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Chain Routing for Convergecast Small Scale Wireless Sensor Networks

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Abstract. Wireless sensor networks have many applications involving autonomous sensors transmitting their data to a sink placed in the network. A protocol by name Chain Routing for Convergecast Small Scale (CRCSS) Wireless sensor networks is proposed in this paper. The set of sensor nodes in the network send the data periodically to the sink located in the area of interest. The nodes who cannot reach sink in one hop choose one of the neighbours for forwarding the data to the sink by forming a chain of links. The selection of forwarding node and the waiting period before forwarding plays an important role in the protocol. The proposed CRCSS protocol exhibits improvement in energy spent per packet and latency per packet for a wireless sensor network as compared to ConverSS protocol for small scale wireless sensor networks. In CRCSS protocol energy spent per packet is independent of the network radius.

Keywords: Communication System, Convergecast Routing, Energy, Latency, Multi-hop Networks**.**

1 Introduction

Wireless sensor network is a collection of sensor nodes deployed to monitor an area of interest in the environment. The nodes in the sensor network sense a parameter of interest in the network and report it to the base station or the sink located in the network. The nodes can be homogeneous or heterogeneous in terms of transmission range, initial energy stored, mobility, etc. The nodes are connected to the sink through a single hop or more than one hop through intermediate nodes. The routes formed prior to the start of packet communication from the sensor node to the sink are called static routes. Dynamic routes between the source and the sink are the routes that are formed as and when an intermediate route is reached. Two types of links between the sensor nodes are possible. In symmetric links the transmission power and receive threshold are same in both direction of the data flow between any two sensor nodes. Transmission power and receive threshold vary in case of asymmetric nodes.

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Wireless sensor networks find applications in many fields of human life. Initially wireless sensor networks were used in the Military fields for surveillance application. Now wireless sensor networks find applications in field such as intruder detection in any restricted area, weather monitoring, health monitoring, etc. Automobile industry is another area where wireless sensor networks are used for tracking of vehicles and as an information system. It is possible for a bus passenger to know the location of the bus he is waiting for and to know whether he can get a seat in the bus or not when he gets into the bus in his stop. The network size and network area depends on the type of application of the wireless sensor network.

The sensor nodes comprise of a sensing unit, a memory unit, a transmitting unit, a receiving unit and a central processing unit. The sensing unit is responsible for sensing the parameter of interest and transfers it to processing unit. Memory unit present in sensor nodes is smaller in size as the data sensed is not bulk in size and there is no need to store the sensed data in the memory for longer time. The sensed data is transferred to the processing unit or the sink. The transmitter is used for transmitting the sensed or the received data to another node or the sink. The function of receiving unit is receiving the data from a neighbouring node or receiving acknowledgement from the sink node. The processing unit does the minimal processing required on the data before it is transferred to the sink node.

The data sensed by the sensors is communicated to the sink in the specific location within the network which is known as convergecast routing. In convergercast routing the route leading to sink will be congested as all the sensor nodes have to communicate their data to the single sink. Route congestion results in loss of data and longer latency period in packet transmission. Fig. 1 shows an example of convergecast network. Node 0 is the sink node. The remaining nodes send the data if they have to the sink in their sending slots. Nodes 1, 2, 3, 4and 5 are one hop distant from the sink node. Nodes 6, 7, 8, 10 and 11 are two hops away from the sink node. Packet from node 12 takes three hops to reach the sink node. If all the nodes have data to send to the sink in all the sending slots congestion occurs around node 0. This congestion cannot be completely eliminated but it can be reduced.

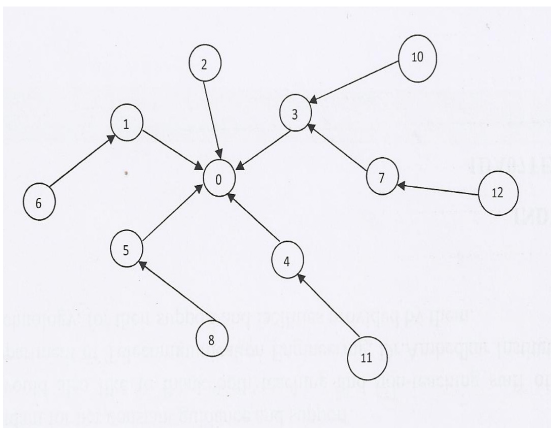

Fig. 1. Convergecast Routing

The CRCSS is a combined MAC and routing solution for reliable and energy-efficient convergecast for small-scale sensor networks. CRCSS is designed specifically for cases where most nodes are one to three hops away from the sink. The protocol proposed in this paper Chain Routing for Convergecast Small Scale wireless sensor networks has two fold contributions. First it reduces the energy spent by the sensor nodes in the network irrespective of the number of nodes in the network. Second it decreases the latency per packet transmission from source node to the sink node.

The rest of the paper is organised as follows. Section 2 lists and discusses the papers related to convergecast routing in wireless and other networks. Background work needed for proposing the new protocol is discussed in Section 3. Problem definition and algorithm are explained in Section 4. Section 5 analyzes the results of network simulation. Finally the paper concludes in section 6.

2 Literature Survey

This section discusses some of the papers related to convergecast routing, their advantages and disadvantages.

Chen et al., [1] present a novel convergecast tree protocol and a distributed algorithm to attain load balancing among the nodes of the network and to extend network lifetime. Dynamic adjustment of convergecast tree structure avoids breaking tree link, and is controlled by sensor's grandparent to avoid looping problems. The adjustment mechanism is localized and does not require global information. The simulations performed on convergecast networks demonstrate that throughput is increased. Fu et al., [2] design two cooperative schemes called convergimo schemes, for static and mobile ad hoc wireless networks. Static convergimo, utilizes Multiple Input Multiple Output (MIMO) technology to turn interfering signals into interference-resistant ones. Mobile convergimo characterizes on joint transmission from multiple nodes to multiple receivers, to maximize the throughput.

Hong and Kim [3] propose the Express-MAC, EX-MAC, protocol to conserve energy in a wireless sensor network using asynchronous duty cycling and to decrease end-to-end latency in packet transmission using wakeup time reservation. The EX-MAC protocol supports multi-hop network applications through a cross-layering interface, and provides convergecast packets with unidirectional interfaces to optimize performance and to support reconfiguration routing. Bernson and Manivannan [4] discuss design the factors of Vehicular Ad Hoc Network routing protocols. The authors classify and characterize the existing greedy routing protocols and provide a qualitative comparison of all the routing protocols with respect to their objectives, design approaches and requirements. The approaches discussed focus on dense traffic scenarios in wireless sensor networks.

Kam and Schurgers [5] propose a combined MAC and routing protocol ConverSS that uses contention-free MAC in conjunction with beaconing and overhearing in small scale convergecast wireless sensor networks. The protocol is optimized to handle single-hop networks, but, has the ability to route a packet through multiple hops, when necessary. An improvement of a factor of 10 is observed by ConverSS routing protocol, as compared to ideal protocol for small scale wireless sensor networks. X. Zhang et al., [6] analyze the performance bounds of typical many-to-one communication represented by convergecast scheduling, oriented to industrial applications. Three scenarios are considered in analyzing the networks. They are the lower bound on number of time slots to finish intra-cluster and inter-cluster convergecast transmissions, lower bound on the number of channels based on the number of timeslots and available channels and packet re-transmissions to meet the reliability requirements.

H. Zhang et al., [7] study time-optimal convergecast under the communication constraints of commodity sensor network platform. The authors propose a novel convergecast model in which packet copying between the processor and transceiver are separated from packet transmission. Both centralized and distributed schemes are proposed for computing time-optimal convergecast schedule. Augustine et al., [8] study the network in which the sensor nodes send information to the sink node as a byte packet. The path between the sensor node and the sink is the shortest one and the sensor node packs the data sensed into fully packed packets before sending it to the sink. This protocol reduces the energy consumed by nodes in packet transmission as the packet count is reduced.

Theoleyre [9] propose C-MAC protocol for multi-hop convergecast wireless network that selects a sub-tree of the shortest paths to the sink containing exactly k leaves to forward maximum of the traffic towards the sink. C-MAC is based on CSMA-CA like approaches and assigns priorities to the k-tree core nodes to avoid collisions among themselves to increase the throughput compared to original IEEE 802.11 protocols. Advantage of this protocol is that it does not require any synchronization mechanism among the sensor nodes in the network.

3 Background

Convergecast for Small Scale (ConverSS) networks [5] is a combined MAC and routing solution for small-scale, mobile networks. ConverSS is designed specifically for cases where maximum of the nodes are one hop away from the sink. For many of these real-time sensing applications, sensor generated data must be sent to the sink periodically. In one cycle of the protocol operation, or a sending interval, each node has one data packet to deliver to the sink. Because these are small networks, it is feasible to use a fixed-assignment TDMA MAC, in which each node is assigned a dedicated time slot for sending. This MAC requires that the number of nodes in the network be fixed at the system initialization. However, this setup is sufficient for most sensing missions, which have a small, consistent team of vehicles.

ConverSS [5] operates under two phases in each sending slot. Every node is given a time slot to send its packet to the sink based on Time Division Multiple Access Technique. Phase 1 operates under the assumption that nodes are one hop from the sink. Each node attempts to send the packet directly to the sink in its sending slot. Since there is no routing in this phase, nodes do not need to listen in the other nodes slots in phase I. They can instead be placed in sleep mode, in which nodes turn off the radio and thus consume very low power. All nodes check the Delivery Status Bit (DSB) sent by the sink to discover if their data have been delivered. In case of packet errors, more frames are allotted in which nodes can retransmit any undelivered data. By the end of phase 1, packets from all 1-hop nodes should have been received by the sink. If this includes all nodes, then they all go to sleep until the next sending interval. The operation described is efficient because there is no route setup, and nodes only send in their own slots and do not need to listen in the other slots.

It is possible that there are still undelivered packets after Phase 1 because of packet errors or nodes being out of range of the sink. In Phase 2, any nodes whose packets were not delivered to the sink perform a type of controlled flooding, in which nodes broadcast their data and receiving nodes can rebroadcast to try to deliver it to the sink. The reason for using flooding rather than a route setup followed by data transmission relates to the presence of asymmetric links. Fig. 2 shows the header details for ConverSS protocol. Studies have demonstrated the problem of asymmetry in radio propagation, in which a link is stronger in one direction than in the reverse. In typical routing, only symmetric links can be used because a handshake is required before a packet can be sent over a link.

The ConverSS header consists of the following fields: Packet Type, Packet Sequence Number, Source Address, Destination Address, Delivery Status Bit (DSB) and Acknowledgment Bitmap (ACKB). The type of packet is a data packet or acknowledgement packet. The Delivery Status Bit indicates the source node's knowledge of which nodes' data have been successfully delivered. The Acknowledgment Bitmap indicates from which nodes it has received since its last sent packet. Every data packet uses this header.

Packet Type	Seq. No.	Source Address	Destination Address	DSB	ACKB

Fig. 2. ConverSS Header Fields

Flooding is used during the phase 2 of packet transmission from sensor nodes to the sink. Flooding does not require a handshake, thus enabling the use of asymmetric links in routing the data to the sink. Since these are small networks, routes with asymmetric links may be the only ones available. Therefore, with more options for routing, data delivery has an improved chance of success. After the two phases are completed, the network can go to sleep until the next sending interval. As the network has small number of nodes, the two-phase sending interval is typically short enough so that the network topology will be stable during that time. Because no routes are assumed prior to Phase 1, the protocol is robust to changes in topology in between sending intervals. The sensor nodes cannot go to sleep until all the nodes have sent the data to the sink. A sensor node might be required to forward the packet to the sink. This results in higher consumption of energy by the sensor nodes. The proposed CRCSS constructs chain of links from source node to the sink in the network ensuring the delivery of packet to the sink. The proposed protocol reduces this waiting period by the sensor nodes by using the location of the sensor nodes to find the number of hops required to reach the sink. This reduction in waiting period reduces the energy consumption by the nodes and reduces the latency of packet transmission.

4 Problem Definition

In the proposed CRCSS protocol the two phases of ConverSS [5] are combined into a single phase to reduce the waiting period of the sensor nodes in the wireless sensor networks. The objective of Chain Routing for Convergecast Small Scale wireless sensor networks is to reduce the energy consumed by the network and latency per packet as compared to ConverSS routing.

The following points are assumed in the simulation of the wireless sensor network under consideration.

1) The sensor nodes in the network are homogeneous nodes.
2) The sink has infinite energy and transmission distance.
3) Small size network topology is considered up to 50 sensor nodes.
4) The transmission range of sensor nodes is fixed to 100 meters.
5) The network is error free.

Table 1. Algorithm CRCSS: Chain Routing for Convergecast Small Scale Wireless Sensor Networks

```
Input: Wireless sensor network with sink and sensor node positions.
Output: Chain of links from each of  sensor node to the sink.

wake up at the start of sending slot
for all the sending slots do
  if current time!= end of sending slot then
    if I have data packet to be sent then
      if D_N,S  <= T_r
        then
          send packet to S
          Delivery Status Bit DSB = 1
          P = S
        else
           find the neighbor whose DSB=1
           if such node exists then
             route the packet through that node
          endif
          if (DSB=1) for more than one node
            choose the node nearest to sink.
          endif
          P = N
        endif
      else
        sleep until the next sending interval
      endif
   endfor
```

Table 1 explains the algorithm CRCSS to find the chain of shortest path from sensor nodes in the network to the sink. Wireless sensor network with sink S and other sensor node *N* positions is the input to the algorithm. In each sending slot Ts the sensor node sends the data to the sink node. The source node goes to sleep till the next sensing slot, if it does not have any data to send to the sink. The sensor node finds the distance between itself and the sink node $D_{N,S}$. If this distance is within Ts then the packet can reach the sink in one hop and the sink becomes the parent of the sensor node.

On the other hand, if the sink is not reachable from the source, the source node selects among its neighbours the ones that have sink as the parent node. One of them is allowed to forward the packet to the sink and the forwarding node becomes the parent of the sending node. This process continues till all the sensor nodes in the network send their data packet to the sink and all the sending slots are completed. After the completion of the algorithm the path from sensor nodes to sink is defined. Energy consumed by the nodes, average number of hops in transmission and latency of packet delivery are analyzed.

Figure 3 shows an example convergecast wireless sensor network of 12 nodes. Node 0 is the sink node and the remaining nodes send the data to the sink periodically. Number of hops varies from one hop to three hops depending on the distance from the sensor node to the sink and the transmission range of the sensor nodes. The sensor nodes are initially supplied with an initial energy. The sensor nodes consume energy for sensing, receiving and transmitting packets. Small amount of energy is spent by sensor nodes in idle mode and sleep mode. The nodes will spend energy for all their activities over time.

5 Performance Analysis

The network is simulated using Network Simulator NS2 to analyze the behaviour of sensor nodes. Three different network scenarios are considered to analyze the performance of the proposed Chain Routing for Convergecast Small Scale wireless sensor networks protocol. In the first case network is of 11 sensor nodes and a sink is considered. Node 0 is the sink node and the other nodes send the data to the sink at regular intervals. Second network considers sensor nodes numbering from 5 to 40 to observe change in the latency per packet.

Finally, in the last case wireless sensor network radius is varied from 100m to 160m to measure the saving in energy spent per packet transmission by the sensor nodes during the simulation time. The sensor nodes in all the three cases are initially loaded with an uniform energy of 5Joules. All the wireless sensor nodes are deployed in the area of 500m by 500m. Energy is spent as and when the nodes transmit and receive packets during simulation in the network. The duration of the simulation time is taken as 100 seconds for all the cases.

5.1 Case 1

The protocol CRCSS is implemented on a 12 node wireless sensor network shown in Fig. 3 to analyze the energy spent per packet transmission between the source nodes and sink. Transmission energy and reception energy are measured per packet transmission. Sleep energy is measured per unit time such as energy spent by a sensor node in sleep mode per second. Table 2 shows the energy model parameters values used in the simulation environment.

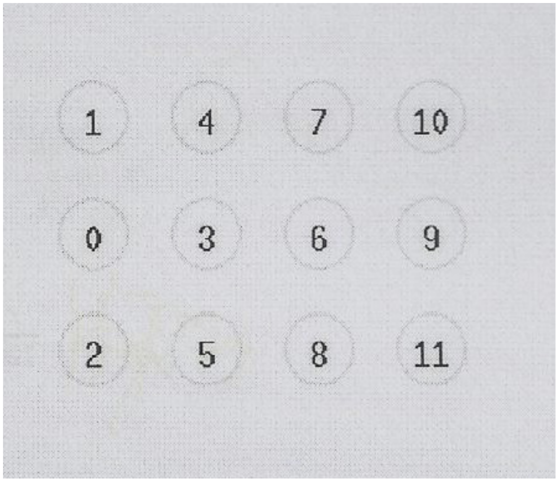

Fig. 3. Convergecast network of 12 nodes

Table 2. Energy Model Parameter Values

Parameter	Symbol	Value
Initial Energy	E_I	5J
Transmission Energy	E_T	0.14J
Reception Energy	E_R	0.095J
Idle Energy	E_D	0.08J
Sleep Energy	E_S	0.06J

Figure 4 shows the energy spent by sensor nodes to transmit a packet to the sink node for different power values in case of ConverSS [5] and the proposed CRCSS protocols. Sensor power values 1 and 2 are representing different transmission ranges of the sensor nodes as 50m and 100m respectively. For power =1 or transmission distance of 50m, the reduction of energy spent by sensor nodes for CRCSS is less than that of existing ConverSS [5] by 9mJ when all the 11 sensing nodes are considered. A reduction of 14mJ is obtained when the number of sensing nodes is 11 for power =2 or transmission distance of 100m.

5.2 Case 2

A wireless sensor network with size *N* = 12 nodes with base station in the centre is considered with number of nodes increased up to 40. The transmission range *Tr* of the wireless sensor nodes is fixed to 100m. Data packets are transmitted from the sensor nodes to the sink at the rate of one packet per second. Energy model for this network is as given in Table 2. The packet latency *L* and energy spent per packet transmission *Ep* are analyzed for this network setup. Latency is the time interval between the sending of the packet at the source node and the reception of the packet at the destination node. A sensor node spends energy in sensing, transmitting, receiving and forwarding operations. The energy spent in sensing an event is very less compared to transmission energy and reception energy and hence it is neglected in the energy computations.

Graph in Fig. 5 shows the latency per packet in case of convergecast(CON) protocol and CRCSS protocol. Up to 25 nodes the sensor nodes are connected to the sink through single hop. As the number of hops between source and sink nodes is same, latency per packet transmission is same for both CON and CRCSS protocols. For more than 25 nodes CRCSS reduces the number of hops as compared to CON routing. As a result of this reduction a decrease of 70% and 88% in latency per packet is observed when the number of nodes is 30 and 40 respectively in case of CRCSS protocol.

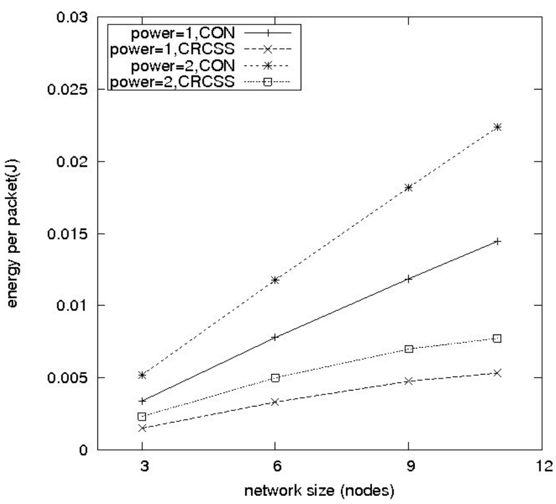

Fig. 4. Network Size versus energy spent per packet

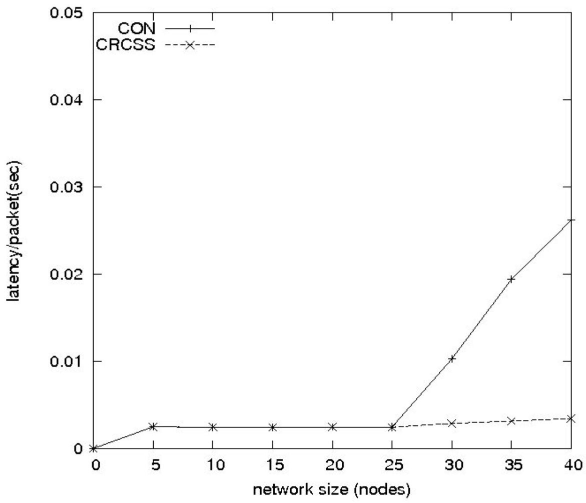

Fig. 5. Network Size versus Latency Per Packet

Figure 6 shows the energy spent per packet when data is sent from source node to sink for network size varied up to 40. The initial energy of the sensor nodes is 5J. The nodes consume energy for different operations in the network. The number of hops remains same in existing convergecast and the proposed CRCSS up to 25 nodes because major of the communication requires one hop. The same number of hops results in same energy spent per packet transmitted between source and sink. Transmission range of the nodes is 100 m and all the nodes are within one hop distance from the sink. For 30 and 40 nodes energy spent in CRCSS protocol is lesser by 20% and 36% respectively as compared to convergecast routing protocol. The reason for the reduction energy spent by the nodes in packet transmission is the decrease in the waiting time of the nodes in the case of CRCSS protocol.

5.3 Case 3

This subsection studies the effect of network radius *R* on the energy spent per packet transmission in a wireless sensor network. Keeping the number and density of sensor nodes as constant the network radius is varied to analyze the energy spent in the network. With the increase in the network radius the distance between the sensor nodes increases correspondingly. This results in reduction in number of hops between the source and the sink in the network. Fig. 7 shows the energy spent per packet when the network radius is increased from 100m to 160m. For less than 100m network radius all the nodes in the network can send their data to the sink in one hop that results in uniform energy consumption by all the sensor nodes in the network. A decrease of 4mJ of energy spent per packet transmission is seen from the graph when the network radius is 100m. For network radius of 160 m reduction in the energy spent for transmission of one packet to the sink is 18mJ.

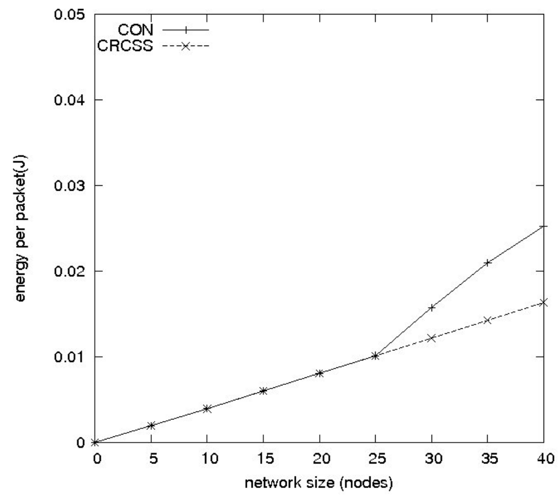

Fig. 6. Network Size versus energy spent per packet

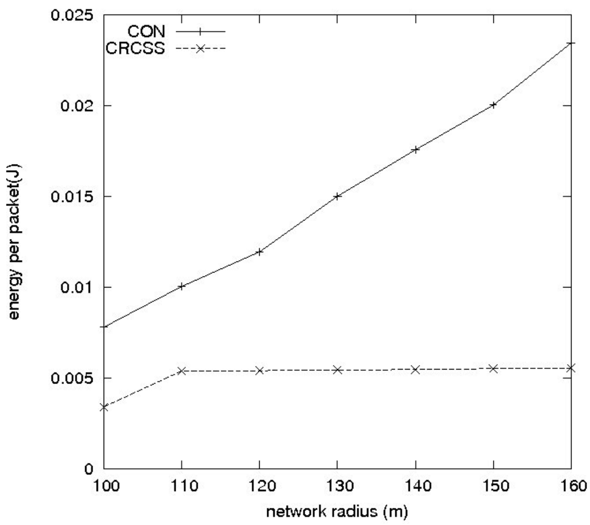

Fig. 7. Network Radius versus Energy Spent per Packet

6 Conclusion

A new protocol CRCSS is proposed for small scale wireless sensor networks in this paper. The proposed CRCSS protocol uses controlled flooding instead of broadcasting. Sending of packets from the source to sink is done by forming a chain from the source to the sink when they are more than one hop away. The proposed CRCSS protocol exhibits up to 36% improvement in energy spent per packet and up to 88% improvement in latency per packet for 40 nodes network. It is proved by simulation that the network radius does not affect energy spent per packet in CRCSS protocol. Analysis of the energy, latency and number of hops in the routing for mobile sensor nodes is considered for future work. Another direction for future work is to consider network with errors and attackers in the network. Parameters like current energy of the node and path length to the source can be considered in the selection of the forwarding node.

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