# Multi-hop Route Discovery using Opportunistic Routing for Wireless Sensor Networks

**Yamuna Devi C R, S H Manjula, K R Venugopal, L M Patnaik**

***Abstract – In wireless sensor networks multi-hop routing is often used because of the limited transmission range of sensor nodes. Opportunistic Routing is a multi-hop routing for wireless sensor networks. In this routing, the neighbors of sender node overhear the transmission and f```orm multiple hops from source to the destination for transfer of information. The neighbor nodes set participating in the routing are included in the forwarder list in the order of priority. The node with highest priority is allowed to forward the packet it hears. A new protocol by Energy Efficient Selective Opportunistic Routing (EESOR), is implemented in this paper that reduces the size of forwarder list by applying a condition that the forwarding node is nearer to the destination. The path followed by acknowledgment packet follows opportunistic routing, assuring reliability of transmission and energy balancing. NS2 is the simulator used to implement the algorithm and results of simulation show that proposed EESOR protocol performs better than existing Energy Efficient Opportunistic Routing (EEOR) protocol with respect to parameters End-to-End Delay, Throughput, Routing Overhead and Network Lifetime.***

***Index Terms: Delay; Lifetime; Opportunistic Routing; Reliability; Throughput; Wireless Sensor Network.***

## I. INTRODUCTION

A group of communicating devices constitutes a network. A wireless sensor network is a collection of spatially distributed autonomous sensors to cooperatively monitor parameters like temperature, sound, vibration, pressure, motion or pollutants. Micro Electro Mechanical Systems (MEMS) technology is used in building sensors. Sensory data comes from multiple sensors in distributed locations in the area where the sensor nodes are deployed. Wireless sensor networks perform the function of sensing and processing the sensed data depending on the requirement of the network. The occurrence of an event may cause sensor to register the data or sensing may be done periodically depending on the application to which they are used.

Wireless sensor networks have many applications. Industrial application areas where wireless sensor nodes are used include Industrial process monitoring and control machines. Civilian applications of wireless sensor networks include Health monitoring, environment and habitat monitoring, health care applications, home automation, and traffic control. Many applications of wireless sensor networks demand smaller size for the nodes, and in turn, the components of the nodes.

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The lifetime of a sensor node is limited by the life of the battery contained in the nodes. Because of the wireless nature of nodes, the applications demand long life for sensor nodes.

This requires energy of the sensor nodes to be used very efficiently. Many applications demand minimum delay in data transmission, good throughput, and longer network lifetime.

Components of a typical wireless sensor node are shown in Fig. 1. A sensor node has the following components. A sensor unit to perform the basic sensing operations, a memory unit to store the sensed information, a battery for power requirements, a processor for data processing operations and a transceiver for transmitting and receiving the data. The transceiver unit is provided with a limited range antenna. The memory provided in the sensor node is normally a limited storage memory to facilitate small size, as normally the node is transmitting the data sensed and does not store it. The battery is loaded with an initial energy and has limited life. With the five necessary units, a sensor node can be equipped with optional units such as a mobilizer, location finding unit and power generator. Normally, about 50% of the cost of the sensor node is meant for the cost of the actual sensor unit.

The factors that influence the design of a routing protocol for wireless sensor network are *scalability, fault tolerance, network topology, transmission media, operating environment*

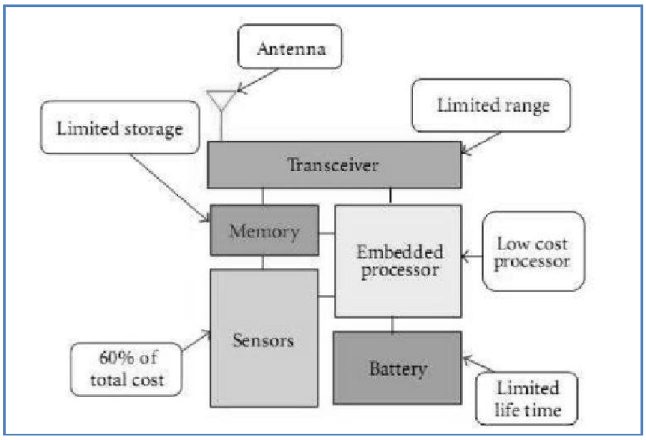


**Fig. 1. Block Diagram of Wireless Sensor Node**

*and power consumption*. These factors are used as guidelines in the design of a routing protocol and it is difficult to integrate all these factors into a single network. The influencing factors are used for the comparison of different routing schemes for wireless sensor networks. Applications in wireless sensor networks require information to be transferred between source-destination pairs that are connected using one or more hops.

It is required to connect the source-destination pairs of a wireless sensor network using the shortest distance, with minimum hops, in the shortest possible time with more reliability. When the source and destination are more than one hop away, one of the nodes has to be selected from the set of neighbors of the source to forward the packet towards the destination. The nodes in the forwarder list are prioritized based on different metrics like hop count and packet delivery ratio. The choosing of forwarding node continues till the destination node is reached. Different routing protocols are used in disseminating information from source to destination in a wireless sensor network.

Multi-hop routes are formed based on different parameters. Opportunistic routing is one of the flat based reactive routing protocols. Reliability and transmission range enhancement of a node are the advantages of opportunistic routing in a wireless sensor network. Network reliability is increased by transmitting a packet through any possible link in the network rather than a specific link. Variants of opportunistic routing, *viz*, Energy Efficient Opportunistic Routing (EEOR) [1], Exclusive Opportunistic Routing (ExOR) [2], Assistant Opportunistic Routing (AsOR) [3] are discussed in this paper. Each of the opportunistic routing protocol mentioned above has its own advantages and disadvantages.

Energy Efficient Opportunistic Routing is one of the multi-hop routing protocol for wireless sensor networks. It makes use of the forwarders list of the node to choose the forwarding node to transfer the data towards the target. Priorities are assigned for the neighbours of a node to choose the forwarding node. Parameters analysed for the network of interest are Energy consumption, packet loss ratio, and delivery delay. Efficient protocols are required to reduce delay in transmission and to prolong the network lifetime. EEOR [1] protocol gives better results compared to ExOR [2] protocol in terms of packet loss ratio, average delivery delay and energy consumption. The proposed Energy Efficient Selective Opportunistic Routing protocol achieves better throughput, maximum end-to-end delay and network lifetime, by reducing the size of the forwarder list and opportunistically routing the acknowledgment packet from target to source in the network.

## II. RELATED WORK

Some of the important works related to opportunistic routing related to wireless sensor network are discussed below.

Mao, Tang, Xu, Li, and Ma [1] focused on selecting and prioritizing the forwarder list of a node to minimize energy consumption by all the nodes by designing Energy Efficient Opportunistic Routing. The output parameters analyzed are energy consumption, average delivery delay and packet loss ratio of the network. Biswas and Moris, [2] proposed ExOR, to describe an integrated routing and MAC protocol that increases the throughput of multi-hop wireless networks. The protocol chooses each hop destination of a packet's route after the completion of the hop. The protocol gives the choice to decide which of the neighbouring nodes receives the packet. ExOR protocol gives a better throughput compared to traditional routing with the same network capacity. Chen Wei, Chen Zhi, Pingyi Fan, and Khaled Ben Letaief [3] discussed Assistant Opportunistic Routing (AsOR) protocol, which is a unicast routing protocol for multi-hop wireless sensor networks. The authors have provided a method for the optimal value for the number of nodes in one transmission segment for multi-hop wireless sensor networks.

Anand Nasipuri, Castaneda, and Das [4] developed algorithms to find the path that consumes minimal energy for node and link-disjoint wireless networks. The performance evaluation shows that the link-disjoint paths consume less energy compared to node-disjoint paths. The issues related to distributed implementation and optimal centralized algorithms are discussed.

Andrea Passarella, Mohan Kumar, Marco Conti, and Eleonora Borgia [5] investigated the use of a series of opportunistic contacts, in an opportunistic routing environment. The authors implemented a scheme for supporting service provisioning in opportunistic networks, and an analytical model for determining the optimal number of parallel executions required to minimize the service time in the network. Che-Jung Hsu, Huey-Ing Liu, Winston Seah [6] reviewed the basic concepts of opportunistic routing and describes the components of opportunistic routing. Current trends, issues and challenges in opportunistic routing are explained with examples. Many of the the key challenges in opportunistic routing to be addressed by the researchers are discussed in detail.

Myung and Lee [7] proposed a method for avoiding duplicate forwarding of packets in opportunistic routing in a wireless sensor network. Each packet includes a small information piggybacked, that reduces the number of repeated packet transmissions. Reduction in packet re-transmission in turn increases the throughput. Zeng, Lou, and Zhai [8] gives a comprehensive study on the impacts of multiple rates, interference, and prioritization on the maximum end-to-end throughput and capacity of opportunistic routing. The results obtained indicate that opportunistic routing has a higher potential to improve end-to-end throughput.

Shengling Wang, Siuzhen Cheng [9] suggested two opportunistic routing algorithms for Peer to Peer networks that exploit the spatial locality, spatial regularity and activity heterogeneity of mobile nodes in a network. Both theoretical analysis and simulation based study reveal that the proposed algorithms outperform the other algorithms in terms of delivery latency and delivery ratio. Won-Yong Shin, Sae-Young Chung, Yong H. Lee [10] proposed a parallel opportunistic routing for wireless ad-hoc networks to observe the changes in power, delay and throughput as the number of source-destination pairs increases in the network. A net improvement in overall power-delay trade off is observed as compared to conventional routing since the interference tolerance of receivers is increased in the network.

Yanhuva Li, Abedelaziz Mohaisen, Zhi-Li Zhang [11] proposed the Localized Opportunistic Routing (LOR) protocol that utilizes the distributed minimum transmission selection algorithm to partition the topology into several nested close-node-sets using local information. Localized Opportunistic Routing protocol improves performances over extremely opportunistic routing and MAC-independent opportunistic routing protocol considering the parameters control overhead, end-to-end delay and throughput.

Zehua Wang, Yuanzhu Chen, Cheng Li [12] provided a solution for maintaining quality in transmission, with the combination of link quality variation and broadcasting nature of wireless channels. The solution called CORMAN, is obtained that shows significant performance improvement over Ad hoc On-demand Distance Vector routing, with varying mobile settings.

Bogdan Pavkovic, Fabrice Theoleyre and Andrzej Duda [13] defined an opportunistic forwarding scheme that accepts Routing Protocol for Low power and lossy networks (RPL) with the possibility of forwarding packets with multiple paths. Opportunistic RPL is compared with basic RPL with respect to end-to-end packet delivery delay and network lifetime parameters. Future scope of this scheme is to validate the scheme considering the limited packet buffers in the network. Azad and Joarder Kamruzzaman [14] propose three schemes to optimize the ring thickness, hop size and sensor node duty cycles in the network to optimize the network lifetime. Results show that the proposed schemes are better in energy consumption compared to single hop, multi hop and hybrid routing. Xiaoli Ma, Min-Te Sun, Gang Zhao and Xiangqian Liu [15] discussed an efficient Path Pruning (PP) algorithm to reduce the number of hops in transmission of packets in geographical routing protocols by using channel listening capacity of wireless nodes. The PP algorithm has low complexity of implementation and gives improved routing performance and delivery rate compared to Greedy Perimeter Stateless Routing (GPSR) and Greedy Other Adaptive Face Routing (GOAFR).

## III. MOTIVATION

The aim of all the routing protocols is to improve the performance of wireless sensor networks. The important parameters to be improved are the lifetime of the network, the delay in transmission and the network throughput. Routing protocols are classified as single hop and multi hop networks, depending on the number of hops to connect the source and target in the network. Based on the network structure routing protocols are classified as flat based, cluster based and location based routing protocols. The establishment of routing path in a wireless sensor network gives reactive and proactive routing protocols. Opportunistic routing is a flat based, reactive, multi-hop routing protocol for wireless sensor networks that applies to both small scale and large scale wireless sensor networks. Opportunistic routing takes advantage of broadcast nature of sensor nodes in wireless sensor networks.

Some of the metrics used for forwarder set selection in opportunistic routing are hop-count, packet delivery ratio and end-to-end delay. Any one or a combination of these metrics can be used in selecting the nodes in forwarder set and for prioritizing the forwarder nodes. Opportunistic routing has potential benefits brought to wireless sensor networks. Challenges faced by opportunistic routing are taken based on network coding coordination, multi-flow rate control, power control with proper bit-rate selection, multi-channel scenario, deployment of nodes and combination of opportunistic routing with selection diversity. Opportunistic routing is analyzed for fixed power model and adjustable power model of wireless sensor network.

EEOR [1] forms the set of forwarder list of a sensor node and allocates cost to each of the links connecting the node and its neighbours. Based on the cost of the links the forwarder list is prioritized and node with highest priority is allowed to participate in the forwarding of the data packets, from source to destination in multi-hop transmissions in a wireless sensor network. To handle the network traffic efficiently, congestion is controlled in the network dynamically adjusting the flow from each source node in the network. Penalty is imposed on the nodes that choose more than one forwarder nodes in multi-hop transmission. The protocol computes the expected cost for each node and uses that in selecting the forwarder list. From the forwarder list the optimal forwarder list is found by opportunistic routing. The proposed EESOR performs better than the existing EEOR in terms of average End-to-End delay, maximum End-to-End delay and network lifetime.

ExOR [2] is a multi-hop routing protocol for wireless sensor networks that integrates routing and MAC protocol to increase the throughput of multi-hop wireless sensor networks. ExOR uses long radio links with high loss rates for transfer of data in a network that usually is avoided in traditional routing. With the same network capacity as traditional routing, ExOR protocol results in high throughput in a multi-hop wireless sensor network. AsOR [3] forwards the data from the source to destination through a sequence of intermediate nodes. The assistant sensor nodes in the network are used to provide protection for unsuccessful opportunistic transmissions. Priority is given to conservation of energy in wireless sensor networks in the implementation of AsOR as energy consumption is an important parameter in the analysis of wireless sensor networks.

## IV. PROBLEM DEFINITION

The sensor nodes in a wireless sensor network can be connected using single hop or multiple hops depending on the transmission range of the sensor nodes. More number of hops in connecting source and destination nodes increases the delay in transmission and energy consumed by the nodes. The objective of this work is to reduce the energy consumed by the sensor nodes in receiving, transmitting of information and to decrease the delay in transmission of data from source to destination in a wireless sensor network.

The following are the assumptions in the wireless sensor networks considered:

1) The type of sensor node deployment is static.
2) The node density in the network is uniform.
3) All the sensor nodes have same initial energy.
4) The frequency of data generation in the network is uniform.
5) All the nodes in the network have same transmission range.

Sending a packet from source to target in a network can be considered to include three parts,

1) The source sending the packet to one neighbour node and that node is the target node.
2) If the target is more than one hop away from the source, then there is at least one node in the neighbours list to relay the packet to target.
3) Agreement on choosing the actual relay node, among the neighbours of the transmitting node.

The time and effort incurred achieving the part 1, is constant. The same for part 2 depends on the distance between the source and the destination. It is very hard to find the cost on coming to an agreement as to choose the relaying node. It is assumed that the overall cost of communication is represented by the distance between the nodes to be communicated in the wireless sensor network. The Euclidian distance *d* between two nodes *A(x1,y1)* and *B(x1,y2)* is calculated by using the equation,

$$d = \sqrt{(x2 - x1)^2 + (y2 - y1)^2} \tag{1}$$

Table 1 given below shows the list of variables used in the representation of wireless sensor network and their notations.

## V. IMPLENTATION

Let *s* represent the source node, *t* represents the target node and

$$IS(n) = \{i_1, i_2, .., i_n\} \tag{2}$$

**Table 1 Network Parameter Notations**

| Variable | Description |
|---|---|
| $N$ | Number of the Nodes in the Network |
| $P$ | Number of the Packets Transmitted between a pair of Source and Destination |
| $X, Y$ | Maximum value for Node's Position |
| $T_r$ | Transmission Range of Sensor Node |
| $n_x$ | *x* Co-ordinate of Node *n* |
| $n_y$ | *y* Co-ordinate of Node n |
| $d$ | Time taken by a Packet in Reaching Destination from the Source Node |
| $E_I$ | Initial Energy of the Node |
| $E_c$ | Critical Energy Level of the Node |
| $E_r$ | Residual Energy of the Node |
| $T$ | SimulationTtime |

represent the intermediate nodes in connecting the source and target nodes in the network. *F(n)* represents set of forwarder nodes for node *n*. The set of sorted forwarder nodes of *n* is represented by *FS(n)*. It is obvious that *FS(n)* = $i_1, i_2, .., i_n$ probably in a different order. Let α represent the probability that a packet sent by node *s* is not received by any of the nodes in *FS(n)*. Then β represents the probability that a packet sent by node *s* is received by at least one node in *FS(n)*, which implies the equation

$$\beta = 1 - \alpha \tag{3}$$

The network scenario can be represented by the mathematical model shown below.

Optimization function is to

Minimize $d$ (4)

Subject to the following constraints

$E_r \;<=\; E_I$ for all nodes; (5)

$E_r \;>=\; E_c$ ; for all live nodes; (6)

$0 <= n_x <= X$ ; $0 <= n_y <= Y$; (7)

In the network considered, the source node forms the set of neighbouring nodes to forward the packet, when the destination is more than one hop away from the source. The set of neighbours is sorted according to its distance from the destination, and normally the first of these nodes in the forwarder list relays the packet towards the destination. The procedure continues till the destination node receives the packet.

The routing table of a node consists of the following fields:

1. Destination.
2. Next Hop.
3. Packet Sequence Number.
4. Distance from the node to destination.

Each node has a routing table of all its neighbours, consisting of all the required fields. Distance between node and target node is used in updating the routing table entry of the node during multi-hop transmission. Construction of routing table of a node is considered in the following phases. In Phase I, the routing table for all the nodes in the wireless sensor network is constructed. Phase II updates the routing table of the forwarding nodes depending on their distance from the target node in multi hop wireless sensor networks.

### A. Phase I – Construction of the Routing Table.

Initially, the routing table of every node is constructed based on the neighbouring node information. This phase starts with the construction of a *HELLO* packet from the node to all its neighbours. Once it is done, a timer is used to *broadcast* the *HELLO* packets to all of its neighbours. The *HELLO* packet is not sent to any particular node. The node that receives packet, checks the packet source field to find out the address of the node that originated the *HELLO* packet. If the receiver node routing table already has an entry of the source node of the *HELLO* packet, it drops the packet. Otherwise, it creates a new entry for the node that has sent the *HELLO* packet with all the necessary fields.

**Table 2 Construction of Routing Table**

**Step 1 :** for all *N* nodes in the network
**Step 2** : broadcast HELLO packets
**Step 3** : endfor
**Step 4** : for every node receiving HELLO packet
**Step 5** : if sending node is not included in routing table of receiver node
**Step 6** : add sender to routing table of receiving node
**Step 7** : else drop the packet
**Step 8** : endif
**Step 9** : endfor

This process of sending *HELLO* packets and updating the routing table entry, if needed, is continued for all the nodes in the networks have the complete routing table entries. Table 2 gives the algorithm for Phase I. At the end of Phase I, each node is having a routing table for itself, containing all the information of its immediate neighbouring nodes.

### B. Phase II – Route Set Up

The routing table constructed in Phase I, is sufficient for communication in a network, if the nodes are one hop distant away only, that is not true always. In Phase II, the entries in the routing table are updated, depending on the position of the source, intermediate nodes and the destination.

The distance between the forwarding node and the target node is updated in the routing table entry, so that the next hop node is the one with smallest distance between itself and the target node. According to the concept of Energy-Efficient Selective Opportunistic Routing (EESOR), the next hop to a particular destination is decided on the fly and new protocol implemented is completely opportunistic. This process is repeated till the destination node is reached. At the end of Phase II, we have a shortest path from the source to destination for multi-hop paths in a wireless sensor network. Table 3 is the algorithm for Phase II for the construction of route form source to target.

The Transport Layer Protocol used in this communication is Transmission Control Protocol (TCP), a reliable protocol, where every packet is guaranteed to be delivered to the destination, by making use of the acknowledgment packet sent from target to source node. In the existing protocols the acknowledgment packet flows in the reverse path of the data path, using same intermediate nodes. The newly implemented protocol EESOR sends the acknowledgment packet opportunistically. Real time communication involves transmission between different pairs of nodes at different instances of network functioning and the intermediate nodes are chosen according to steps of the algorithm.

**Table 3 Route Set Up**

**Step 1 :** For all *Sources* in the network
**Step 2 :** if t is neighbour of s
**Step 3 :** send packets to t.
**Step 4 :** else
**Step 5 :** form set of forwarder nodes $F_n$ of s.
**Step 6 :** form the set of sorted forwarder nodes $FS_n$ of s.
**Step 7 :** repeat through step -- until t is reached.
**Step 8 :** choose first node in $FS_n$ to forward the packet from s towards t.
**Step 9 :** endrepeat
**Step 10 :** endif

This real time communication and the use of different paths for the data and acknowledgment packets balances the energy consumed by the nodes in the network and prolongs the network lifetime.

## VI. RESULT ANALYSIS

### A. Simulation Setup

The network behaviour is analyzed for the parameters shown in Table 4 using network simulator NS2. The behaviour of the network is observed for End-to-End Delay, network lifetime, System Throughput, and Routing Load. 50 nodes are deployed randomly in the network. In these 50 nodes, 9 different source- destination pairs are randomly chosen for one-hop, two-hop, and more than two-hop communications. Table 5 shows the details of the nodes connected in the wireless sensor network. The node-pairs 4-41, 43-34, and 39-40 represent one hop communication pairs. The node-pairs 30-32, 10-20, and 1-5 represent two hop communication pairs. The last pairs 0-24, 11-22, and 33-49, represent more than two hops communication source-destination pairs.

**Table 4 Network Parameter Values**

| Network Parameters | Values |
|---|---|
| Number of Nodes | 50 |
| Network Area | 500m X 500m |
| Packet Generation Rate | 1 Packet per Second |
| Transmission Range | 250 meters |
| Data Packet Size | 1000 bytes |
| Acknowledgement Packet Size | 40 bytes |
| Simulation Time | 150 Seconds |
| Initial Energy of Nodes | 50 Joules |
| Transmission Energy per Packet | 0.38 Joules |
| Reception Energy per Packet | 0.36 Joules |
| Idle Energy per Second | 0.003 Joules |

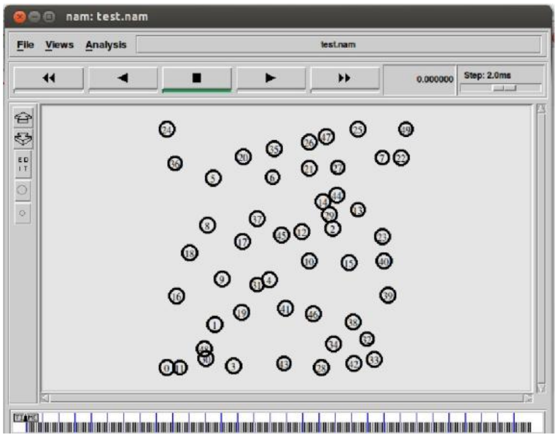

**Fig. 2. Network Scenario with 50 Nodes**

**Table 5 Details Of Connected Pairs In The Network**

| Number of Hops | Source Node | Destination Node |
|---|---|---|
| 1 | 4 | 41 |
| 1 | 43 | 34 |
| 1 | 39 | 40 |
| 2 | 30 | 32 |
| 2 | 10 | 20 |
| 2 | 1 | 5 |
| More than 2 | 0 | 24 |
| More than 2 | 11 | 22 |
| More than 2 | 33 | 49 |

For one hop communication, it is not necessary to find the forwarder list and sort it. For two hop communications, the neighbour list of the source has to be formed, prioritized and sorted according to their distance from the target. The node in the forwarder list that is nearer to target is chosen as the forwarding node. For the pairs, 30-32, 10-20 and 1-5, the nodes 28, 35 and 8 are used as relaying nodes, respectively. For more than two hop node-pairs, 0-24, the nodes 18 and 36 are used as relaying nodes. For the next pair 11-22, data from 11 goes to node 31, then from node 31 to node 14, and from 14 it reaches the target 22. Nodes 40 and 22 are used as relaying nodes in connecting the last pair 33-49.

### B. Performance Analysis

Figure 2 shows the network scenario of the wireless sensor network with 50 nodes randomly deployed in the area of 500 m X 500 m. The parameters packet delay, network lifetime, throughput and routing overload are analyzed in this section.

*Average End-to-End Delay*

The time elapsed between the source node sending the packet and the destination node receiving the packet is *End-to-End Delay*. The average of the End-to-End delay of all the packets transmitted between each of the pairs of source-destinations gives the average End-to-End delay. The average End-to-End delay is plotted against all 9 pairs of source and destinations as shown in Fig. 3.

From the graph it is observed that for one hop networks, Energy Efficient Selective Opportunistic Routing does not show any improvement as compared to Energy Efficient Opportunistic Routing, because the time for choosing the set of forwarder list is not needed. As the number of hops increases, the reduction in delay is more. For two-hop and three-hop communications the delay is reduced up to a maximum of 90 minutes which is around 9% for 10-20 source-destination pair and 295 meters that is approximately equal to 30 %for 11-22 source destination pair, respectively.

*Maximum End-to-End Delay*

Figure 4 shows the graph of maximum of End-to-End delay values, for the same 9 pairs of nodes considered for analyzing average End-to-End delay. Once again, single hop communication takes same amount of time in Energy Efficient Selective Opportunistic Routing and Energy Efficient Opportunistic Routing. Two-hop communications between the nodes 30 and 32 shows the maximum improvement of around 300 meters, or 3 % of total delay for each source destination pair. And more than two-hop communication yields a maximum reduction of delay by approximately 1000 meters, or 50 %, for the source destination pair 11-22. The reason for this improvement is decrease in the size of forwarder list in case of Energy Efficient Selective Opportunistic Routing, by considering only the neighbour nodes that are nearer to destination.

The reduced size of forwarder list reduces the time taken for prioritizing and sorting the nodes needed for choosing the forwarder node. The analysis of maximum End-to-End delay shows that, as the number of hops increases, the transmission delay increases in both types of routing considered. The maximum End-to-End delay is lesser in Energy Efficient Selective Opportunistic Routing as compared to Energy Efficient Opportunistic Routing.

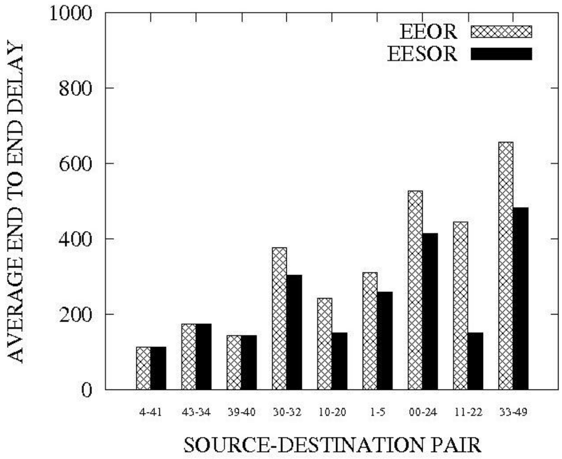


**Fig. 3. Average End-to-End Delay**

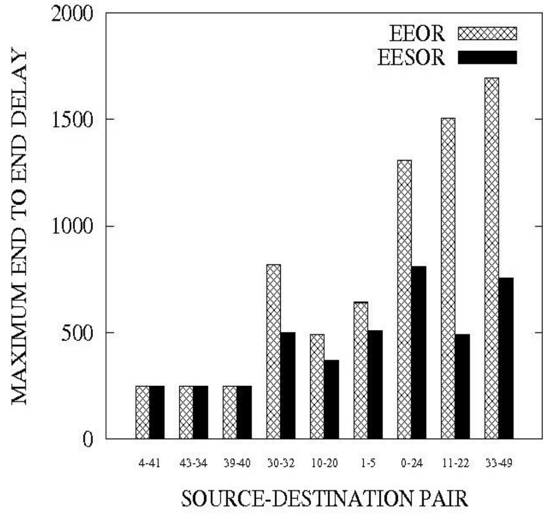


**Fig. 4. Maximum End-to-End Delay**

*Network Lifetime*

The *lifetime* of a sensor node is considered as the time from its deployment to the time till which the node is having more than 10% of its initial energy. The node is said to be *alive* in this period. Beyond this period the node is said to be *dead. Network Lifetime* is the time between inception of the network to the time up to which 10% of the sensor nodes are alive. Network size is considered as 25 nodes, 50 nodes, 75 nodes and 100 nodes for comparing the performance of Energy Efficient Opportunistic Routing and Energy Efficient Selective Opportunistic Routing. Fig. 5 shows the network lifetime for both Energy Efficient Opportunistic Routing and Energy Efficient Selective Opportunistic Routing protocols plotted against different network sizes mentioned above.

The network performance is analyzed for the network sizes 25, 50,75 and 100 nodes for network lifetime. The graph shows that the network lifetime increases for all the networks considered, irrespective of the network size. The reason is

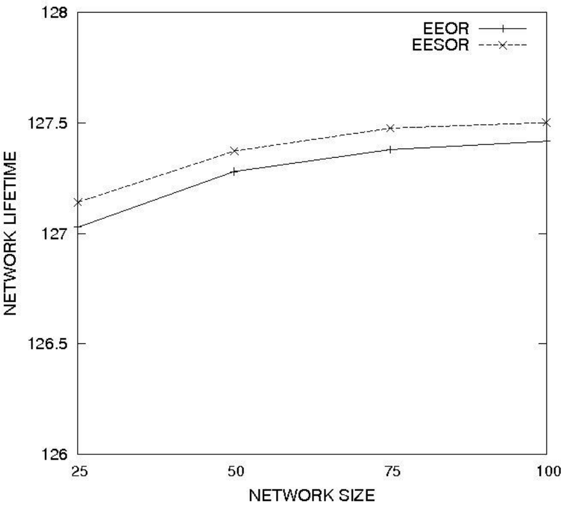


**Fig. 5. Network Lifetime**

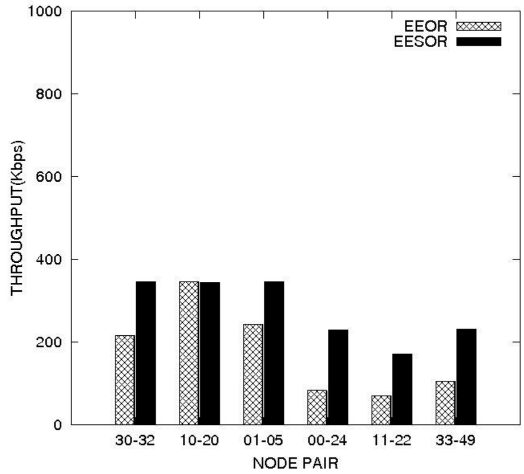


**Fig. 6. Network Throughput**

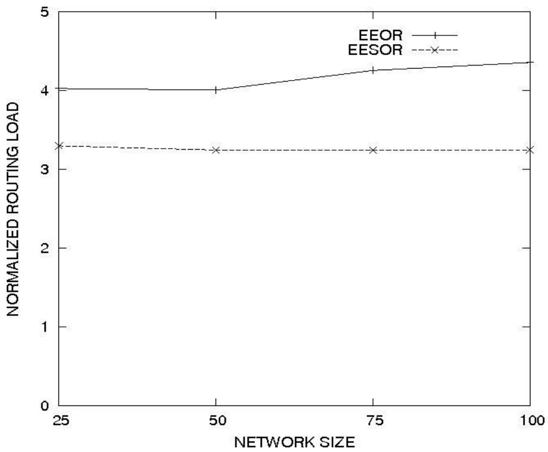


**Fig. 7. Routing load in the network**

Energy Efficient Selective Opportunistic Routing uses lesser number of hops to reach destination from the source and the acknowledgment packet traverses a path that may not be the same as the data path as compared to Energy Efficient Opportunistic Routing.

*Network Throughput*

Network throughput is the number of Kilo bits received per second in the network. Six different pairs of nodes are considered for measuring the network throughput in a network consisting of 100 nodes. Packets are transmitted continuously between the source and destination pairs for a simulation time of 10 seconds. The bar graphs in Fig. 6 show that the performance of EESOR is better than EEOR for five pairs out of six pairs considered for transmission in the network. EESOR connects the source and destination nodes with lesser number of hops as compared to EEOR protocol and increases the throughput of the network.

*Network Routing Load*

The *network routing load* is the number of forwarded packets for every packet transmitted between source and destination pairs. It represents the additional packets transmitted for every data packet in the network. Six pairs of nodes are considered for transmission in the network for number of nodes equal to 25, 50, 75 and 100 and the routing load is calculated for all the cases. The graph in Fig. 7 shows that the network routing load decreases for all the networks considered, as compared to EEOR protocol, irrespective of the network size. The reason for this decrease is the reduction in the number of neighbour nodes used in choosing the forwarding node in case of multiple hops is lesser in EESOR as compared to EEOR.

## VII. CONCLUSIONS

In this paper, a novel approach, Energy Efficient Selective Opportunistic Routing is presented, to reduce the end-to-end delay, routing overhead and to increase the throughput and lifetime of a multi-hop wireless sensor network. The size of set of forwarder nodes of the source node is reduced by imposing a condition that, the neighbour nodes of the source node nearer to the destination are selected to be included in the set of forwarder nodes. These nodes in the forwarder list are sorted according to the descending order of their distance from the destination node. This technique decreases the average End-to-End delay and maximum End-to-End delay up to maximum of 50% for some of the source and destination pairs as compared to existing Energy Efficient Opportunistic Routing. Opportunistic routing is applied for the flow of acknowledgment packet from target to source, to balance the energy consumption among the nodes in the network. The throughput of Energy Efficient Selective Opportunistic Routing is almost double for many of the source destination pairs chosen than that of Energy Efficient Opportunistic Routing as the number of hops are reduced in the former routing method. The network routing overhead is reduced considerably in the case of Energy Efficient Selective Opportunistic Routing.

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