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Adaptive Routing Model in Wireless Sensor Network

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Abstract. Wireless sensor network is meant for monitoring any area, for sensing any physical attribute of the same and communicate it to the competent authority for some decision making. Since wireless sensor network is resource constrained so any task here should be done in low power mode such that the nodes do not consume much energy. Hence network lifetime of a sensor node is directly proportional to the energy consumption of the node and network. Therefore an energy aware routing model become essential for low power consumption and facilitating each node to select an appropriate forwarding node or parent to send data to its destination. Here in the article an energy aware adaptive routing model is proposed. The proposed routing scheme is evaluated and presented here. Moreover a comparative study, of some of the existing routing techniques, is also presented in the results and discussion section.

Keywords: energy consumption, energy efficiency, adaptive routing model, wireless sensor network

1 Introduction

Wireless Sensor Network (WSN) consists of tiny sensor nodes with some basic components viz. microcontroller, a communication device, a sensing device, a power supply and a minimal memory and altogether they work to monitor and observe any physical feature of any target area; however after that the nodes communicate the corresponding data, in form of signal, to the base station (BS). The BS is responsible for some technical decision making. But inherently WSN is resource constrained, infrastructure-less hence vulnerable system. Energy consumed by the sensor nodes, for performing each of its jobs, is a critical point of concern. So, all the jobs done by sensor nodes should be done in a low power mode such that energy consumption can be minimized. Among all the other tasks done by sensor node, data communication to the BS is the most energy exhaustive one. Therefore routing strategy needs to be low power-consuming since network lifetime of a sensor node is directly proportional to the energy consumption. Therefore an energy aware routing model is required, that will facilitate each node to select an appropriate forwarding node or parent to send data to its destination. Routing criticality lies in construction and maintenance of these routing tables in the WSN. A significant design challenge for a routing algorithm is minimizing routing cost.

According to Karl et al., and many other researchers, in WSN, data forwarding can be done by flooding, gossiping and controlled flooding [11]. Moreover the routing nature also varies with the structure of network, which can either be flat, location-based and hierarchical-based. Keeping reliability of any link is highly prioritized and with the knowledge of graph theory it is always recommended for a source to choose a suitable neighbor as a parent depending on the link quality through the same, and then forward data through it. However the objective of this research paper is to design an adaptive energy aware routing model, which can find a minimum cost path from any sender node to the BS. This adaptive and fault tolerant routing is based on a built-in learning based link quality estimation approach proposed by Mitra et al.[17]. The evaluation of the proposed

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scheme is presented in the result section. The remaining portion of the article is organized into four sections, in which Section 2 contains the related work of the existing research about the routing in WSN, where Section 3 contains the proposed adaptive routing model and algorithm. Section 4 contains the result and discussions while Section 5 concludes the article.

2 Related background survey

The related background survey and current state of technology from the perspective of various other researchers is presented in this section. There are a number of hierarchical-based routing protocols, and the most popular among them is Low Energy Adaptive Clustering Hierarchy (LEACH) proposed by Heinzelman et al.[1]. LEACH is a clustering based routing protocol, where the main idea is to share and delegate the energy consumption among sensor nodes in WSN by cluster head (CH) rotation to enhance network lifetime. Similarly another well known technique called Power Efficient Gathering in Sensor Information system (PEGASIS), proposed by Lindsey et al. in [14]; however this is a negotiation based aggregation less routing protocol. The thumb rule for PEGASIS is to create a chain for route generation, where no path is revisited during a round. Virtual Grid Architecture (VGA) in [5] routing technique for hierarchical-based WSN. It is a routing protocol for static sensor nodes and performs negotiation based data aggregation before transmission. Chen et al. propounded Link Quality Estimation based Routing Protocol more famously known as LQER[8]. It is a learning based method, where historical link statistics are used to estimate the quality of uplink or downlink. Collection Tree Protocol (CTP), a data collection protocol is proposed in [2] and [9]. CTP uses expected transmission count (ETX) for selecting a route from source to destination.

In the research article presented in [6] a rigorous study of various routing protocols for WSN is presented. Classification of routing in WSN with respect to the type of network structure is also discussed here. Khan et al. in [12] also has done a comparative study of three different hierarchical-based routing protocols namely LEACH, PEGASIS and TEEN in their research work. A generic comparison is done considering hop-count, transmission time and count, along with energy consumption as the performance metrics. Researchers in [20] have shown WSN as a combination of static fixed nodes and mobile sink node; they have proposed a mobile node based data communication scheme based on the cost of communication. Pal et al. proposed a simple cluster head selection algorithm[16] named Smart Cluster Head Selection (SCHS). During routing the area is divided into inner and border area. The nodes lying in the inner area can susceptibly become cluster head and the other nodes can act as leaf node. Their simulation results shows that their algorithm woks in a more energy saving way than the LEACH. In the research article[4] they have proposed a routing algorithm based on multi-hop unequal clustering in WSN. The proposed energy efficient routing minimizes the disadvantages of the LEACH protocol.

Boukerche et al. has presented tutorial on various routing schemes in WSN[7]. In their research work they have already proposed an Opportunistic Routing scheme using Discrete Time Markov Chain and also have evaluated the performance of the same. Again a Divide-and-Rule based routing protocol is designed in [13] where fixed number of cluster heads is selected for each round of data transmission. An analysis of various hierarchical routing protocols is presented in [19]. A comparative study of the same is also shown. Moreover Sule et al. have proposed an on demand multicast routing approach[18], which is energy efficient also as far as rapid power consumption is concerned. Han ZhiHui has proposed a routing protocol which is based on artificial ants[10] and has designed ant colony and optimized the same. The protocol is claimed to be improved from energy consumption point of view. The motivation to this research work is to develop a routing strategy, which can be used to generate economic routes for data from, each interested sender senor node to the BS. This proposed technique is an intrinsic part of a fault tolerant framework proposed by Mitra et al. mentioned in [15]. Each node can adapt a stipulated technique to generate the path to the sink. The nodes execute the routing process by estimating the corresponding uplink quality to each neighbour in an energy aware approach.

3 Proposed routing model for WSN

In this section a routing technique for WSN is proposed and discussed in detail. Here the basis of the routing technique is established and assumptions are stated. Dynamic route selection is trivial in WSN and it is a challenge also from routing efficiency point of view. There can be multiple possible routes, which a data packet can use, for reaching its destination; but the agenda over here is the how cost effectiveness of the consequent path. In Fig. 1 the dynamic route selection ambiguity of a node is presented. After this the following sub-sections demonstrate the network model, routing flow chart and the proposed routing algorithm and each of them is explained over here.

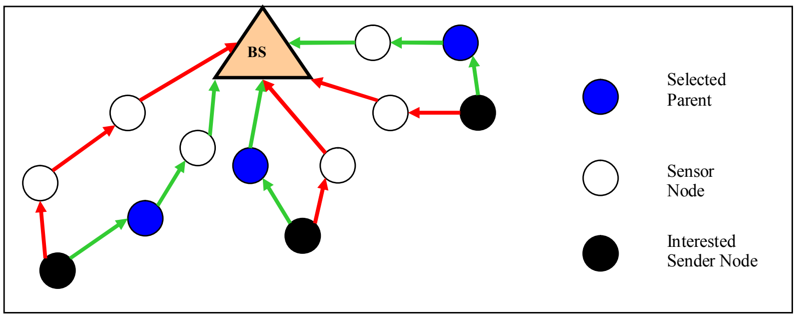

Fig. 1: Route Selection Ambiguity is WSN

3.1 Network model and assumptions

In the current research work WSN consists of static sensor nodes with a fixed transmission range is deployed randomly in an ambient area. It is considered to be analogous to a graph; say $G(S, E)$ where S is a set of sensor nodes and E being the set of edges in between all these sensor nodes. The edge between two nodes only exists if both the nodes are in each others' transmission range. Some edges form a set to make a path from the source to the destination for data transmission. The network model defined over here has a set of n nodes S with the members $S_1, S_2, \cdots S_n$ and E is a set of edges between the sensor nodes. After random deployment of the nodes, in a target area say A, each node S_i performs sensing, transmitting receiving etc. and computation. The node density can be considered as $\rho = n/A$. Now according to the mentioned Euclidean distance given by $e_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$, where $e_{i,j}$ is the link between S_i and S_j. However (x_i, y_i) and (x_j, y_j) are the coordinates of S_i and S_j respectively; this is as per. The area in which the nodes are deployed can be broken up into regions using Voronoi diagram. Each node is identified by its node identification number i.e. node ID. Nodes communicating with some other node are supposed to be the each others' neighbor and one of the neighbors, among all possible neighbors of a node, is a susceptible parent through which the data can be forwarded towards BS. Partition nature of the network is supposed to hierarchical; so the CHs play the role of aggregating and forwarding data packet from leaf nodes to the BS. The energy consumption of these nodes is serious point of concern. In the current research scope it was assumed that each sensor node is static and homogeneous in nature. Route development is done on the basis of Manhattan distance mentioned in Eq. (1). The initial route development was made on the basis of Voronoi distance and the corresponding definition is mentioned in Eq. (2). Here in the algorithm address of node means the node ID. Table 1 contains the detailed meaning of the notations used in the algorithm presented in Fig. 2.

3.2 Routing algorithm

The proposed routing algorithm presented here is actually a path selection strategy from source to destination. The sender wants to push data in such a way that it reaches to the BS. The route selection is done on the basis of some of the significant parameters like, Manhattan distance between two nodes, link quality estimation

```
For each Sender node (i)
{
      Generate Neighbor Table
      For each Neighbor (j)
      {
            Compute Manhattan distance with j Store in MD_i,j;
            Compute f (LQE) of j Store in f (LQE)_i,j ;
            If (MD_i,j < MD_i,j+1)
            {     Then ADD1=ID_j ; k=j;  }
            Else
            {     Then ADD1=ID_j+1; k=j+1;  }
            If (f (LQE)_i,j < f (LQE)_i,j+1)
            {     Then ADD2=ID_j ; t=j;  }
            Else
            {     Then ADD2=ID_j+1 ; t=j+1;  }
      }
            If (ADD1==ADD2==NULL)
            {
                       No Decision made;
                       Continue for next i value;
            }
      If (ADD1==ADD2 and NOT NULL)
            Route data through either k or t;
      Else
      {
            Compute E_ox-k and E_ox-t;
            If (E_ox-k < E_ox-t)
                  Route data through k;
            Else
                  Route data through t;
      }
}
```

Fig. 2: Proposed Adaptive Routing Algorithm

of the current uplink and a comparison of overhearing energy of the current susceptible parents of the sender. Manhattan distance between two nodes is as per as mentioned in Eq. (1), and the distance between two nodes is equal to the Euclidean distance between the two. Assuming a random node S_j the Voronoi region can be evaluated from Eq. (2); here S_j, is the neighbour, which can be one of the susceptible parents and S_k is any other reference point in the set of sensor nodes S. Actually the distance between two neighbors as given by $\|S_i - S_j\|$ should always be less than equal to the distance $\|S_k - S_j\|$ then and only then the node S_j is in the Voronoi region of S_j, mentioned as Vor (S_j). Moreover (x_i, y_i) and (x_j, y_j) are the coordinates of S_j and S_j, where $S_j \in S_i$. NBR, where NBR is neighbour table of S_j. Now link quality estimation for the current uplink is mentioned as $f(LQE)$[17]. Definition of $f(LQE)$ is given by $f(LQE) = \omega_1 ETX + \omega_2 EEC + \omega_3 ENR$ dependant on EEC, ETX and ENR, where,

$$\omega_1 + \omega_2 + \omega_3 = 1, EEC = E_{SPENT}(i, j),$$
$$ETX = hop - count(i, j), ENR = previous - retransmission - count(i).$$

The main target of the routing model is to enable an interested node, to select a neighbour node for becoming a parent with minimum $f(LQE)$ value. For minimizing $f(LQE)$, the objective function, the constraints are given in Eqs. (2), (3), (4) and (5).

$$\text{manhattan distance} = |x_i - x_j| + |y_i - y_j|; \tag{1}$$
$$Vor(S_i) = S_j : distance(S_i, S_j) \leq distance(S_k, S_j), \forall S_k \in S; \tag{2}$$
$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} < |x_i - x_j| + |y_i - y_j|; \tag{3}$$
$$\sqrt{\frac{logn}{+} f(n)\pi n} \leq CR; \tag{4}$$
$$T_{TOTAL} = T_{RECEIVE} + T_{QUEUING} + T_{PROCESS} + T_{PROPAGATE} + T_{TRANMIT} \tag{5}$$

The first condition in Eq. (1) is Manhattan distance and Eq. (2) shows the Voronoi distance among two nodes. Eq. (3), states that the actual Euclidean distance between two nodes is always less than the Manhattan distance, which is obvious. Eq. (4) tells about the critical transmission range of a sensor node, where n nodes are deployed. To route data nodes should be connected and the probability of connectivity $P(connectivity) = 1$, when for the above Eq. (4) the condition $Lim_{n \longrightarrow \infty f(n) = +\infty}$ is true. The total time elapsed T_{TOTAL}, for data to be transmitted, by a sender node is integration of time of receiving, time of queuing, time of processing, time of propagation and time of transmission of the data. Moreover it satisfies Eq. (8), as longer a node works, higher the energy is spent given by ESPENT. According to the proposed algorithm each node willing to transmit data to the receiver evaluates a neighbor with respect to some parameters. Initially $ADD1$ and $ADD2$ are initialized to NULL. First of all each node generates a neighbor list and maintains neighbor count. Each node i selects any j-th neighbor and check two things as mentioned in Eq. (6) and (7) for all the neighbors. Whichever be the TRUE value finally k-th node is stored in $ADD1$ and t-th node is stored $ADD2$ for the minimum value of $MD_{i,j}$ and that of $f(LQE)_{i,j}$ respectively. Finally, after all the iterations both $ADD1$ and $ADD2$ may have some value if not NULL; as no decision is made for NULL value. Now, any one of the node can be selected as a parent to the current sender, by comparing their overhearing-energy consumption satisfying, Eq. (9). Lower overhearing energy means the node has lesser number of interfering nodes.

$$MD_{i,j} < MDi, j + 1 \tag{6}$$

$$f(LQE)_{i,j} < f(LQE)_{i,j+1} \tag{7}$$

$$T_{TOTAL} \propto E_{SPENT} \tag{8}$$

$$E_{OX-k} < E_{OX-t} \tag{9}$$

4 Simulation result and discussion

In this section the results of the implementation of the existing routing schemes for WSN and that of the proposed routing scheme are presented. For the simulation purpose MATLAB version 7.11.0.584 (R2010b) and Java (JDK 7.0) was used. During simulation the route generation was monitored and graphs were generated. Sensor node specification and the simulation environment details are mentioned in the Tables 2 and 3 respectively. During the simulation process 36 to 50 sensor nodes are deployed in a target area ranging from 5050 m^2 to 100100 m^2. For computation of energy consumption some previous calculation table, available in [3] is used. Existing routing protocols like LEACH, CTP, VGA, PEGASIS and LQER were evaluated; performance issues and comparison of them is presented in Table 4.

Table 1: Notation Used

Symbol used	Meaning of the Symbol
CR	Communication range
$MD_{i,j}$	Manhattan Distance between nodes i and j
$f(LQE)_{i,j}$	$f(LQE)$ value for the uplink i to j;
ADD1	System variable for address storage
ADD2	System variable for address storage
NODE-ID	Node identification number of current Neighbor
i, j, k, t	Variables with finite value
E_{OX}-k	Overhearing Energy of the node k
E_{OX}-t	Overhearing Energy of the node t
T_{TOTAL}	Total time elapsed for data transmission
E_{SPENT}	Total energy spent for data transmission

Table 2: Sensor Node Specifications

Parameter	Value
Frequency Range	2.4 C 2.48 GHz
Data Rate	250 Kbps
Current Draw	16 mA @ Receive mode
	17 mA Transmit mode
	8 mA Active mode
	8 μ A Sleep mode

Table 3: Simulation Environment

Parameter	Value
Number of Nodes Deployed	36-50
Area Covered	5050 m^2 to 100100 m^2
Communication Range	15-25 meter
Node Density (ρ)	0.0036 - 1.00 nodes/ m^2
Initial energy of the Nde	0.25 J (250 mJ)
Data Packet Size	30 bytes
Control Packet Size	5-12 bytes

Table 4: Comparison of Routing Protocols

Routing Protocol	Mode of Operation	Classification	Energy Efficiency	Scalability	Data Aggregation
LEACH	Cluster based with random rotation of CH	Hierarchical; node centric	No	Average	Yes
PEGASIS	Employs greedy algorithm; chain based method	Hierarchical; multi-hop	No	Good	No
CTP	ETX based; with link estimation, data path validation and adaptive beaconing	Flat based; Low power data collection	Yes	Good	No
VGA	Cluster based, data aggregation through negotiation	Hierarchical; location-based	Yes	Good	Yes
LQER	Link quality estimation based on dynamic sliding window concept	Data centric, minimum hop based	Yes	Average	No

Fig. 3 shows a comparison of different routing protocols. The scenario in case of LQER is different and better than LEACH in spite of same number of rounds of data transmission. In LQER only 33 percent of the total number of nodes has exhausted their power, which is much less than LEACH. In PEGASIS, after approximate rounds of data transmission, the residual energy of the 94 percent of sensor nodes is approximately below 10 percent. This indicates that almost all the nodes are dying altogether making the WSN defunct. Now in VGA it is observed that approximately 59 percent of the total nodes have consumed their full energy. And in case of CTP protocol the situation is better in comparison to others. In the next part of this section the results related to

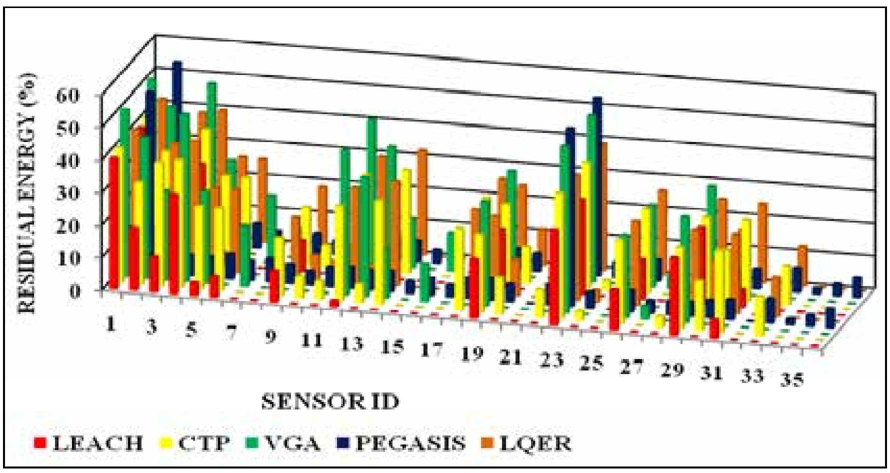

Fig. 3: Comparison of Residual energy for LEACH, CTP, VGA, PEGASIS and LQER

the proposed algorithm is presented. For simulation of the proposed algorithm 50 sensor nodes were deployed in an area of 100 sq. meters, the communication range was supposed to be 25 to 30 meters. The nodes were assumed to be homogeneous. In the subsequent Fig. 4 some of the nodes are demarcated with green circles as the immediate neighbor to the sink (BS) were identified as CH for the other nodes. The nodes demarcated with blue circles in the Fig. 5 represent those nodes, who select an alternative path out of other available paths to BS, depending upon the criteria set by the proposed algorithm. The paths shown in green line are the selected paths and those in red line are secondary available path but not used by them. Node B is observed to select a path having higher hop count, but in the green path the cost accompanied is lesser than the red path. In the Fig. 5 below node A, B and C are the nodes, which remove the parent selection ambiguity by using the proposed routing model. Not only the said nodes but also many other nodes take the routing decision based on the algorithm mentioned in Fig. 2. The corresponding details of route selection for the nodes A, B and C are mentioned next as case I, case II and case III respectively.

Case I. As available in Fig. 5 Node A has two neighbours N_i and N_j, but it selects the latter as its parent even though it is relatively farther from A than N_i but the hop count of N_j to B_S is lesser. The computation conditions for Manhattan distance and the $f(LQE)$ are shown in the inequalities below.

$$MD_{A,N_i} > MD_{A,N_j} \quad (i) andf(LQE)_{A,N_j} < f(LQE)_{A,N_i} \quad (ii)$$
$$ADD1 = ID(N_i) \quad (iii) andADD2 = ID(N_j) \quad (iv)$$
$$\because E_{OX-N_j} < E_{OX-N_i}$$

Therefore, N_j is selected as the parent node through which data is forwarded.

Case II. However the Node B, in Fig. 5, has two neighbours X_i and X_j, and both have same hop count from the BS; but here B selects the node X_i as its parent, it is relatively near to B than X_j. The computation details are shown in the inequalities below.

$$MD_{B,X_i} < MD_{B,X_j} \quad (i) andf(LQE)_{B,X_i} < f(LQE)_{B,X_j} \quad (v)$$
$$ADD1 = ID(N_i) \quad (vi) andADD2 = ID(N_j) \quad (iv)$$
$$\because E_{OX-N_i} < E_{OX-N_j}$$

Therefore, X_j is is selected by B for forwarding data to BS.

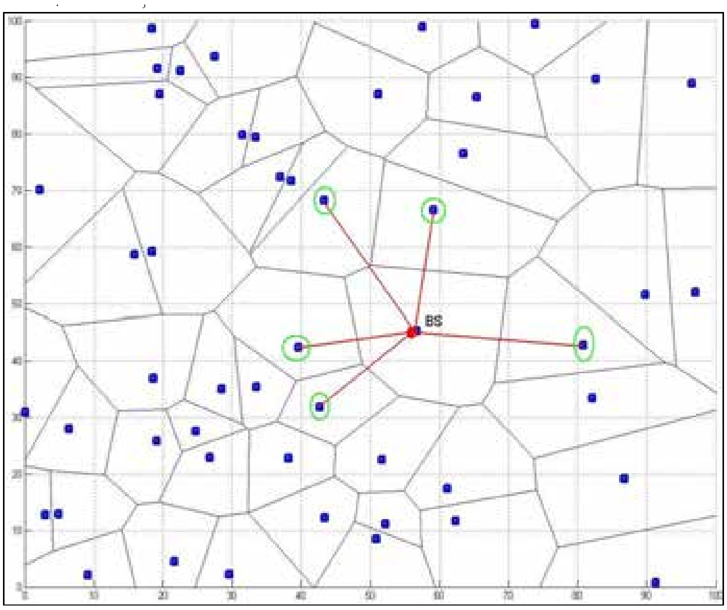

Fig. 4: Random Cluster Heads and BS in WSN

Case III. Node C has two neighbours L_i and L_j, but it selects the latter as its parent even though it is relatively farther from A than L_i but the hop count of L_j to BS is lesser. The computation details are mentioned below.

$$MD_{C,L_i} > MD_{C,L_j} \quad (i) andf(LQE)_{C,L_j} < f(LQE)_{C,L_i} \quad (ii)$$
$$ADD1 = ID(L_i) \quad (iii) andADD2 = ID(L_j) \quad (iv)$$
$$\because E_{OX-L_j} < E_{OX-L_i}$$

Therefore, l_j is selected as the parent node through which data is forwarded.

5 Conclusion

In this research article a comparative analytical study of some of the existing routing protocols namely LEACH, PEGASIS, VGA, LQER and CTP is presented. This paper proposes a novel fault tolerant adaptive routing model, which is energy aware in nature. Simulation results show how the routing scheme performs, as the sensor nodes can select a better path out of available data paths from source to BS. Also this adaptive scheme proves that network lifetime can be enhanced with proper routing scheme. The future scope of this research work lies in implementation of the proposed algorithm in a real life sensor test bed such that the effectiveness of the technique can be well established.

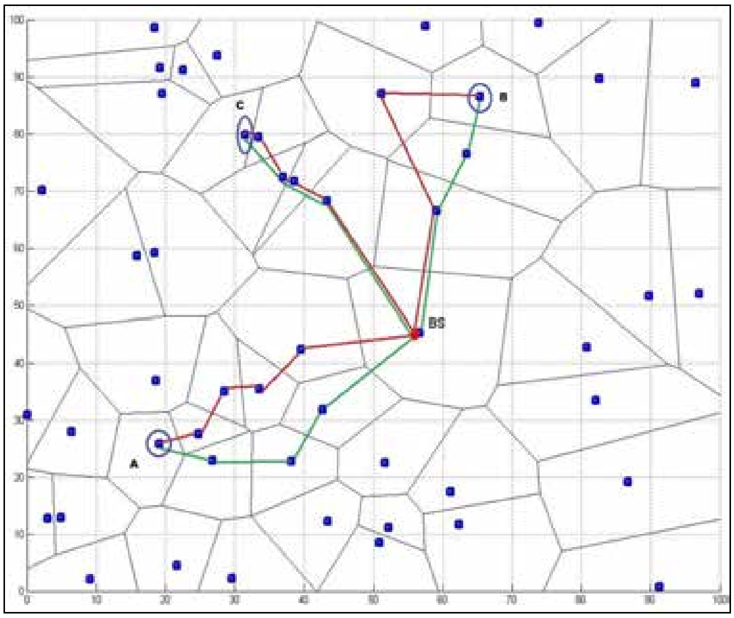

Fig. 5: Alternate Route selection by sensor nodes

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