefore, directed diffusion is not a good choice as a routing protocol for the applications such as environmental monitoring. In addition, the naming schemes used in directed diffusion are application dependent and each time should be defined a priori. Moreover, the matching process for data and queries might require some extra overhead at the sensors.

2) Hierarchical Protocols:

Similar to other communication networks, scalability is one of the major design attributes of WSN. A single-tier network can cause the gateway to overload with the increase in sensors density. Such overload might cause latency in communication and inadequate tracking of events. In addition, the single-gateway architecture is not scalable for a larger set of sensors covering a wider area of interest since the sensors are typically not capable of long-haul communication. To allow the system to cope with additional load and to be able to cover a large area of interest without degrading the service, networking clustering has been pursued in some routing approaches. The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on the energy reserve of sensors and sensor's proximity to the cluster head. LEACH is one of the first hierarchical routing approaches for sensors networks [17,19]. The idea proposed in LEACH has been an inspiration for many hierarchical routing protocols, such as PEGASIS [12], TEEN [13]. The hierarchical routing paradigms can progressively prolong the network system lifetime because of its dynamic cluster operation. Also they have the advantages such as distributed property and no global network topology information is needed. However, the single hop assumption makes it not be suitable for WSN deployed in wide area. Another disadvantage is that dynamic clustering brings additional cost, such as the changing operation of cluster header.

3) Location-Based Protocols:

The idea of location-based protocols is using an area instead of a node identifier as the target of a packet. Any node that is positioned within the given area will be acceptable as a destination node and can receive and process a message. In the context of WSN, such location-based routing is evidently important to request sensor data from some region. Since there is no addressing scheme for WSN like ip-addresses and they are spatially deployed in a region, location information can be utilized in routing data in an energy-efficient way. For instance, if the region to be sensed is known, using the location of sensor nodes, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. Some of the protocols are designed primarily for mobile ad hoc networks and consider the mobility of nodes during the design. However, they are also well applicable to WSN where there is less or no mobility. Three main protocols of this category are SMECN, GAF and GEAR. The location-based routing protocols take into account the mobility of sensor nodes and perform very well when the density of network increases. But, the performance is very poor when the network deployment is sparse, and there is no any data aggregation and further processing by the header node.

4) Network Flow and Qos-Aware Protocols:

In some approaches such as maximum lifetime energy routing and maximum lifetime data gathering, route setup is modeled and solved as a network flow problem [15,17]. In real-time applications including target tracking in battle environment and emergent event triggering in monitoring applications etc, QoS-aware protocols consider end-to-end delay requirements while setting up the paths in the WSN. Currently, there is very little research about QoS-aware protocols for WSN, among which are two examples: SAR and SPEED. The network flow based and QoS-aware routing algorithms can provide good QoS performance resulting from its design goal.

III. RELATED WORK

In Ref. [1] 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. [2] 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. [3], 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. [4] 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.

In Ref. [5], 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. [6] 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. [7] 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 neighboring nodes. The simulation results show that, compared with SMAC protocol, proposed protocol has improved a lot in the delay of packets, reception rate, energy consumption and throughput of the networks.

In Ref. [8], 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. [9] 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. It also prevents some edge nodes from early death. The results of simulation displays that N-MAC is better than the SMAC.

Zhenzhou Tang et al. [10] 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.

P. Jiang1 et al. [11], gives a short overview of recent routing protocols for sensor networks and presents a classification for the various approaches. The four main categories studied in their paper are data-centric, hierarchical, location-based, and network flow and QoS-aware. Then, the existing hardware research platforms are explored as well as the software platforms such as simulation and development tools.

S. Dai et al. [12], summarized recent research results on data routing in WSN and classified the approaches into three main categories, namely data-centric, hierarchical and location-based. Few other protocols followed the traditional network flow and QoS modeling methodology. Their study also observed that there are some hybrid protocols that fit under more than one category. The most interesting research issues in their study related to routing protocols for WSN are how to form the clusters so that the energy consumption and contemporary communication metrics such as latency are optimized, the consideration of node mobility, and integration of WSN with wired networks (i.e. Internet).

H Zhou et al. [13], proposes reactive ID assignment, which is an efficient ID assignment in a WSN. Noticing that ID is not needed if there is no data communications, if we could delay ID conflict resolution until data communications are necessary, and can preserve as much power as possible. Compared with proactive schemes, a reactive ID assignment approach is proposed to accomplish the goal and preserve more power by means of delaying ID conflict resolution until necessary. It has no requirement on apriori unique IDs of the Wireless Sensor nodes, and is easy to integrate with the directed diffusion communication paradigm.

J. H. Kang et al. [14], proposed a structure-based algorithm that assigns globally unique IDs to sensor nodes. The proposed algorithm aims at assigning globally unique IDs to each node by using two grouping algorithms. Through these two grouping algorithms, it structures two levels of groups. In each group, headers take roles of sink and it assigns neighbors' IDs instead of sink node. Sink node cannot only easily assign IDs to all other nodes via header nodes but also save the energy consumption up to 25%.

IV. SIMULATION RESULTS

This section presents the simulation results. The impact of varying packet inter arrival period on the energy consumption of entire wireless sensor network with Data Dissemination routing protocol under Sensor-MAC (SMAC) protocol is analyzed. Here, we calculate the remaining energy, collision counts, and average delay metrics with respect to packet inter arrival time for 150 m. We work on the direct diffusion routing protocol and omniscient multicast protocols due to one of their properties is maximum energy is saved in these protocol.

Parameter	Value
Simulation time	100 Sec
Simulation area	600m x 600m
Antenna	Omni antenna
No. of subscriber	50
Routing protocol	DD, omniscient multicast
Packet inter-arrival time	1.5 to 2 seconds
Transmission range	150m
SMAC duty cycle	10 %
Packet size	64 Bytes

Table 1: Salient Simulation Parameters

A. Remaining Energy:

Figure 4.1 shows the simulation graph for directed diffusion and omniscient multicast routing protocols under S-MAC protocol in terms of the measured average remaining energy of sensors nodes when packet interval time is varied between 1.5 to 2 seconds.

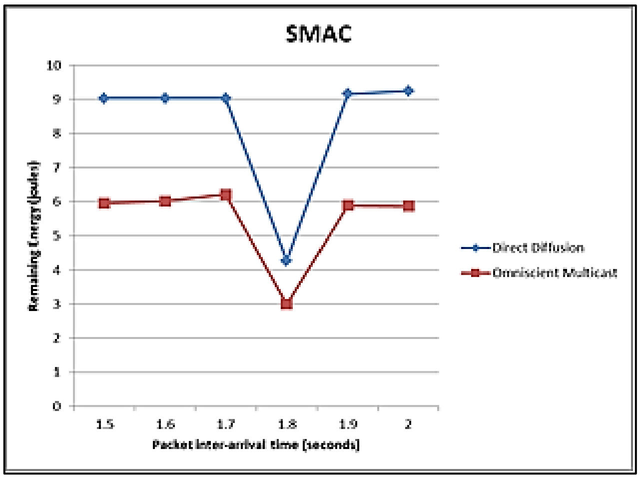

Fig. 4.1: Remaining Energy V/S Packet Inter-Arrival Time.

B. Average Delay:

Figure 4.2 shows the simulation graph for directed diffusion and omniscient multicast routing protocols under S-MAC protocol in terms of the measured average delay of sensors nodes when packet interval time is varied between 1.5 to 2 seconds.

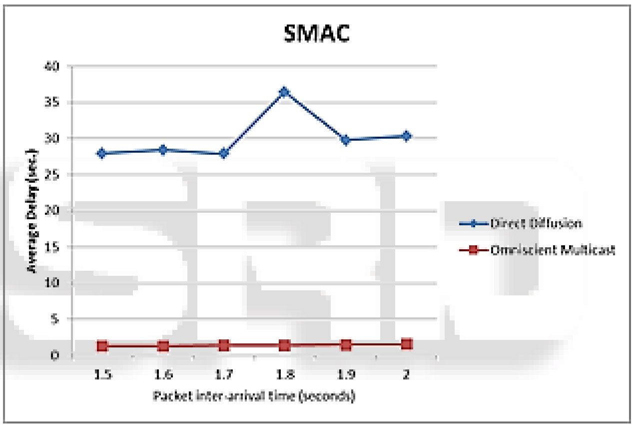

Fig. 4.2: Average Delay V/S Packet Inter-Arrival Time.

C. Collision Count:

Fig. 4.3 shows the measured collision counts for different packet interval times.

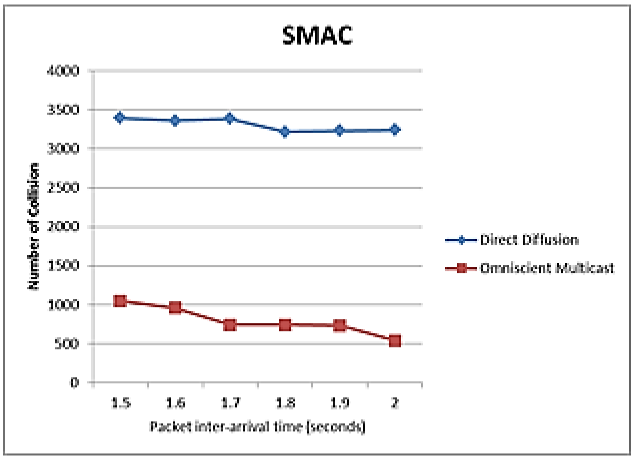

Fig. 4.3: Collision Counts V/S Packet Inter-Arrival Time.

V. CONCLUSION

Directed diffusion protocol solves many problems of efficient data dissemination for WSNs. Directed diffusion has several features and it differs from earlier networking. First, directed diffusion is data-centric; all communication in a directed diffusion-based sensor network uses interests to specify named data. Second, all communication in directed diffusion is neighbor-to-neighbor, unlike the end-to-end communication in traditional data networks. In this paper, energy efficient data dissemination protocols namely directed diffusion and omniscient multicast protocol with S-MAC protocol are compared on the bases of different QoS parameters under varying packet-inter arrival period. The comparative evaluation was made for Data Dissemination protocols such as Directed Diffusion and omniscient multicast, which are simulated in ns2. The simulation results shows that remaining energy increases as increase in the packet inter-arrival period. Thus network with above said parameter shows better results in term of remaining energy and other performance metrics if the packet inter arrival time is higher under sensor MAC.

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