Role of Relay Node in Wireless Sensor Network: A Survey

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***Abstract*—This paper describes the concepts of Relay node characteristics, various deployment methods, and their internal behaviors in the Wireless Sensor Networks (WSN). First, the internal behavioral characteristics of relay node and their different state processing are analyzed using algorithm. Then, the influence of relay nodes in WSN and the potential relay node deployment methods were explored and with the efficient deployment of relay nodes, a simple research-level review of WSN accuracy and network energy consumptions are provided via Simulation results. Exposed research issues for the realization of relay node deployment in WSN were also discussed.**

Keywords- Wireless sensor network, Relay node, RCS, IRS, ICS

I. INTRODUCTION

To ensure and incorporate Fault Tolerance in WSN, the usage of relay node is unavoidable. Since the wireless sensor nodes are low-powered, energy-constrained, relay nodes are responsible for data packet fusion from the sensor nodes in their clusters and transmitting them to the destination/sink node via wireless multi-hop paths. The relay node performs three sections of operations. They include a radio communication section (RCS) for transmitting/receiving the information, an information recording section (IRS) for storing the information received from the sensor node, and an information conveying section (ICS) for determining a destination of the information. Fig.1 depicts the internal processing architecture of relay node. The wireless sensor network was more self-configuring in that there was no need for manually configuring.

Each node configured itself for relaying if the connectivity to sink was above a threshold. The position of the relay nodes and communication topology are carefully engineered. The unique feature of relay nodes in WSN is to make the network highly reliable in nature. The Relay nodes share the burden of sensor nodes and provide energy efficient data gathering, increase network life time for WSN. Mostly, large numbers of sensor nodes are densely deployed and minimum number of relay nodes are deployed in-between the sensor node in WSN. These ways of deployment ensure multihop communication to minimize less power consumption.

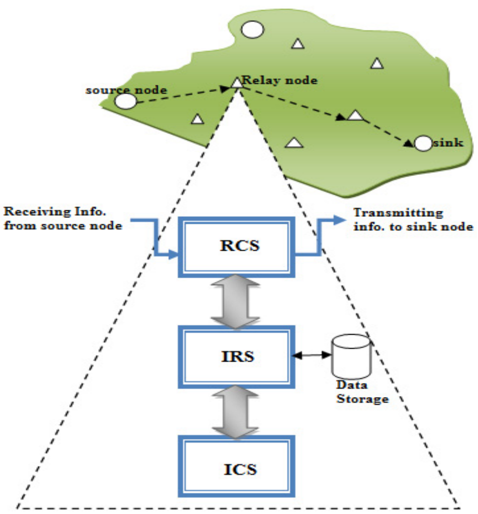
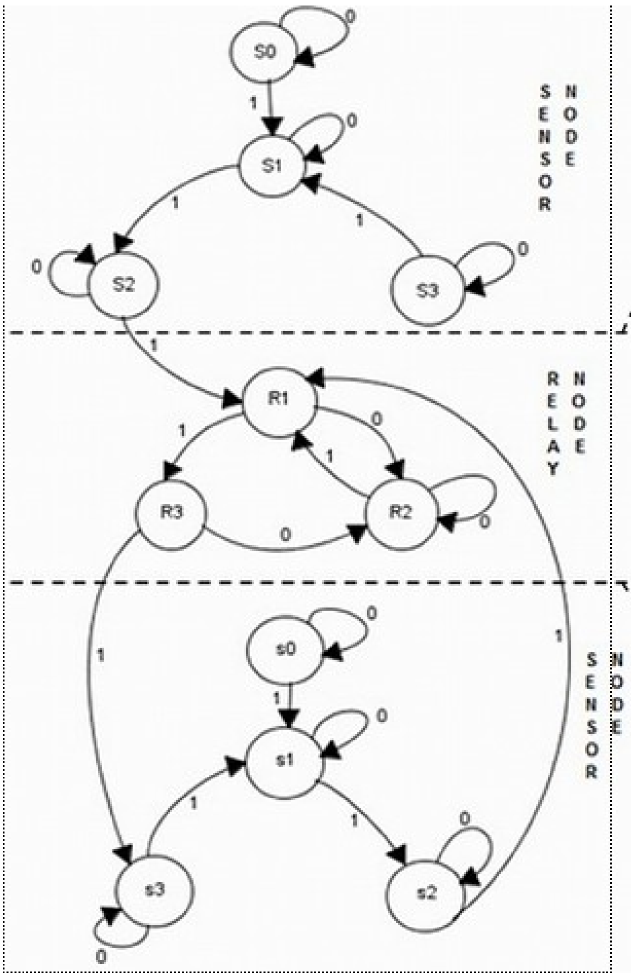


Figure 1. Internal Processing Architecture of Relay Node

II. Transition State of Relay Nodes

The state diagram in Fig.2 describes the entire behavioral nature of the relay node in WSN. The internal processing of relay node includes three modes a) idle mode, b) Receiving (Rx) mode, c) Transmit (Tx) mode. At the initial moment, the relay node is uncharged [5]. It will migrate into the receive state, when the node is fully charged. When the relay node receives any data packet in the receive state, it would compute the data packet and schedule it for possible transmission at the end of receive period. If a node acquires a packet to transmit at the end of receive period, then as per the scheduling computations it will transmit the data packet, when it senses that the channel is clear. Otherwise, it will go into the charging state until it is fully charged and the entire cycle repeats itself [5].

SENSOR NODE STATE	RELAY NODE STATE
S0 ➡ ***Sensing state***	***R1*** ➡ ***Receiving state***
S1 ➡ ***Processing State***	***R2*** ➡ ***Idle state***
S2 ➡ ***Transmit State***	***R3*** ➡ ***Transmit state***
S3 ➡ ***Receiving State***	




```
Initialize: Main Parameters
Boolean Charge;
    Charge == TRUE (charged)
    Charge == FALSE (charging)
Ix → Idle mode;
Rx → Receiving mode;
Tx → Transmit mode;
Input → Sensed Data;
Label → L1, L2, L3;
Begin Loop
  L1: IF (condition   : FALSE) Then
        Next_State : Ix
    Else IF (condition : TRUE)
        Next_State : Rx; GOTO L2
L2: IF (Rx contains Data_Packets)
        IF (channel == Free)
          Condition : Send_Packets)
          Next_State : Tx; GOTO L3
        ELSE
          Next_State : Ix; GOTO L1
    ELSE
        Next_State : Ix; GOTO L1
  L3: IF(Tx gets Data_Packets)
        Condition : Transmit_Data
        Next_State : Ix; GOTO L1
End Loop
```

Present State	Next State	
	X=0	***X=1***
S0	*S0*	*S1*
S1	*S3*	*S1*
S2	*S2*	*R1*
S3	*S3*	*S1*
R1	*R2*	*R3*
R2	*R2*	*R1*
R3	*R2*	*S3*

Figure 2

III. INFLUENCING FACTORS OF RELAY NODE ON WSN

A. *Scalability*

Scalability is the major factor that makes it greater consideration during designation of sensor network important factor because it initiates the guidelines to design a protocol or an algorithm for new schemes in sensor networks. Depending on the applications, the number of relay node deployed in the network may be in the order of few hundreds. According to the requirement of the applications the number may vary. The density of the network can be calculated according to [1] as

$$\mu(R) = (N\pi R^2)/A \quad (1)$$

Where N is the number of scattered sensor/relay nodes in region A; and R is the radio transmission range. Thus μ(R) provides the information regarding number of nodes within the transmission radius of each node in region A. The scalability may create a direct/indirect impact on various other parameters of the network. One such parameter is accuracy rate, which should be always high for a good designated network.

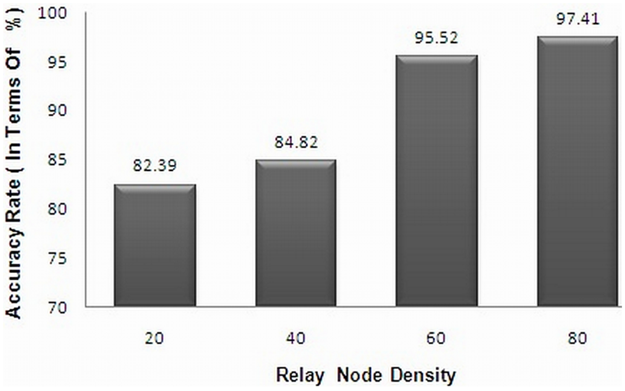


Figure 3: Effects of Relay node in WSN

In Fig.3 simple practical simulation results describe the accuracy rate of the network, with gradual increase in number of relay nodes. Also the relay node is gradually increased as the network increases and it's of 20 relay nodes to 250 sensor node capable network, 40 for 500 capable network, 60 for 750 capable network, 80 for 1000 capable network. From the graphical results, a significant analysis has been noticed, that is the percentage of accuracy rate has a gradual increase inorder as the relay node increase as well. Thus, with proper deployment methods, any new schemes must able to adapt with this number of sensor/relay nodes and must utilize the current density nature of the network. The number of nodes participating in a sensor network is mainly determined by requirements relating to network connectivity and coverage, and by the size of the area of interest.

B. *Net Network energy consumption*

The major tasks of any relay node are

- Receiving the data packets from source node and transmitting the data packets to destination/relay node, which is handed by RCS
- Information recording (IR) handled by IRS
- Information conveying (IC) handled by ICS

Power consumption can hence be divided into the above three domains: RCS, IRS, ICS. Of these three domains, a relay node expends maximum energy in Radio Communication Section; this involves both data transmission and reception. In [2], the authors present a formulation for the *radio power consumption (RP_C)* as

$$\begin{aligned} RP_C = N_T[P_T(T_{ON-T} + T_{ST}) + P_{OUT}T_{ON-T} \\ + N_R[P_R(R_{ON-R} + R_{ST})] \end{aligned} \quad (2)$$

Where $P_{T/R}$ is the power consumed by the transmitter/receiver; P_{OUT}, the output power of the transmitter; T_{ON-T}, is the actual transmission time; R_{ON-R}, is the actual receiving time; T/R_{ST}, the transmitter/receiver start-up time and $N_{T/R}$, the number of times transmitter/receiver is switched on per unit time, which depends on the task and medium access control (MAC) scheme used. $T_{ON-T} = L/R$; $R_{ON-R} = L/R$, where L is the packet size in bits and R is the data rate in bits per second.

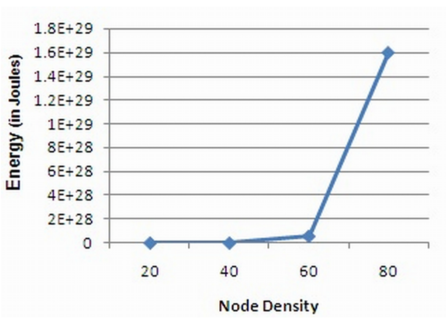


Figure 4: Relay node's Energy Consumption in WSN

Fig.4 represents a simple practical simulation results that describe the level of energy consumption of relay node with different node densities. The graphical representation mainly exposed higher accuracy rate but in controversy, from the Fig.4, it is observed that with the same number of deployment of relay node exposes higher energy consumption too. This is because of malfunctioning of few nodes that causes significant topological changes and might require re-routing of packets and re-organization of the high density network. Hence, energy conservation and power management take on additional importance. It's for these reasons that researchers are currently focusing on the design of energy-aware protocols and algorithms for sensor networks.

From [3] the energy consumption of a node is given by the sum of the energy consumption within the states and the energy needed to switch between different states. According to [3], the energy consumption within a state r_j can be measured using a simple index t_j, e.g. number of instructions or execution time. Within the relay node the energy needed to switch between different states can be calculated based on a relay node state transition matrix rst, where rst_{ij} denotes the number of times the component switched from state r_i to r_j. Let P_j denote the power needed in state r_j for one time unit, and E_{ij} denote the energy consumption when switching from state r_i to state r_j. The total energy consumption of the relay node within the states (E_1) is given by

$$E_1 = \sum_{j=1}^{k} t_j p_j + \sum_{i,j=1\, i\neq j}^{k} rst_{ij} E_{ij} \qquad (3)$$

Thus, for processing the relay operation, the total energy consumed (E_C) by the relay node is calculated by combining the equations (2) and (3)

$$TE_C = RP_C + E_1 \qquad (4)$$

Fig.4 represents the average energy consumption of various densities of relay nodes in WSN. From the graph, it is observed that, the relay node with lower density consumes smaller amount of energy. And with the gradual increase it is also observed that, the relay node with higher density consumes larger amount of energy. exposes the relay node energy consumption in the entire network. From the previous Figure: 3, the deployment of 80 numbers of relay nodes in 1000 nodes capable network

C. Communication

The logical organization of any relay node implies three types of communications

SensorNode→SensorNode communication
SensorNode →RelayNode communication
RelayNode →SensorNode communication
RelayNode → Relay Node communication

According to [3], the major types of this WSN communication are

- *Sensor Node to Sensor Node communication:*

This direct communication is used for local operation such as Cluster process and route creation process.

- *Sensor Node to Relay Node communication:*

Sensing data's are transmitted from sensor node to relay node. This type of communication often UNICAST, mainly to avoid the overheads.

- *Relay Node to Sensor Node communication:*

Request for data, signaling messages, forwarding data to sensor nodes. This type of communication often MULTICAST. Thus, the relay node forms the backbone for the wireless sensor network. Moreover the MULTICAST enables the dissemination of data to a group of sensor node that are interested in the same content.

- *Relay Node to Relay Node communication:*

Relay the sensed data to neighbor relaying nodes. This type of communication often UNICAST.

1) Receive Mode

During communication the coordination work of each layer in the combined manner communicate with relay node. The internal processing of relay node; Radio Communication Section (RCS), Information Receiving Section (IRS), Information Conveying Section (ICS) process the data obtained from the source sensor node and transmit the data to relay/sink node.

2) Transmit Mode

Before the transmission starts, a relay node undergoes several activities such as discovering the address and routing path to the relay/sink node, which has been illustrated as flow diagram in Fig.5.

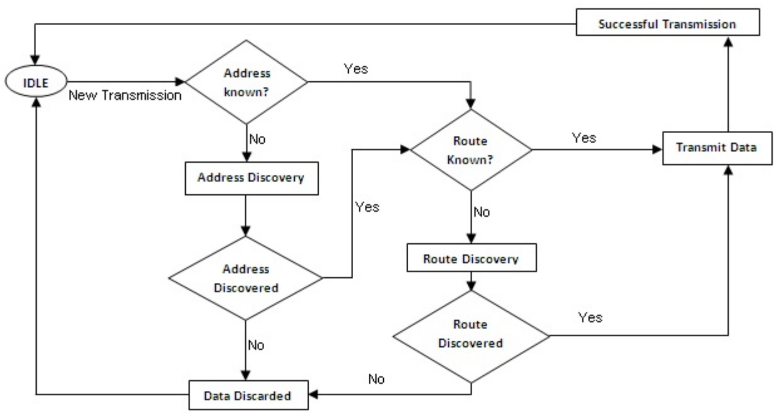


Figure 5: Relay Node's Transmit Mode

D. Relay node assisted WSN architecture

The basic sensor network architecture consists of several layers that communicate with the Relay node as shown in Fig.6.

- *Physical (PHY) Layer:* The main function *of* Physical layer is transmission of bits reliably over a point-to-point wireless link, Modulation and frequency Selection, coding, diversity and power control.
- *Medium Access Control (MAC) Layer:* MAC layer controls how different users share the given spectrum. The spectrum allocation can be done through either deterministic or random access. The main function is frame control and error detection.
- *Network Layer:* Network layer provides the means of transferring data sequences from a source to a destination. This layer performs major functions like routing the data and dynamic resource allocation.
- *Application Layer:* Application layer generates data to be sent over the network and processes the data received over the network. The main function is source coding and maintains the flow of data.

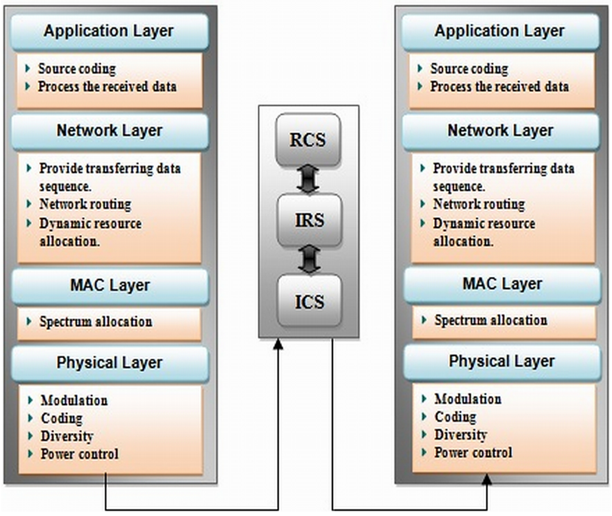


Figure 6: Relay node assisted WSN architecture

E. Fault tolerance

In WSN, actualizing fault tolerance is one of the most vital parts. Since sensor nodes are prone to failure due to several reasons, e.g. running out of battery power, physical damages and malicious attacks. A detailed analysis of framework has been proposed in [6]. The framework achieves the following:

- Provide general guidelines for the design and development of solutions for FT in WSNs.
- Present a unified approach for FT which can be used to identify main modules and compare and contrast different solutions.

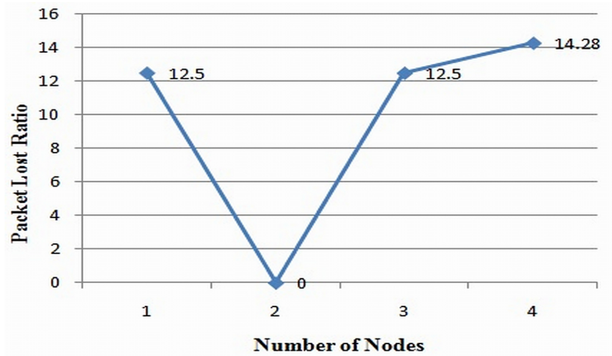
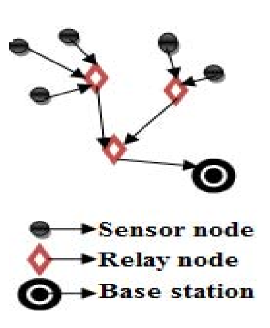
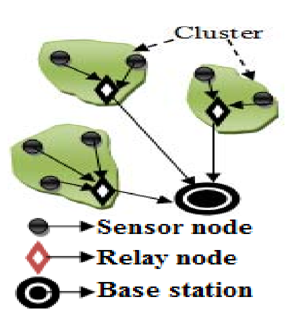


Figure 7: Packet loss ratio Vs Number of nodes

Fig.7 indicates simulated results of relay nodes packet lost ratio. This loss factor creates a deep impact in the entire network and draws the focus of the researchers on fault tolerance and reliability.

To ensure fault tolerance and reliability in WSN, many researchers proposed various algorithms and frameworks. Few such recent algorithms are LOPA [7] and LODA [7]. Former algorithm [7] was proposed to tolerate the power lagging and also checks the battery level, while the later algorithm was proposed to avoid/prevent the data loss. In general, the loss of data packets in WSN is much higher; a sample simulation analysis of data loss is illustrated in Fig.7. Beyond the effective analysis of relay nodes, there exist several functional classifications of relay nodes in both flat and hierarchical architectures. Responsibilities of relay node in both Flat and Hierarchical Architecture are distinguished in Table 1.

TABLE 1

Flat Architecture	*Hierarchical Architecture*
Each sensor nodes shares the burden of routing.	Each sensor nodes belongs to only one cluster.
Each node is responsible for *sensing* and *relaying* its own as well as neighborhood nodes data's towards the base station.	Cluster nodes acts as a *relay node.*
	

IV. LITERATURE REVIEW

TABLE 2

Ref	Year	Focus	Role	Solution/

				Model
[7]	2010	Fault Tolerances	Relaying	Heuristics Algorithm
[5]	2009	Efficient Routing	Relaying	Geographic Routing Algorithm
[3]	2003	Resources limitations	Relaying	Collaborative Algorithm

V. OPEN RESEARCH ISSUES AND ANALYSIS

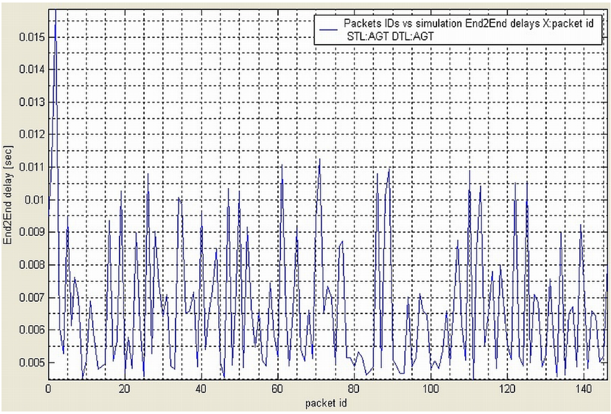


Figure 8: Packet ID Vs End to End Delay

CURRENT ANALYSIS: Fig.8 represents delay variations among the packet in relay node, while it is transmitted to the Access point. Note that schedule of each packet ID consumes delay asynchronously. In the initial stage during the start-up of packet transmission, the relay node packets (especially 0-4 packet IDs) faces higher delay compared to all other packet IDs, this factor is due to the transmission triggering activity of a relay node.
ISSUE: Initial delay occurrence during the triggering of transmission activity.

FUTURE WORK: By comparing the current analysis, suitable delay-minimizing Algorithms are recommended to implement.

CURRENT ANALYSIS: Here, Fig.9 depicts the metric that was collected for the relay node and the evolution of its value along the simulation time (in X-axis) was recorded. From the figure we observed the uniform acquisition of throughput by relay node throughout the simulation. Hence the relay node plays a vital role in optimal communication.
FUTURE WORK: Deploying and analyzing with numerous number of relay nodes in WSN.

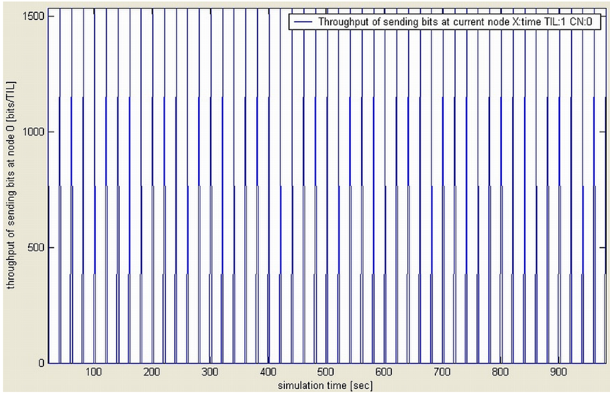


Figure 9: Throughput of sending bits at current Relay Node

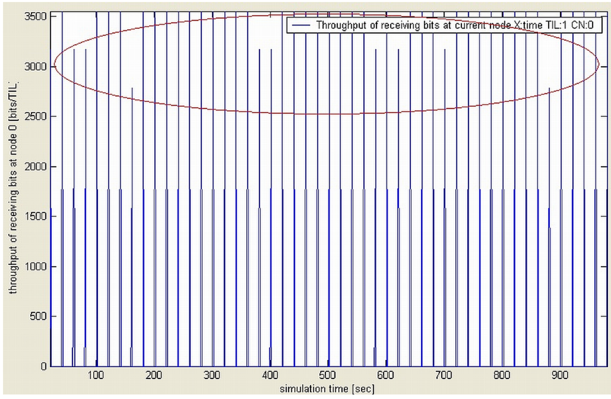


Figure 10: Throughput of receiving bits at current Relay Node

CURRENT ANALYSIS: Fig.10 illustrates the average throughput of receiving packets at the relay node expressed in bits per second. In multicast communication, throughput of receiving bits with respect to the simulation time shows loss of packets at various time (indicated as red marked).
REMARK: We observed that the throughput of receiving packets deteriorated from tolerable range *(especially at simulation duration:* 200 to 350, 425 to 550, 725 to 850*)* to considerable range (*especially at simulation duration: 50 to 175, 375 to 400, 575 to 625, 875),*

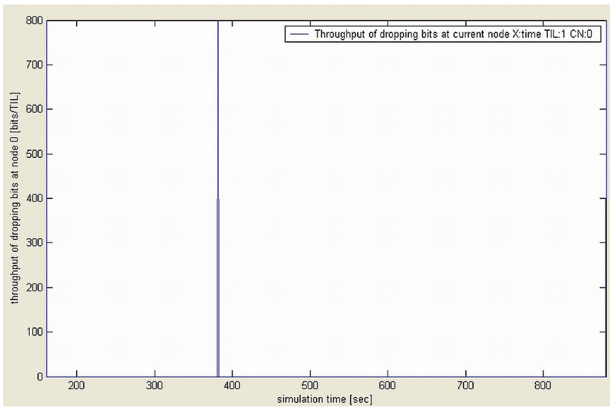


Figure 11: Throughput of Dropping Bits at current Relay Node

CURRENT ANALYSIS: According to the Fig.11 the total number of dropped packets by the relay node is **3 (2.0408% of generated packets).**

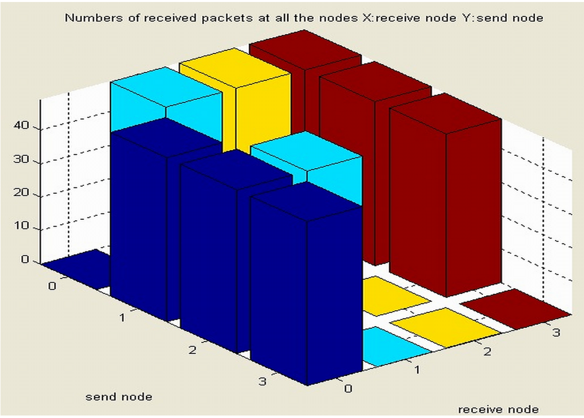


Figure 12: Number Of Received Packets at all Nodes

CURRENT ANALYSIS: Fig.12 implies the overall flow of packets among all nodes in the network. The following sequence between the nodes illustrates; number of packets received at all nodes.

- **1→0=50 packets**
- **2→0=50 packets**
- **3→0=50 packets**
- **0→1=50 packets**
- **2→1=50 packets**
- **0→2=50 packets**
- **0→3=50 packets**
- **1→3=50 packets**
- **2→3=50 packets**

Node 0, node 1, node 2, and node 3 receive equal number of packets.

CURRENT ANALYSIS: Fig.13 represents the packet holding status of a relay node. Here, the current node 0(relay node) posses the forwarded packets, that are received from node 1 and node 2 respectively.

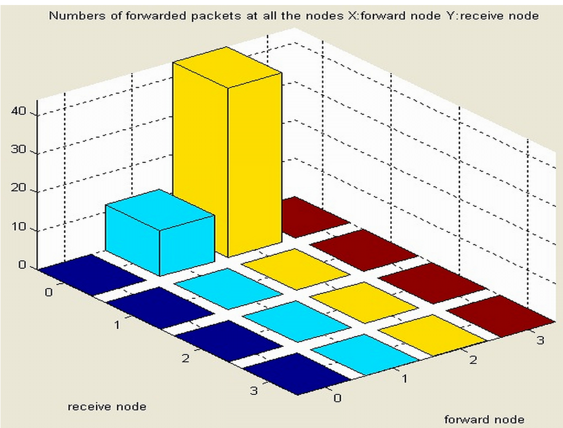


Figure 13: Number of Forwarded Packets to Relay Nodes

- 1→0 =10 packets
- 2→0 =45 packets

The energy consumption of relay node for receiving the packets is **0.012 Joule**. Here, the initial energy the relay node is **10.0 Joule** and after receiving the packets, total remaining energy is **9.556 Joule**.

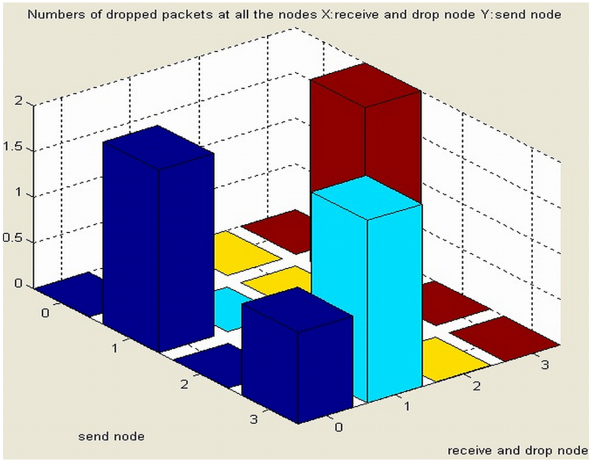


Figure 14: Number of Dropped Packets at all Nodes

CURRENT ANALYSIS: The Fig.14 depicts the dropping range of packets by each node in the networks. Here, the average percentage of packets dropped by relay node is around **4.0%**.

1→0=1.5 packets dropped

3→0=0.5 packets dropped

ISSUES: congestion (Type: collision-MAC)

FUTURE WORK: Implementation of collision control algorithms are recommended to avoid packet loss.

VI. CONCLUSION

In recent years, the use of relay nodes in sensor networks has drawn a lot of attention from researchers around the world. In sensor networks, the use of relay nodes has been mainly proposed for maximizing the network lifetime, energy-efficient data gathering, load-balanced data gathering as well as making the network fault tolerant. In this paper Section II implies internal behavior of the relay node, Section III deals with the relay node influencing factor in WSN, Section IV highlights the literature review and Section V reveals the analyzing factors and their issues, and Most of the research has focused on improving the performance of sensor networks using relay nodes in hierarchical architectures, while some have focused on flat architectures. In addition, some papers have addressed the placement problem and the computational complexity of the placement problem of relay nodes in sensor networks. Some of the major models, their focus areas, the roles played by the relay nodes and solution methodologies adopted by the literature have been summarized in Table 2. Along with the future research issues on relay node, we encourage more insight into the problems and more improvement in solutions to the open research issues as described in this paper.

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