Innovative Systems Design and Engineering www.iiste.org
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol 2, No 4, 2011

# A Deadline Aware Real-time Routing Protocol for Wireless Sensor Networks

Cherian Mary (Corresponding author)

Dr.Ambedkar Institute Of Technology, Outer Ring Road, Mallathahalli

Near Jnanabharathi Campus , Bangalore-560056, Karnataka, India

E-mail: thamasha2005@yahoo.com

Nair Gopalakrishnan T.R.

Vice President, Research and Industry centre

DSI Institutions, Bangalore, Karnataka, India

E-mail: trgnair@gmail.com

**Abstract**

Wireless sensor networks (WSN) find application in real-time events reporting and data gathering. When the sensor detects an event it is reported to the base stations, which then takes appropriate action. The course of action should have finite and bound delays defining a hard real-time constraint for time critical applications. This work proposes a network layer based, deadline aware real time routing protocol, which assumes a collision free known delay MAC (Medium Access Control) layer. The protocol works in three phases-the initialization phase, path establishment phase and the bandwidth division phase. This protocol ensures bounded delay in transmission of sensed data to the sink. It establishes a single path from each sensor node to the sink and allocates bandwidth for that path thereby reducing the time required for the sensed data to reach the sink.

**Keywords:** Wireless Sensor Networks (WSN), hard real time protocol, select, deselect, fixed route

## 1. Introduction

Wireless sensor networks find their extensive use in vivid applications like environmental/health monitoring, traffic control and weather monitoring mainly due their flexibility and ease of deployment. They can be used in almost any environment where in, the use of wired sensor system may seem impossible. These sensors are small in size and are able to sense, process data, and communicate with each other, typically over an RF (radio frequency) channel. Simon (2007) specifies that a sensor network is designed to detect events, collect and process data, and transmit sensed information to a central monitoring station.

Lee *et al.* (1995) have reported that the widest of the limitation for wireless sensor is its limitation in power, memory and computational capabilities. The often changing network topology due to the failure in the deployed sensor node also poses a new problem. The sensory data is routed in a multi-hop fashion from the source node to a remote control station often called the sink. It is essential that sensory data, which accounts for a critical event in the monitored environment, reaches the destination in a short time, to take the correct actions. It has been reported (Peng *et al.* 1995) that in the case of critical application, rendering a bound delay is of at most importance. Wireless sensor networks are vulnerable, due to their inherent limitations. Time requirements are generally in the form of end-to-end deadlines of sensory data packets from source node to the sink.

The communication systems are of two types (Lu *et al.* 2002): hard real time and soft real-time. In hard real-time systems communication of messages is associated with timing constraints, in the form of deadlines. A message should be received at the destination before its deadline expires. Any data reaching the sink after timeout will be un-useful. Whereas, in soft-real time systems, there is no strict timing constraint on the messages sent and the system allows part of message to reach after deadline. The portion of message reaching after the deadline is called “miss ratio". Soft real time system thrives to reduce the miss ratio by prioritizing the real time messages. For time critical messages the network must ensure statistical bound on delays. Thus, in summary once guaranteed timeliness delivery of packets at the destination is ensured, bound response times also have to be ensured.

The rest of the paper is organized as follows: Section 2 discusses the related work. Section 3, explains the proposed technique for rendering hard real time communication in sensor networks. Section 4, deals with simulation and results. Section 5, draws conclusions.

## 2. Related Work

This section explains the work done, related to real time delivery of data in sensor networks.

In soft real-time systems there are timing constraints, but occasionally missing them has minor effects, as application requirements as a whole is still met. Soft real-time communication system guarantees prioritized treatment for real-time messages so that a minimum miss ratio is maintained.

RAP (Lu *et al.* 2002) attaches a velocity message to each of the message which is a function of deadline over the geographical distance. The message takes a multi-hop route and if the velocity constraints of the message cannot be met at any node, the message is discarded. RAP has the high miss ratio and does not guarantee the real- time delivery of data.

SPEED (He *et al.* 2003) adds a velocity to each path to the sink. The velocity is determined using probe messages. A message will take a given path only if the velocity for the path is higher than the velocity associated with the message.

R2TP (Kim *et al.* 2008) takes note of the time stamp at which the message is generated and then attaches the time for the message to reach the destination. At each hop the time stamp attached with the message is subtracted from the current time and cross checked with duration for the message to reach the destination. If the time has exceeded the one attached to the message then the message is discarded. The disadvantage is that there is an overhead of maintaining multiple paths which drain the sensor node energy.

Protocols for self-organization of a wireless sensor network, (Sohrabi *et al.* 2000) creates trees rooted at one-hop neighbors of the sink considering the QoS metrics, available energy resources on each path and the priority level of each packet. Failure recovery is done by enforcing routing table consistency between upstream and downstream nodes on each path. It provides energy-efficiency and fault tolerance, but suffers the overhead of maintaining the tables. Protocol has scalability problem. It does not support redundant routes to split the load to increase the bandwidth.

The Single-path Streaming Optimized Routing Protocol (Sudheer *et al.* 2010) establishes the routing table during the initialization phase of the protocol. Base station is the only node in tire zero and each node away from base station belongs to a tire in the increasing order above tire zero. The tier number indicates its shortest possible distance to the BS. When a packet is received from an upstream node to be forwarded to the BS, a routing table entry is made for tier number with the source address of this packet. When a packet is received from a lower tier node with destination address being any node in the higher tiers, the packet would be forwarded to all the next hop nodes for destination tier number in the routing table. Once a node becomes part of the streaming path, route broadcast would be suspended so that data packets would flow at regular time intervals from the node. The protocol does not work for complex topologies and has a scalability problem.

These are all soft-real time solutions (Liu 2005) in which probabilistic guarantee is required but a certain amount of latency is allowed. Even if the soft real-time solutions reduce the miss ratio, for critical applications no activity must ever miss a deadline or timing constraint, otherwise the system fails or results in catastrophe.

In I-EDF developed by Thomas & Isabelle (2005) nodes are organized in hexagonal cells. For intra-cellular communication, each cell is assigned a different frequency. As for inter-cellular communication, the six direction of the hexagon are numbered and communication slots alternate with a given direction. Inside a cell, each node knows its neighbors and the characteristics of all messages that need to be exchanged (frequency, deadline, duration). Thus, collisions are avoided for intracellular communication.

Using time-based scheduling with multiple frequencies ensures permissible delay in I-EDF. The rigid cell-based organization of the topology has a limitation in real environment where there is random deployment of the sensor nodes take place.

Several solutions for providing hard real-time guarantees are available for wired networks, but as in wireless sensor network there is no remarkable work done.

## 3. Protocol description

This protocol provides end to end delay guarantees. The delay along the path to the sink can be calculated as the packet delay if the delay at each sensor node is known. Sum of the node delays and the transmission delay in the transmission medium gives the path delay. The bandwidth is partitioned for each node, depending on the number of flows passing through the node. Thus if there are multiple routes to the sink from a node then the bandwidth is divided in all paths from a node to the sink. This makes the response time high. With limited bandwidth assigned to a path the data generated at a node will use the limited bandwidth for that path. Those paths for which the bandwidth is allocated but the data does not take the path, the bandwidth is wasted for not either being utilized or not being assigned to the path in which the data travels.

Our protocol assigns a fixed route to the sink from all sensor nodes and thus all the bandwidth is equally partitioned among those routes and thus data flowing through a particular route gets the bandwidth allocated for that path, thereby lowering the response time. By knowing the allocation for bandwidth at each sensor node, we can calculate the worst case end to end delay for a particular path. The major assumption here is an ideal (collision free and known delay) MAC layer underneath network layer based solution.

Figure 1 depicts a typical wireless sensor network scenario.

*3.1 Initialization Phase*

In this phase the initialization process starts by broadcasting an init message informing the neighboring nodes about the sink and the location of the sink.

During initialization, the routing load is distributed among the available sensor nodes, on all the paths towards the sink and hence the bandwidth division parameter is lowered initially. So initially the bandwidth is calculated using the formula:

Present_Bandwidth/Count_of_flows (1)

The Present_Bandwidth indicates the available bandwidth for the sensor node, and the Count_of _flows gives the number of flows passing through the node. The sink broadcasts an init message to its neighbors, informing them to commence the initialization phase. Then the immediate neighbors of the sink will broadcast the init message to verify the number of nodes that will receive the advertisements from them. Here the node that is broadcasting the init message becomes the advertising node or the initiator and the node that receives the init message becomes the selecting node or the responder. These selecting nodes after establishing the path to the sink in turn broadcast the init message thereby becoming the advertising node for the remaining selecting nodes that haven’t received the init message. This process continues until all nodes are covered or the init message has reached the edge nodes. Here edge nodes are those that broadcast the init message but won’t get the response within the timeout period.

The advertising nodes shall set a timeout period for the init message. An arbitrary time out period is assumed initially and later adjusted dynamically based on the calculation as follows.

No_of_receivers_one_hop_away/Time_taken_for_ack__reach_initiator (2)

No_of_receivers_one_hop_away indicates the number of respondents of the advertising node one hop away and Time_taken_for_ack__reach_initiator denotes the time taken for the acknowledgement to reach the initiator.

The format of init message is shown in Figure 2. Responding nodes which have already received the init message shall ignore this while those nodes that are yet to enter the init state reply with an acknowledgement to the initiator nodes. The responding nodes will record the number of initiator nodes that have sent the init message. The initiator nodes record the number of nodes that have sent the acknowledgement before timeout period expires.

*3.2 Path Establishment Phase*

The responder sends a select message to its adjacent advertising nodes intimating that it wants to select the particular advertising nodes as its next hop in its path to reach the sink. Select message is a route request message to its advertising node requesting to establish a path to the sink. It sets an expiry time period for receiving a response to its select message. This expiry time period for each initiator node is calculated as follows:

Total_no_of_ack_sent*No_of_adj_initiator_nodes/Available_Bandwidth (3)

Total_no_of_ack_sent indicates the number of acknowledgements sent by the node, No_of_adj_initiator_nodes gives the number of adjacent initiator nodes and Available_Bandwidth indicates the bandwidth available for the node. The format of select message is given in Figure 3.

After the sender of select message receives the response in the form of accept message it will update its next hop neighbor as the node that has sent the accept message within the timeout period.The format for accept message is shown in Figure 4.

For the nodes for which it has sent the select message but has not received the response within the timeout or has not been selected, the node will send a deselect message. The node receiving the deselect message re-advertize itself. The format of the deselect message is same as the select message, but with the type field containing the value of 4.

*3.3 Bandwidth Division Phase*

In this phase the available bandwidth is divided and allotted to each node so that the individual nodes on the path to the sink get its share of bandwidth. After the completion of the path establishment phase, all the advertisements would have reached the edge nodes and all the sensor nodes know its next hop neighbor in its route to reach the sink. So there is a single path established from each node to the sink. Now the edge nodes send the bandwidth calculation message which is calculated by dividing the bandwidth at a node with the number of nodes traversed so far, in that path. This bandwidth calculation message takes the known path from the sensor to the sink.

The calculation of worst case end to end delay to the sink is initiated by the sink after receiving the bandwidth allocation messages from the edge nodes**.** As the partitioning of bandwidth is known at each node, then by using fair queuing mechanism and assuming known MAC and processing delay (delay due to processing of packets), the total worst case delay at sensor node (j) ,where j is the $j^{th}$ sensor can be calculated as the sum of the delay at the MAC layer , the delay for processing and the transmission delay which can be obtained by dividing the size of data to be transmitted from the node divided by the allocated bandwidth. The total delay in the path from source node to the sink will be, the sum of the delay at each node in the single path from the source to the destination.

Thus the solution proposes bandwidth at each node while sending the control message and hence is energy aware.

## 4 Simulation Results

The results obtained from simulations on ns-2 are charted to show the effects of control packets that are generated during the initialization phase which direct the path establishment in the studied topology (having different degree of connectivity and number of nodes).

Sample execution for simulation is with 50 nodes arranged in a 670m x 670m area. Control packets are generated to establish a path from senor node to the sink. These control packets increase with the number of hops away from the sink. Increase in density increases the delay that is, if the nods are farther away from the sink, the path establishment time increases. This is because as the number of nodes increases the control packet exchanged multiples. If there is a deselect message to a particular node it will re-advertise itself thereby any other node catching the advertisement may try to establish a path through the re-advertising node for which the exchange of select and accept message has to take place which is time consuming. Whereas, if there is an increase in the number of hops alone, while the number of nodes at each level remain the same, then there is only an increase in hello, acknowledgement and advertisement messages. Here there is no re-advertisement and no re-broadcasting of select and accept message to this re-advertisement. Figure 5 depicts the simulation scenario. As the number of nodes remain constant at each level away from the sink the delay increases linearly. The initialization times depend upon the increase in number of hops and nodes. Figure 6 depicts the relationship between the delay and the number of hops for the topology in figure 5.

Figure 7 depicts is the simulation scenario with seventeen nodes with node one as the sink and the rest being the adjacent sensor nodes. The communication is through broadcast messages. Figure 8 indicates the delay graph for random topology with seventeen nodes. This topology has varying density at each hop.

Figure 9 depicts the comparison of delay for both the topologies.

## 5 Conclusion

The real time communication is affected by the chosen protocol. This protocol ensures bounded delay in transmission of sensed data to the sink. It establishes a single path from each sensor node to the sink and allocates bandwidth for that path thereby reducing the time required for the sensed data to reach the sink.

The protocol assumes an ideal MAC layer (collision free and known delay) and future work may consider similar solution at the MAC layer. The number of control messages exchanged can be reduced in the path establishment phase. The simulation model has not included an explicit battery model to account for energy constraints of the WSN nodes. Hence as a future work this model may be included and tested on real platform. It can be extended to three-dimensional space, beyond the two dimensional topologies explored in this paper. Integration of sensor networks with IP based Internet can also be considered.

To deal with the energy constraint of the sensor node a sleep mode for each node may be included where the sensor node that has not been used for long goes to sleep state and may wake upon the reception of the sensed data.

**Acknowledgment**

Authors thank Shilpa K Rao Dr.Ambedkar Institute of Technology, Bangalore for the support for the

required simulation in the laboratory.

**References**

Simon, R.S. (2007), Antennas and propagation for wireless communication systems (second edition), New York: Wiley

Lee, W. C., Hluchyi, M. G. & Humblet P. A. (1995), "Routing Subject to Quality of Service Constraints in Integrated Communication Networks", *Journal of IEEE Network*, **9**(4),46-55

Peng, H., Xi, Z., Ying, C. X. L., & Chuanshan, G. (2007), "An adaptive real-time routing scheme for wireless sensor networks", *Proceedings of the IEEE International Conference on Advanced Information Networking and Applications Workshops*, Canada.

Lu, C., Blum, B. M., Abdelzaher, T. F., Stankovic, J. A. & He, T. (2002), "RAP: A real-time communication architecture for large scale wireless sensor networks", *Proceedings of the IEEE Real-Time Technology and Application Symposium (RTAS)*, San Jose,,CA,USA

He, T., Stankovic, J. A., Lu, C., & Abdelzaher, T. F. (2003), "Speed: A stateless protocol for real-time communication in sensor networks", *Proceedings of the IEEE International Conference on Distributed Computing Systems (ICDCS)*, Rhode Island, USA

Kim, Park, S., Park,H. & Ham,Y.H (2008), "Reliable and real time data dissemination in wireless Sensor Networks", *Proceedings of the IEEE military communications conference* , San Diego,CA

Sohrabi, K., Gao, J., Ailawadhi, V. & Pottie, G.J (2000), "Protocols for self-organization of a wireless sensor network", *Journal of IEEE Personal Communication*, **7**(5), 16-27.

Sudheer, K. N.V. & Brijendra, K. J. (2010), "Single-path Streaming Optimized Routing Protocol for Dense Wireless Sensor Networks", *International. Journal of Advanced Networking and Applications*, **2**(2), 631-635.

Liu, W.S. (2005), *Real Time Systems*,India:Pearson

Thomas, W. & Isabelle, A.(2005), "Proposition of a Hard Real-Time MAC Protocol for Wireless Sensor Networks", *Proceedings of the 13th IEEE International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS'05)*, Blum CITI Laboratory, INSA Lyon, France.

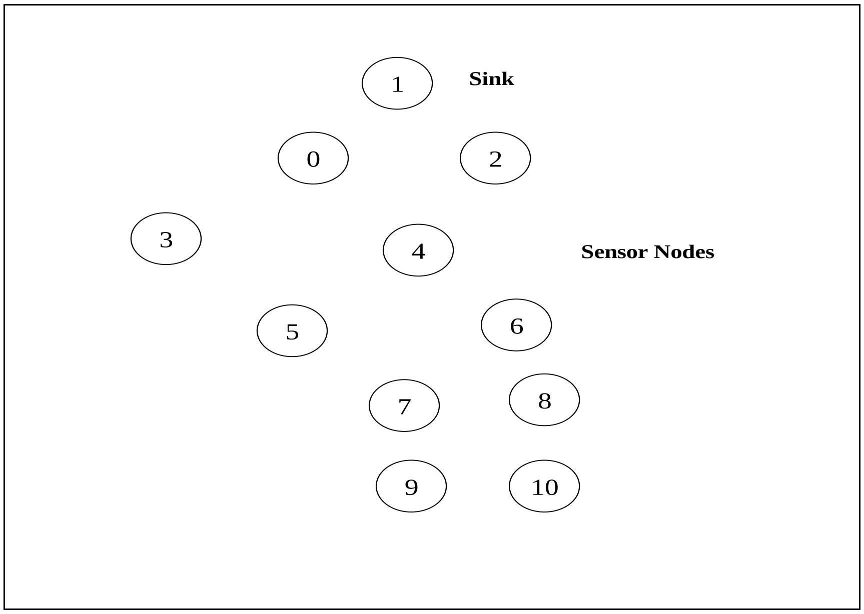


Figure 1. WSN Scenario

Figure 1 depicts a typical WSN scenario with the eleven node wireless sensor network topology for our study with node number one being the sink and rest of the nodes being the sensor nodes deployed randomly.

| 0 | 7 | 23 | 31 |
|---|---|---|---|
| **Type** | **Reserved** | **Hop Count** | |
| **Broadcast ID** | | | |
| **Originator Address** | | | |
| **Originator Sequence Number** | | | |
| **Time-out** | | | |

Figure 2 Init message packet format

Figure 2 indicates the init message packet format with the Type field 1 for init message. Reserved field contains zero value which is reserved for future use. Hop-count gives the distance of the sink from receiving node which is incremented at each hop. Broadcast ID refers to the group address of all adjacent nodes of the sink to which the hello message should reach. Originator address and sequence number corresponds to sink's address and the packet sequence number. Time-out refers to the expiry time within which the acknowledgement needs to be sent.

| 0 | 7 | 23 | 31 |
|---|---|---|---|
| **Type** | **Reserved** | | **Hop Count** |
| **RREQ ID** | | | |
| **Destination Address** | | | |
| **Destination Sequence Number** | | | |
| **Originator Address** | | | |
| **Originator Sequence Number** | | | |

Figure 3 Select message packet format

Figure 3 depicts the select message format with the type field value 2. Hop Count is the number of hops from the Originator to the node handling the request. RREQ (Route Request) ID is a sequence number uniquely identifying the particular RREQ when taken in conjunction with the originating node's address. It helps to identify the request sent for the path from that node and avoid sending request for the same path when already a request is sent for the path. Destination Address is the address of the destination for which a route is requested. Destination Sequence Number is the latest sequence number received in the past by the originator for any route towards the destination. Originator Address is the address of the node which originated the Route Request. Originator Sequence Number is the current sequence number generated by the sender node.

| 0 | 7 | 9 | 23 | 31 |
|---|---|---|---|---|
| **Type** | **A** | **Reserved** | **Hop-count** | |
| **Destination Address** | | | | |
| **Destination Sequence number** | | | | |
| **Originator Address** | | | | |
| **Lifetime** | | | | |

Figure 4 Accept message packet format

Figure 4 indicates the format of accept message. The type for the accept message is 3. The fields in the accept message are the same as that of select message except for the A bit which is the acknowledgment bit and is set. Lifetime is the time in milliseconds for which responder will consider the route to be valid.

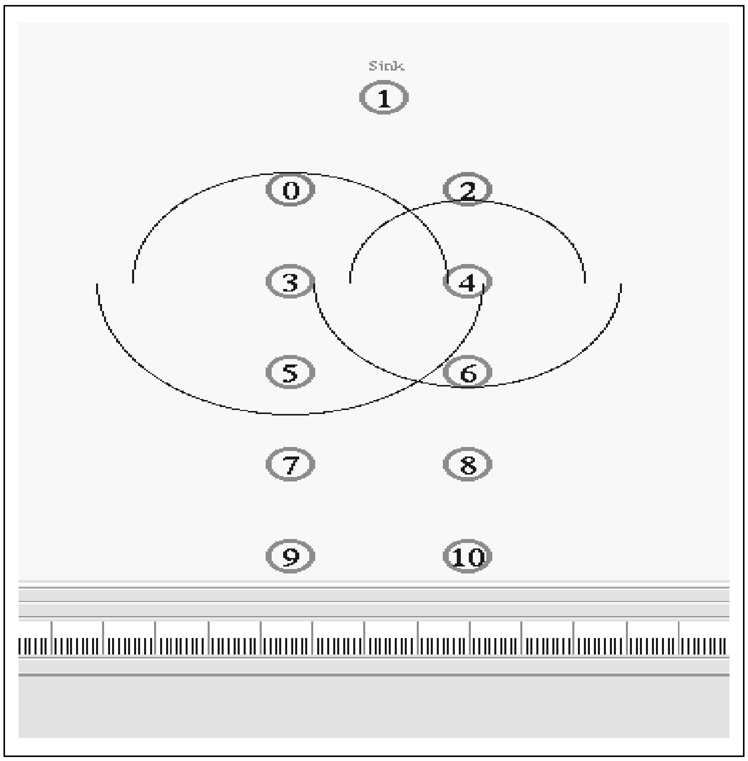


Figure 5 Broadcast in WSN scenario-1

Figure 5 depicts the simulation scenario, with eleven nodes with node one as the sink and the rest being the adjacent sensor nodes. The message exchange is by broadcast and all the sensor nodes are in the radio frequency range of one another. The node one which is the sink starts the broadcast of hello message which travels till the edge nodes which are node nine and node ten. Similarly all the other messages are also propagated across to establish a single path from each sensor node to the sink. Level-one consists of two nodes and is one hop away from sink. Level-two consists of two nodes that are two hopes away from the sink. Level-three consists of two nodes which are three hopes away from the sink. Level-four consists of two nodes four hopes away from the sink. Level-five consists of two nodes which are five hopes away from the sink.

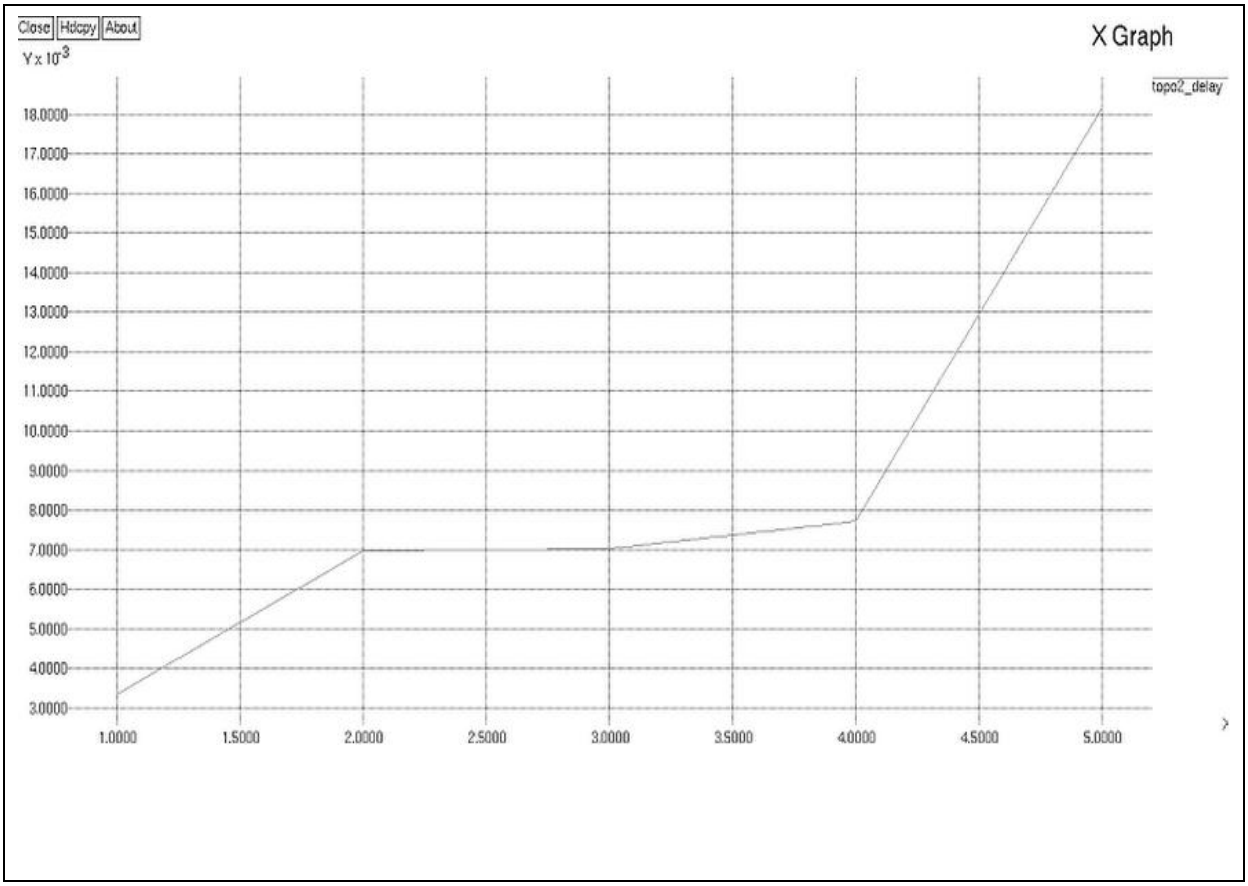


Figure 6 No of hops v/s delay

The graph is plotted with time on the x-axis and density (level) on the y-axis. As the number of nodes increases the messages exchanged required to establish the path too increases and hence the delay also increases .

 

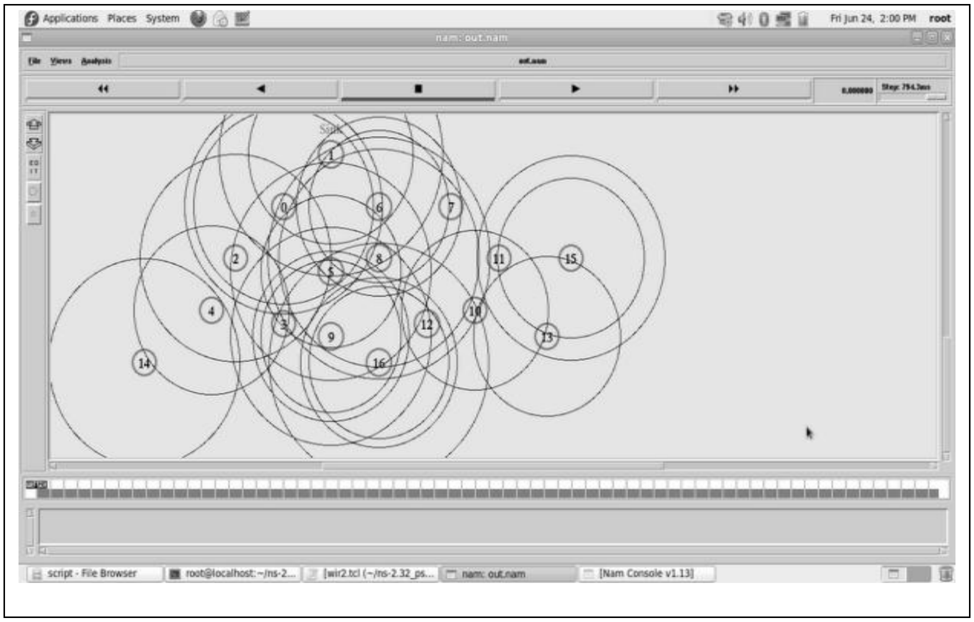

Figure 7 Broadcast in WSN scenario-2

Simulation scenario with seventeen nodes with node one as the sink and the rest being the adjacent sensor nodes. The communication is through broadcast messages.

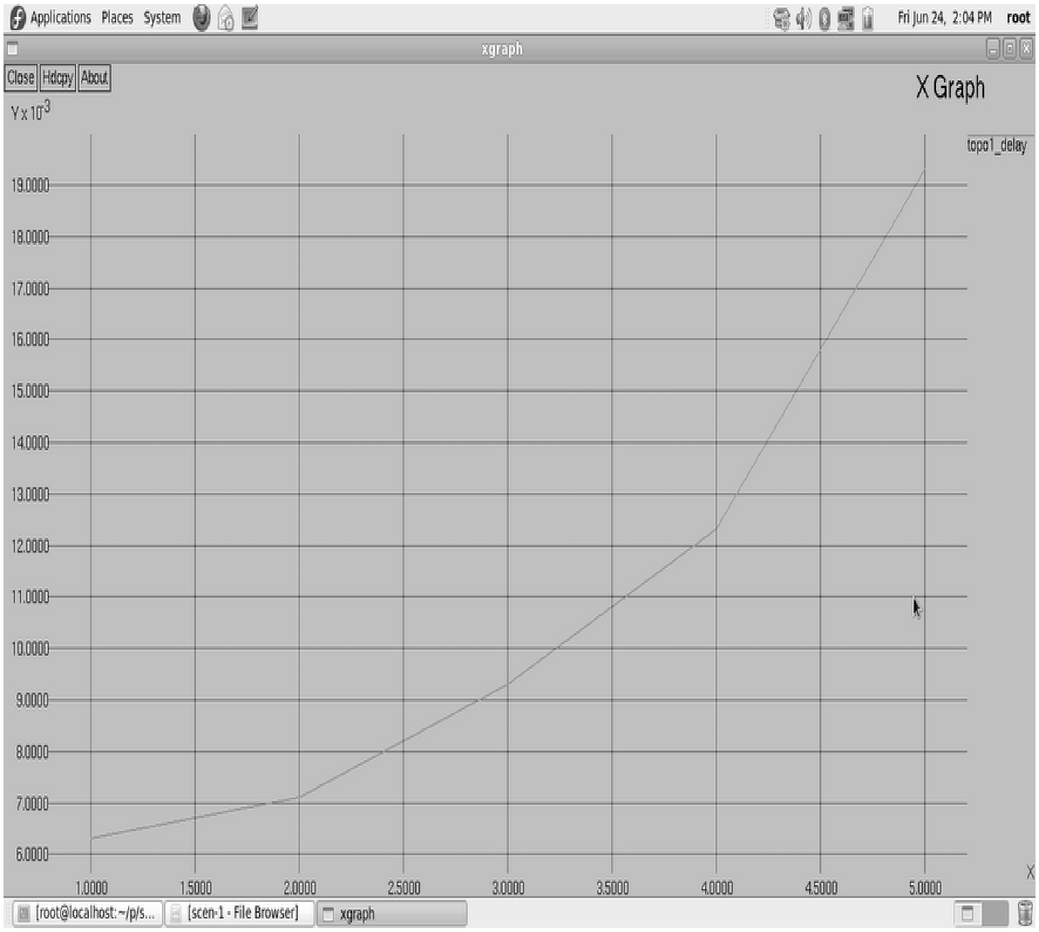


Figure 8 No of hops v/s delay –scenario-2

The delay graph for random topology with seventeen nodes. This topology has varying density at each hop.

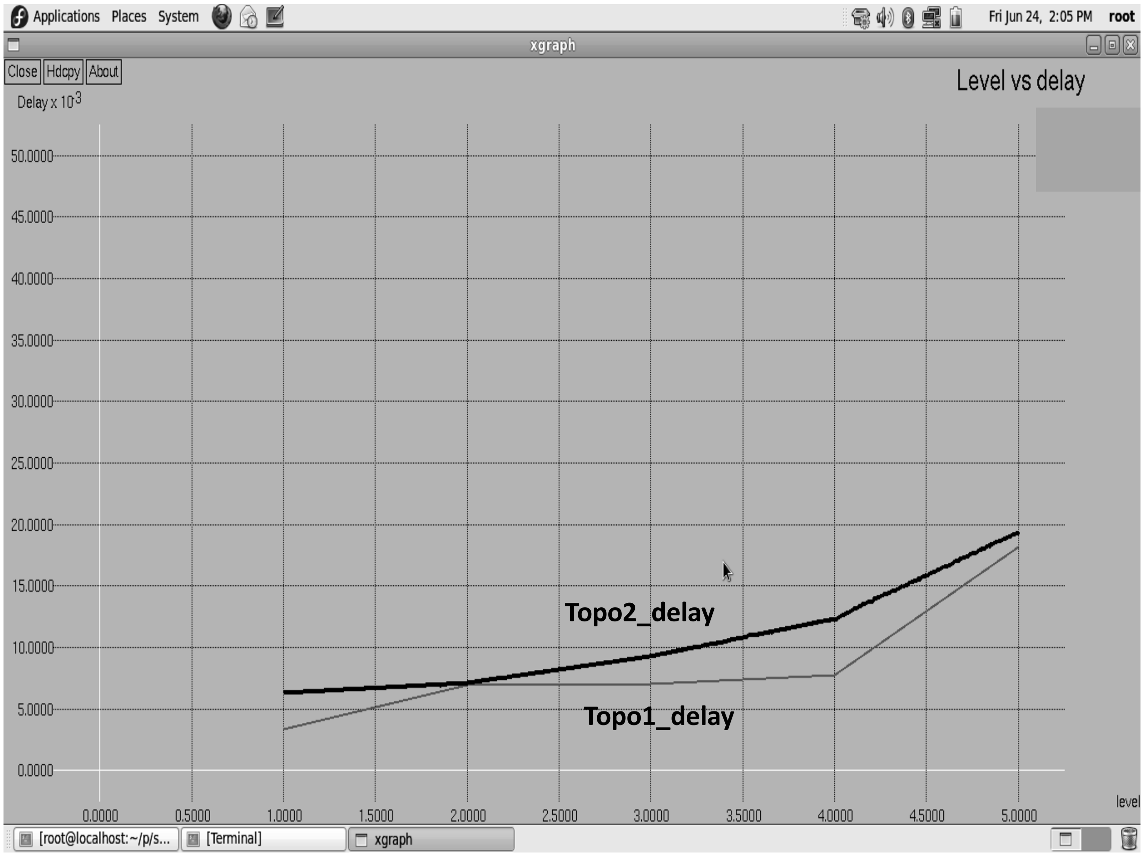


Figure 9 Comparison of Graphs of scenario-1, 2

The time taken for data delivery when the number of nodes at each level is same is less compared to a topology with varied number of nodes at each level, the reason being the increase in the number of messages being exchanged. Here the topology 1 is the topology considered in figure 5 and the topogy 2 is the random topology considered in figure 7.