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Performance Analysis of Three Hop Reliability Model for Wireless Sensor Networks in Nuclear Power Plants

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Abstract: *Wireless sensor networks(WSN) are a good choice for Nuclear Power Plants because of low cost and flexibility. Reliability is a crucial factor for WSN in Nuclear Power Plants since all the data collected are time critical information that should be delivered on time otherwise a huge loss could incur in terms of money, resource or even human lives. So it is a challenging task to design a routing protocol for sensor used in such harsh environments. In Three hop reliability model (3H-ACK), three copies of the same data are maintained without imposing extra cost on the network. This model works best using zone routing protocol .Compared to the models used earlier, this 3H-ACK performs well in terms of delivery ratio, throughput and avoids packet loss as far as possible.*

Keywords: *Acknowledgment, Nuclear Power Plants, Reliability, Sensor Networks,*

I. Introduction

Wireless Sensor Networks (WSN) are used nowadays in Nuclear Power Plants (NPP). Sensors can be used to monitor the current state of the plant including emission of radioactive particles to air and water. Other parameters include neutron flux, monitoring pressure, temperature and water levels in circuits. If these levels exceed a particular threshold levels alarm is raised and information is passed on to the alerting unit whenever necessary. Daily more than 7, 00,000 data are to be collected and send to the base station. Manual maintenance of such data is a tedious task. The challenges posed by WSN in NPP are EMI/RFI, compatibility of WSN in harsh nuclear environment, energy concerns, security and reliability. From authors[1-4] it has been proven that WSN does not pose a threat to EMI/RFI. Moreover suitable test from [1] shows that WSN can withstand harsh conditions in nuclear environments.

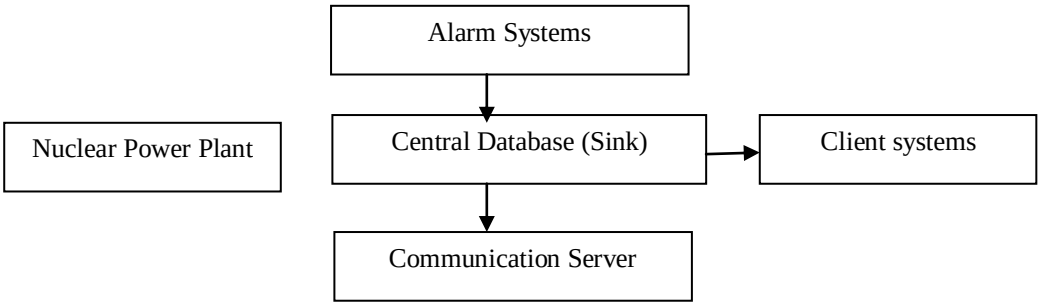

Fig. 1 Technical Components used in Nuclear Power Stations

There are lots of factors that are to be considered when deploying a WSN for a Nuclear Power Plant [4]. First it is necessary to understand the measurement requirement. The purpose for which sensors are used should be known very clearly. Secondly appropriate wireless protocol such as IEEE 802.11 or IEEE 802.15 should be chosen. The chosen protocol must co-exist with other protocols. Finally, deployment of sensor nodes is yet another important issue that is to be considered properly.

In this paper, Section II explains the reliability issues in Sensor Networks. Hop- by-Hop and 2H-ACK models are described. Section III explains 3H-ACK model. The architecture and algorithms are used explained. Section IV explains the simulation parameters and section V gives the conclusion.

II. Reliability In Sensor Networks

Reliability is a key aspect in wireless sensor networks. Reliability is the ratio of number of bits in error to the total number of bits transmitted. Bit error rate should be minimal in such applications. It has been shown that Transport Control Protocol does not work very well with sensors since the three -way handshake procedure causes overhead. TCP relies on end – end acknowledgment whereas wireless sensor networks use multi-hop

approach that relies on hop-hop reliability that lessens congestion and is more efficient in terms of energy savings [5].

Reliability also depends on other parameters like congestion, energy, throughput and delay. TCP provides good congestion control mechanism. On the other hand, UDP does not provide flow or error control. Packet size is another important factor that affects reliability as larger packets are subjected to loss whereas short packets suffer from overhead. So in many situations dynamic packet size is the best one. [6-8]. Packet size can be chosen depending on the link quality. If the chosen route is optimal then larger packet size can be chosen which will be free from packet loss. If the route is not optimal, then smaller packet size can be chosen so as to avoid packet loss. In case of lost packets, retransmission is the best method but it can cause delay.

2.1 Dynamic addressing scheme for wireless sensor networks

Author [6] states very clearly that in Hop – by – Hop dynamic addressing based routing protocol, unique address namely HopID is assigned to every node based on its hop count from the sink. Thus the node that is closer to the sink is assigned smaller HopID and is used frequently to forward the data. In order to know the status of congestion and energy level, Inquiry Request and Inquiry response messages are used. The format is as follows:

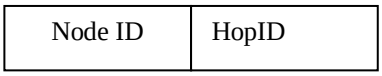

Fig. 2 Format of Inquiry Request

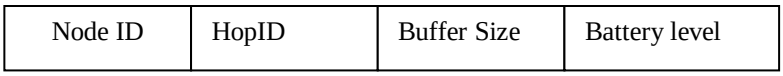

Fig. 3 Format of Inquiry Reply

2.2 Single Hop Reliability Model

Hop-by-Hop ACK(HbH-ACK) is most suitable only for stable environments. In this method, only two nodes are involved namely the source and the destination. The source node sends a data packet to the destination. On the receipt of data, the destination sends out an acknowledgment (ACK) to the source. Once the source receives the ACK, it discards the data packet. Now the current node holding the data packet is responsible for sending the data to the destination. It has to find the next suitable hop that will deliver the data along the path to the destination. Sometimes due to dynamic node movement, the current node may not find the next suitable hop or may die due to energy loss. In such case the actual data is lost since no other node maintains these backup copies. From the simulation conducted by the author [7] it is clear that there are no duplicate packets since only one node maintains the data copy, but the rate of packet loss was very high.

2.3 Two Hop Reliability Model

From authors [8-10], Two Hop Acknowledgment (2H-ACK) provides a guaranteed delivery scheme. In this approach, two nodes maintain the copy of the same packet. The procedure is as follows:

The source node that wants to send the data packet will send an Inquiry request message to all its neighbors using gossiping method. The neighbors will compare their hop id with the sender node's hop id and the node with the smallest hop id will respond with the Inquiry response method. Then the packet is transferred to the node with the smallest HopID. After receiving the data packet the receiving node does not immediately send an ACK to the source node. It will try to find the next hop node on the way to the destination and the same procedure is repeated. After the third node receives the data packet, it sends an ACK to the intermediate node. The intermediate node sends the ACK to the source node thereby the source node will delete the data packet as two copies of the data packet now exist. The same procedure is repeated till the data reaches the destination. The use of Inquiry request and Inquiry response packet solves the problem of congestion and energy usage. The nodes that are free from congestion and that have sufficient energy only replies with the Inquiry reply packet. From the simulation results conducted by the author [8], it is clear that duplicate data packets and packet losses are less in 2H-ACK.

III. Three Hop Reliability Model

From authors [11-12], it is clear that 3H-ACK is the most suitable for most time critical applications used nowadays in industries. 2H-ACK still suffers from packet loss because the intermediate node can die before it can send an ACK to the source node. The source node does not know whether the packet is on the way to its destination. It cannot delete the original data packet and it leads to buffer overflow. If after a stipulated amount of time, the source node once again finds a neighbor to deliver the same data packet, then replication occurs as the data packet has reached another node, but the source node is unaware of this happening since ACK

from the intermediate node was lost. In this model three nodes will keep the copy of the same data packet. Here every node carries a step field along with the data. The step field will be incremented at every intermediate node until the value of step becomes three. This 3H-ACK is best implemented with zone routing protocol.

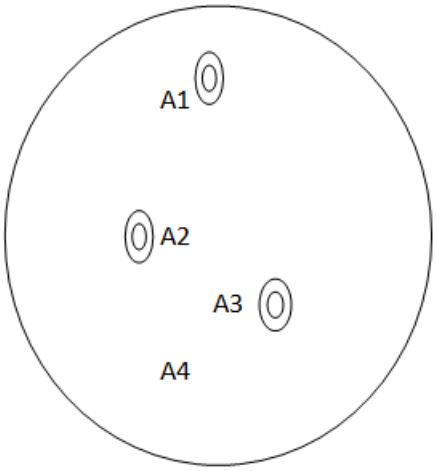

Fig. 4 Three-Hop Reliability Model

In this model, node A4 wants to send the data packet to the destination. It sends a Hello Packet to all the nodes within the zone. A3 is the next hop with smallest Id. So it responds with the Hello reply. The data packet is sent to node A3 and the step value is incremented from 0 to 1. Now the same procedure is repeated and the data packet is sent to node A2. The value of step now becomes 2. When the data packet reaches A1 then the value of step becomes 3. Now the copy of data packet is available in node A1, A2 and A3. When the value of step becomes 3, the original copy of data packet is removed from A4.

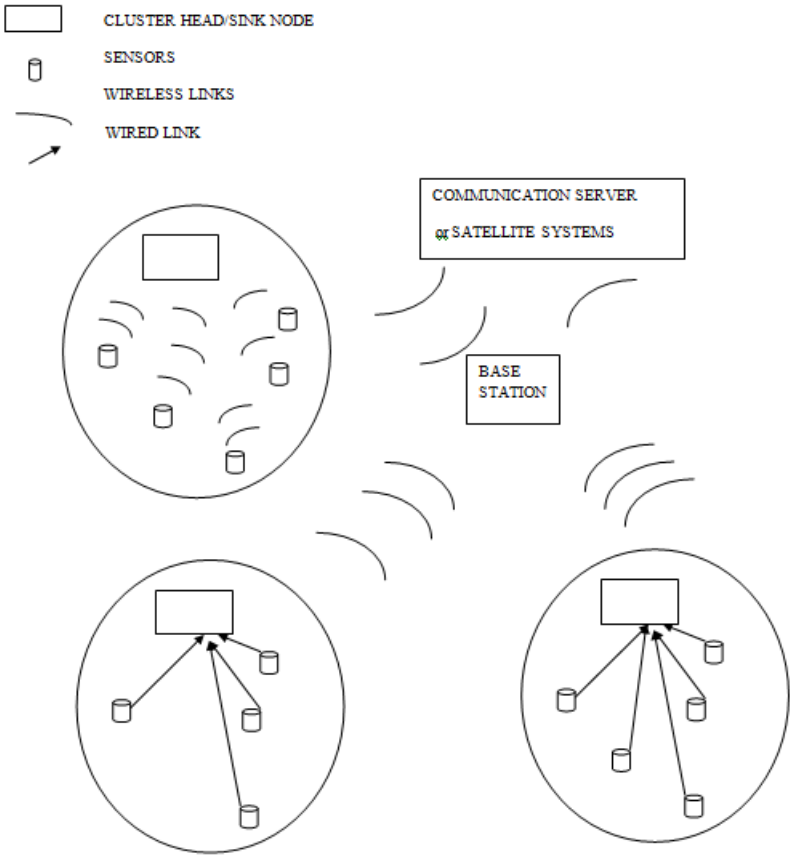

Fig. 5 Architecture of 3H-ACK

Node ID	ClusterID

Fig 6. Format of Hello Request

NodeID	Cluster ID	Energy Level	Priority	Buffer Size

Fig 7. Format of Hello Response

Source Node ID	First Forwarder ID	Second Forwarded ID	Step value

Fig 8. Three Hop Final Message format

Algorithm for 3 H-ACK Model:

1. Initialize the value of step = 0
2. Define the Zone limit
3. Send Hello Packet to find the nearest node
4. If Hello Packet is received then

a. Send the data packet to the nearest node
b. Save a copy of the data packet in the buffer

5. If the value of step <3 then

a) Increment the value of step by 1else
b) Set the value of step by 0 and send the final message to the third hop

6. If the final message reaches is received at the third node then

a) Delete the copy of the saved message else
b) Repeat from step 4 to 6

7. Stop

By using zone routing protocol, the nodes inside the zone alone participates in packet forwarding. The rest of the nodes may remain to be inactive thereby saving energy. Though three copies of the data packet might exist leading to redundancy a times, loss of packet is avoided which in turn reduces retransmission which is very costly compared to this reduced redundancy. Moreover Inquiry reply packet guarantees no congestion and the energy level of node. Therefore problem of congestion and energy are alleviated. Every sensor node can hold 50 packets. The packet size specified by IEEE 802.11 can be upto 1000 byte long. But from author [7], it can be proven that the optimal packet size can be from 128 to 256 bytes. From the simulation results, it is very clear that 3H-ACK guarantees 90% of delivery ratios at various time intervals. The probability of duplication in 3H-ACK is very low compared to the packet loss.

IV. Simulation Results

The proposed algorithm is implemented using NS-2 simulator. Simulation is performed using Cygwin. Cygwin is free software that provides a Unix-like environment. NAM Editor is used to perform simulation operation. The scripting language used is TCL.

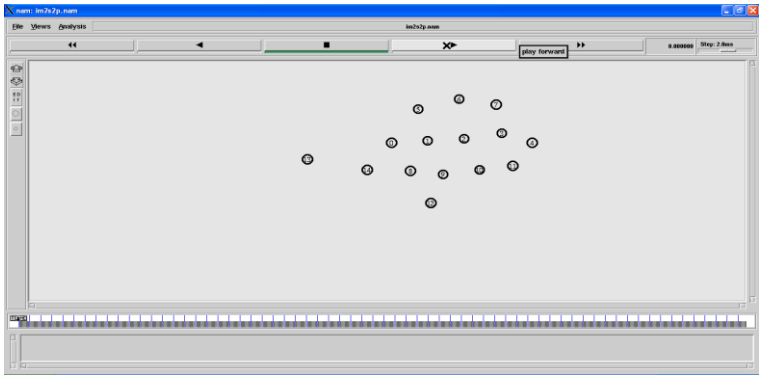

Fig 6. Creation of Nodes

The output produced by NAM simulator is analyzed. The metrics used to measure the performance of the networks are Packet delivery ratio, Packet drop rate and Throughput.

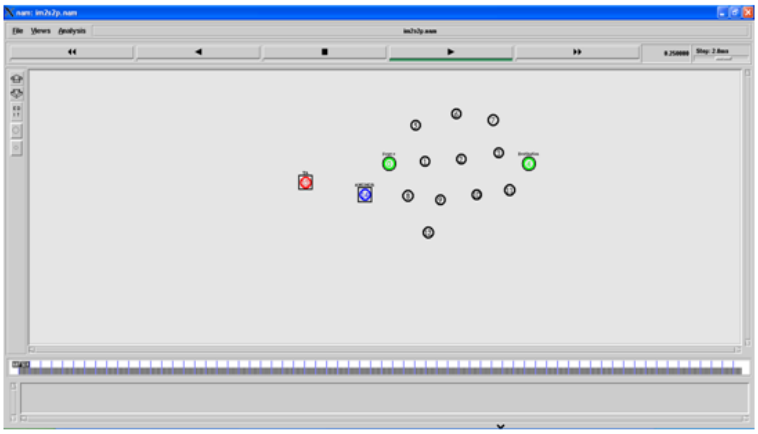

Fig 7. Source and Destination Nodes are selected to deliver messages

Initially 15 nodes are created using NAM editor (Fig 6). The source and destination nodes are selected. The node with the shortest HOPID is selected and the data is delivered to the node. The same procedure is repeated until all three nodes have received the data. Then the data is delivered to the destination and after receiving an ACK, the data is removed from source node.

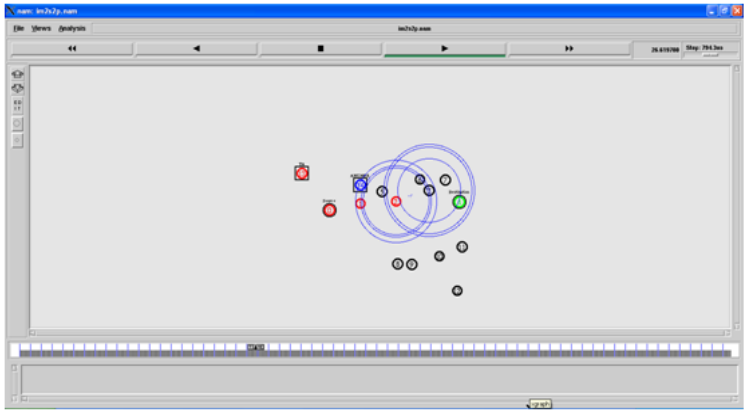

Fig 8. Data is sent to different nodes with smallest HOPID

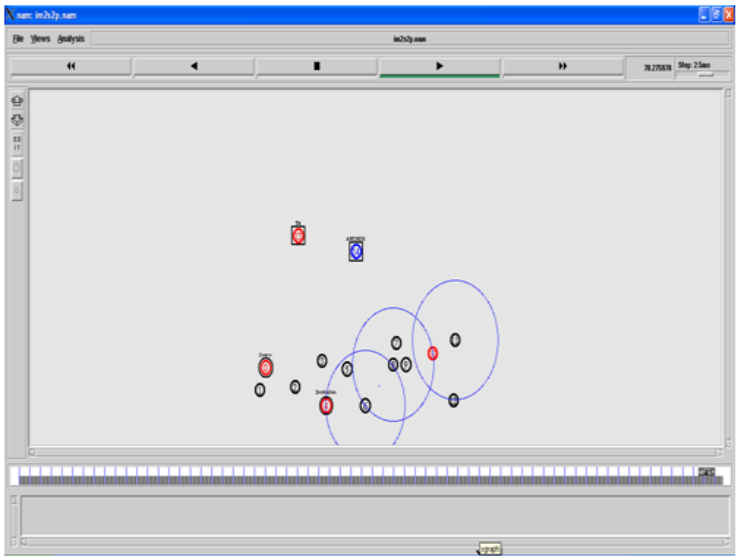

Fig 9. Implementing 3 Hop Reliability Model

Packet Delivery Ratio:

Packet delivery ratio is the ratio of number of packets received at destination node to that of number of packets sent by source node. From the simulation results of author [9], It is shown that Packet delivery ratio and loss in packet for 2H-ACK is better than HbH-ACK. Here 3H-ACK shows the best delivery ratio of 90% thereby avoiding loss in packet.

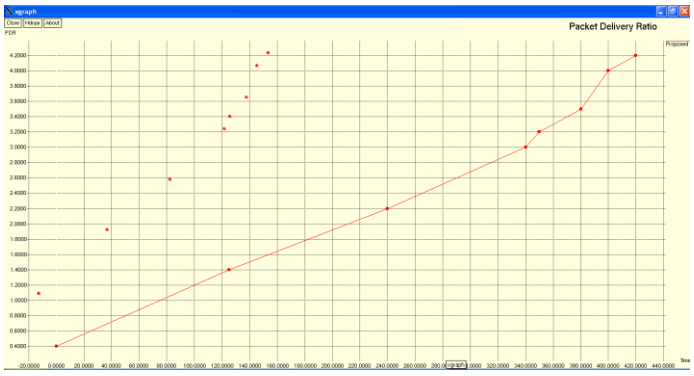

Fig 10. Packet Delivery Ratio of 3H-ACK Model

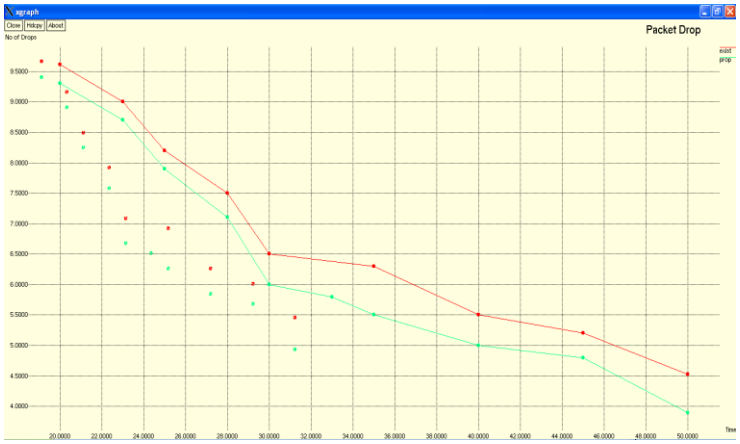

Fig 11. Packet Loss Ratio in 3H-ACK

Throughput:

Network throughput is the amount of data that is received. Though there is a chance that multiple copies of the same data packet can be received at the sink nodes, the probability is very low compared to packet loss.

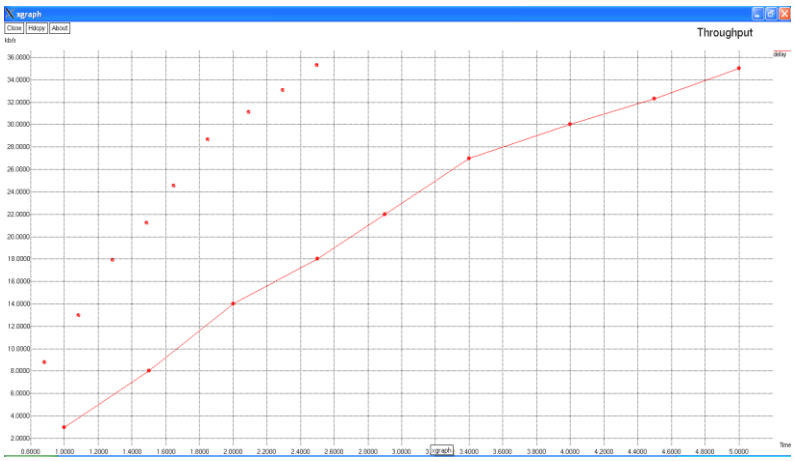

Fig 12. Throughput of 3H-ACK Model

V. Conclusion

Sensors are resource constrained and the harsh environments in which they operate make them die very soon because energy gets replenished very easily. Congestion and weak link are also the main cause of loss in packets. From the studies it is clear that compared to Hop-by-Hop and 2H-ACK, 3H-ACK yields better results. It may be sometimes a time-consuming task or may be considered costly since it involves three copies of the data packets to be transferred between the source and destination, but reliability is sometimes given top priority when compared to cost involved in sending three copies of the packets. Energy consumption through various energy harvesting techniques could be considered as a future work.

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