

An Individual Node Delay Based Efficient Power Aware Routing Protocol for Wireless Heterogeneous Sensor Networks

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Abstract: Wireless Heterogeneous Sensor Networks (WHSNs) are built up of miscellaneous ranges of node transmission and designing an efficient, reliable and scalable routing protocol with intermittent asymmetric links in it is a challenging task. In this paper, we propose an efficient power aware routing scheme for WHSNs, which can provide loop-free, stateless, source-to-sink routing scheme without using prior information about neighbor. It uses both symmetric and asymmetric links to forward data from the source to the sink. The source node broadcasts location information to all its neighbor nodes. Each neighbor node calculates a delay slot based on the information obtained from the source to forward its power value to it. The node that has a minimum delay slot forwards the power earlier than the other nodes during contention phase and the delay slot is used to suppress the selection of unsuitable low-power nodes at that time. We also prove that our protocol is loop-free assuming no failures in greedy forwarding. By simulations we show that our protocol significantly outperforms the other existing protocols in WHSNs.

Keywords: Asymmetric, Heterogeneous, Power aware routing, Symmetric, Wireless sensor networks.

1. Introduction

Power aware routing in Wireless Sensor Networks (WSNs) has each node that forwards packets only based on the power of directed neighbors. This is an attractive scheme to prolong the lifetime of resource-constrained sensor networks. The localized power aware routing eliminates static route establishment indicating the advantages of minimum memory requirement in each node and high scalability in widely distributed sensor networks. In conventional power aware routing schemes, each node is assumed to have equal transmission range and their protocols are very useful in WSNs when network topology changes slowly or invariantly because of simple hop-node selection process. However in many applications, nodes are dynamic where it may not have the same sensing power and transmission range. This irregularity in nodes create WHSNs that has asymmetric links in between them and the conventional power aware routing protocols suffer from at least three drawbacks. First, the neighbor nodes can cause unacceptable communication overhead and results in significant energy expenditure. Second, a suitable neighbor node may not get a chance to be selected as hop-node because of its heterogenic nature. Third, the lifetime of the entire network becomes critical due to significant energy expenditure.

In this paper, we address the problem of providing energy-efficient power aware routing scheme for wireless heterogeneous sensor networks in which each node has an asymmetric link. Without prior knowledge of neighbors, our proposed protocol try to create an efficient data path by delivering each packet to the sink and it works as follows: each source node uses a location message to detect its best-hop node. This location message leads a way to calculate the delay slot value in receiver node level. Receiver node produces their reply message based on the calculated delay slot. Reply message contains the receiver ID and its power. If another neighbor node receives a reply message of a receiver node, it either forwards the message again by appending its node ID or truncates the message by re-producing a new reply message. New reply message contains the new receiver ID and its power. In this way, the reply message generated by one or more nodes will reach the source even if an asymmetric link exists in between them. The key contributions of this paper are summarized as follows:

- We propose an efficient power aware routing scheme for wireless heterogeneous sensor networks, which can provide stateless, energy efficient sensor-to-sink routing at low communication overhead without using prior neighbor information.
- We show that our proposed scheme is loop-free under greedy forwarding mode with an assumption of zero failures in forwarding process.
- We assess the performance of our proposed scheme in three different scenarios: mobile sensor nodes, non-zero packet loss and random sleeping.

One of the major issues is hot-spot which is not considered in this work since the main objective is identifying a best-hop node based on individual node power in the existence of asymmetric links. Various researches have been extensively done concerning hot-spot problems in WSNs [1] [2] [3]. So we are generally addressing the abandoned issues.

The rest of the paper is organized as follows: Section 2 is about the related work which gives the detailed survey of various routing strategies in both homogeneous and heterogeneous sensor networks. Section 3 describes the preliminaries and system model. The proposed protocol is discussed in Section 4. In Section 5, we discuss about the simulation analysis and the performance evaluation of our proposed protocol. We conclude the conclusion and future work in Section 6.

2. Related Work

Data communication is a major source of energy consumption in WSN. Thus, it is essential to design power-aware routing schemes to improve energy efficient source-to-sink communication and prolong the lifetime of the network. In the past few eras, extensive research has been made in routing protocols. In this section, we give an overview of existing routing protocols in both wireless sensor networks and wireless heterogeneous sensor networks.

2.1 Routing Protocols in Wireless Homogeneous Sensor Networks

Routing in homogeneous sensor networks have been explored by many routing protocols. Among them, the main perception is that, all sensors have the same capabilities in terms of communication, energy, computation, reliability etc. Stojmenovic and Lin et al. [4] have designated three different fully localized algorithms to diminish energy consumption. A survey about position based sensor routing protocols is explained in [5]. Exploiting the network lifetime is proposed in [6]. Energy efficient beaconless geographic forwarding [7] is an energy efficient node-to-sink data forwarding scheme which uses the idea of optimum relay search region to identify a best-hop node. MFR protocol proposed by Takagi et al. and Kleinrock et al. [8] is the initial geographic routing algorithm in which each node selects its forwarder that has concentrated progress. In [9], Wu and Candan et al. proposed GPER for power-efficient routing. Packet Reception Rate (PRR) and transmission distance (DIST) is considered based on realistic physical layer model and $PRR \times DIST$ is taken as a decision metric in [10]. Gagneja et al. [11] proposed quality oriented two-tier clustering scheme for sensor networks. Heissenbuttel et al. suggested a protocol called Beaconless Routing (BLR) [12] and it uses the idea termed Dynamic Forwarding Delay (DFD). Fußler et al. proposed an active selection method and the approach is called as Contention-based forwarding for mobile ad-hoc networks [13] which uses several control messages to identify the forwarding nodes. The implicit geographical forwarding (IGF) was proposed by Blum et al. [14] and his idea is integrating beaconless routing with IEEE 802.11 MAC layer. However most of the geographic routing protocols works on the basis of hop-count, which is not efficient in terms of power awareness.

Most of the routing protocols practice greedy forwarding, but it struggles when a node cannot find a better neighbor than itself. This situation grounds local minimum. To improve from a local minimum, few protocols like GFG [15], GPSR [16] and GOAFR [17] uses planer sub-graph when a local minimum is encountered. Another significant aspect in WSN is called guaranteed data delivery. The strength and weakness of wireless sensors in the view of guaranteed data delivery is exploited in [18]. Most of the geographic routing algorithms [19] [20] [21] use greedy forwarding as well as recovery nodes to provide guaranteed data delivery depending on the network topology. However, in the above mentioned applications, heterogeneous sensors with different capabilities are deployed. So routing protocols of WSNs may be inappropriate to WHSNs, as it will not take advantage of the diversity of the sensors.

2.2 Routing Protocols in Wireless Heterogeneous Sensor Networks

In the literature, few routing protocols are proposed for WHSNs [22] [23] [24] [25] [26] where the deployed sensor nodes are divided into powerful and less powerful ones. Powerful nodes are considered as cluster heads in a group and less powerful nodes become data collection centers. These approaches make a two-tier design of a single protocol: The intra-cluster protocol is used in between data centers and cluster heads. Inter-cluster protocol is used to transfer the data from cluster head to the sink. However in the above mentioned protocols, the capabilities of individual sensors are not fully explored and asymmetric links are not fully utilized. Gagneja et al. [27] suggested an improved energy efficient localized routing by selecting a minimum number of hop-nodes. Deploying minimum number of high-end heterogeneous sensors instead of deploying maximum low-end homogeneous sensors is concentrated in [28]. This scheme provides a robust network performance. In [29] Xiao Chen et al. proposed ProHet which uses symmetric and asymmetric links in sensor networks and achieves high data delivery rate. It explores the relationship among neighboring nodes whereas it is missing in [30]. However ProHet does not consider individual node power which is an important issue in heterogeneity.

Designing an efficient routing protocol in the existence of varying network connectivity among the sensor nodes is a challengeable task. Most of the existing routing protocols assume that the network connections are homogeneous. But, the aforementioned concept cannot always be true in real time. So designing an efficient routing under the basis of heterogeneity is a vital requirement. This is a major motivation of our work which proves that our protocol is robust in dynamic environments.

3. Network Preliminaries

3.1 Definitions of Neighbor Relationships

A WHSN can be defined mathematically by a directed graph $G = \{V, E\}$, where V is a set of sensor nodes and E is a set of links in the network. There are four different relationships in the heterogeneous sensor network: (1) In-out neighbor; (2) In-neighbor; (3) Out-neighbor; and (4) Non-neighbor. For example, let us consider two nodes A and B , as shown in Figure 1.A., if $A \rightarrow B$ and $B \rightarrow A$ then A and B are in-out neighbor to each other even though A is having radius r_1 and B is having radius r_2 . On the other hand as shown in Figure 1.D., neither $A \rightarrow B$ nor $B \rightarrow A$ are non-neighbors to each other. Figure 1(b) shows the relationship of an in-neighbor of B from A and an out-neighbor of A from B . As per Figure 1(c), B is an in-neighbor of A and A is an out-neighbor of B .

3.2 Energy Model

The first order radio model [31] is widely used for evaluating energy consumption in homogeneous sensor networks. We used the modified first order radio model to evaluate the energy consumption of our work. We assume that no obstacle is available in between the different sensor nodes to restrict the radio communication. As per first order radio model, the total energy spent for transmitting 1-bit data is the sum of energy spent by a transmitter node and the receiver node. The required energy for transmitting 1-bit data over distance d is

$E_{transmit}(d) = x_{11} + x_2 d^k$, where x_{11} is the total energy spent by the transmitter node, x_2 is the amplification process done at source end and k is the propagation loss exponent. In the receiver side, the required energy for receiving 1-bit data is $E_{receive}(d) = x_{12}$, where x_{12} is the energy spent by the receiver node. Therefore, the total energy consumed by 1-bit to travel from the transmitter to receiver over distance d is

$$E_{total}(d) = x_{11} + x_2 d^k + x_{12} \equiv x_1 + x_2 d^k, \quad (1)$$

where $x_1 = x_{11} + x_{12}$.

In this work, we considered the energy consumption of intermittent nodes along with the parameters specified in first order radio model. Because of its heterogenic nature, few intermittent nodes may require data transmission from the source node to hop-node. Hence, Equation (1) can be modified as follows.

$$E_{total}(d) = E_{transmit}(d) + E_{receive}(d) + E_{intermittent}(d) \quad (2)$$

$E_{intermittent}(d)$ is the total energy spent by the number of intermittent nodes. Let us denote $E_{intermittent}(d) = x_{13}$ and elaborate Equation (2) as follows.

$$E_{total}(d) = x_1 + x_2 d^k + x_{13}. \quad (3)$$

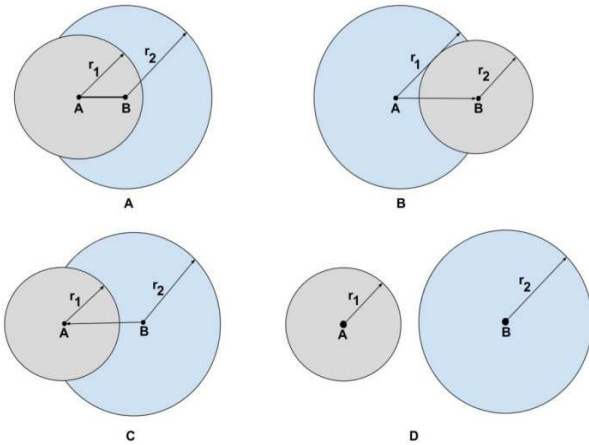


Figure 1. Four different relationships among the nodes in Wireless Heterogeneous Sensor Networks

3.3 Network Model

In this work, we have assumed that no two nodes can be placed at the same location. Also it is assumed that every node has heterogeneous radio transmission ranges $r_1, r_2, r_3 \dots r_n$ and $r_1 \neq r_2$. Each node has knowledge its own location as well as the location of the sink from the time of deployment. In this model, Unit Disk Graph (UDG) communication method is used to analyze the performance of the proposed scheme. As per UDG, any two nodes u_1 and u_2 can transfer a packet to each other only if $|u_1 u_2| \leq r_1 \cap r_2$, where $|u_1 u_2|$ is the Euclidean distance between u_1 and u_2 .

4. The Proposed Protocol

The proposed protocol works in two stages: (1) source broadcast stage and (2) analyzing reply messages stage. In source broadcast stage, the source node broadcasts the source ID and its location information (x_j, y_j) . The node which receives a broadcast message, it calculates the delay slot based on equation (4). For any node $v \in R_u$, instead of forwarding the reply message immediately after receiving a

location message from node u , node v forwards its reply message with an assigned delay slot $\delta_{slot(v \rightarrow u)}$. Delay slot of an individual node can be calculated by using Pythagorean Theorem. Let us assume the location of source and receiver nodes as (x_1, y_1) and (x_2, y_2) respectively in the 2D plane. The delay slot δ_{slot} can be calculated as follows.

$$\delta_{slot} = \left\lceil \left[\frac{1}{(x_2 - x_1)^2 + (y_2 - y_1)^2} \right] * 100 \right\rceil \quad (4)$$

The delay computed by equation (4) guarantees that, no nodes can have the same delay slot based on the assumption in the network model. Let us consider the location of source node s , receiver1 r_1 and receiver2 r_2 as (10.45, 11.82), (16.82, 14.93) and (13.28, 15.37) respectively. The calculated delay slot of r_1 is

$$\delta_{slot(r1)} = \left\lceil \left[\frac{1}{(16.82 - 10.45)^2 + (14.93 - 11.82)^2} \right] * 100 \right\rceil = 14 \text{ seconds and delay slot of } r_2 \text{ is}$$

$$\delta_{slot(r2)} = \left\lceil \left[\frac{1}{(13.28 - 10.45)^2 + (15.37 - 11.82)^2} \right] * 100 \right\rceil = 22 \text{ seconds.}$$

It is known that delay slot of any two nodes cannot be the same because $|sr_1| \neq |sr_2|$. This method controls collision of reply messages, which can be one of the major causes of energy expenditure in WSN. After the delay slot, the receiver node forwards the reply message which contains source ID, receiver ID and its power. Meanwhile, if another receiver node receives the reply message produced by a node before its delay slot, it checks whether the received power value is greater than its own power or not. If it is greater, the receiver appends the node ID as an intermittent ID and forwards it towards the next source. Otherwise, the received reply is truncated immediately by the new node and this node sets its own node ID and power value instead of the old reply message. This updated reply message is again forwarded towards the source. In this way, each receiver node either forwards the reply message or re-produces the new node ID and power value. The entire work is explained in algorithm 1.

Algorithm 1: Source Broadcast Stage

- Event 1** : Source Node S broadcasts a location message with Source Node ID.
- Event 2** : Nodes $\{A_1, A_2, A_3, \dots, A_n\}$ receives a location message & calculates its delay slot δ_{slot} using equation (4).
- 2.1** : If calculated value of Node $A_1 = \delta_{slot}$ then
- 2.1.1**: wait until δ_{slot} expires.
- 2.1.2**: Forward reply with Receiver Node ID and Power value (A_1) towards S .
- 2.1.3**: end if
- Event 3** : If Neighbor Node A_2 receives reply (A_1) then
- 3.1** : If (Power value (A_1) > Power value (A_2)) then
- 3.1.1**: Append Intermittent Node ID and Forward the same reply.
- 3.1.2**: end if
- 3.2** : else
- 3.2.1**: Truncate Receiver Node ID and Power value (A_1)
- 3.2.2**: Update and Forward New Receiver Node ID and New Power value (A_2) towards S .

3.3 : end else

3.4 : end if

Event 4 : If reply reaches Source Node S then

4.1 : do Queue [Reply];

4.2 : end if.

In WHSNs, if a reply message that is originated from receiver node A_i is appended with one or more intermittent ID, then it is known that, source S is an in-neighbor to node A_i where A_i is an out-neighbor to source S . Hence, a direct reply transmission from A_i to S is not possible. Our proposed scheme eliminates this difficulty by selecting few intermittent nodes to establish a data-path between A_i to S . Due to heterogeneity among the nodes, few intermittent nodes are essential to complete the sensor-to-sink data communication process. On the other hand, if a reply message from A_i is not appended by any intermittent nodes, then A_i is an in-out neighbor to source S . In this scenario, direct communication between source node and receiver node is possible. A sample sensor-to-sensor data transmission based on our proposed scheme is shown Figure 2.

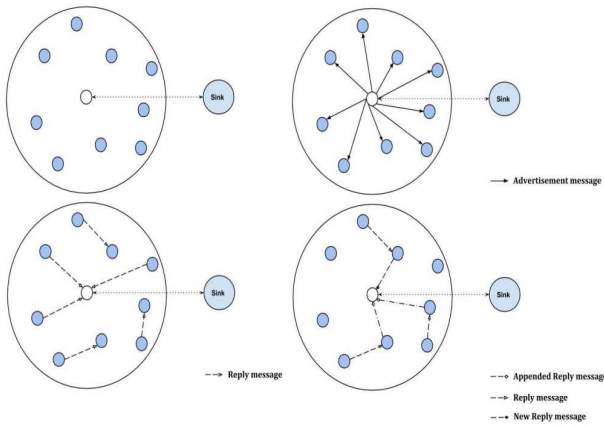


Figure 2. Sensor-to-sensor communication model based on the proposed protocol

Stage two starts after successful reception of reply messages from several receiver nodes. The source node has to select one of the receiver nodes as best-hop and should unicast the data. In this analysis stage, some filtering methods are employed. If the same receiver ID is appended by different intermittent ID, then hop count metric scheme is used to select one data-path where hop-count should be the minimum. In worst case, if hop-count metric is also the same, then choose any one of the data-paths randomly. In some cases, few receiver ID may be recorded directly by the receiver node (*i.e.* in-out neighbor) and also by some intermittent nodes (*i.e.* in neighbor). In this case, the filtering method gives priority to in-out neighbor relationship. This is shown in figure 3. Even though multiple data-paths exist in between v and u , direct communication is always preferred for selection and other data-paths are eliminated. Some sample value recorded at source node is shown in table 1. The filtering process is executed in table 2.

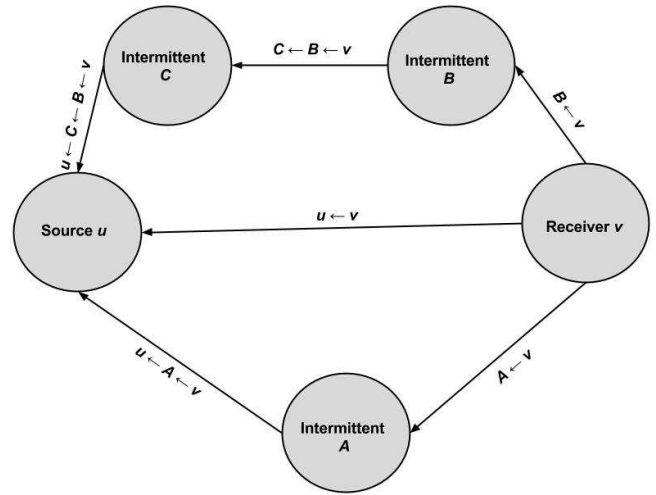


Figure 3. Multiple data-path communication models between node v and u

Table 1. Sample value recorded from a source after broadcasting a location message (Algorithm 1)

Source ID (10.58, 14.21)	Receiver ID	Power	Appended Node(s)
(A_018)	A_026	84.93	A_026←A_020
(A_018)	A_021	53.91	A_021←A_082←A_089
(A_018)	A_072	96.74	A_072←A_09
(A_018)	A_028	48.46	A_028←A_071
(A_018)	A_039	83.92	A_039←A_010←A_048
(A_018)	A_028(1)	48.46(1)	A_028
(A_018)	A_072(1)	96.74(1)	A_072←A_082

Table 2. Sample value recorded from a source after filtering (Before applying Algorithm 2)

Source ID (10.58,14.21)	Receiver ID	Power	Appended Node(s)
(A_018)	A_026	84.93	A_026←A_020
(A_018)	A_021	53.91	A_021←A_082←A_089
(A_018)	A_072	96.74	A_072←A_09
(A_018)	A_028	48.46	A_028
(A_018)	A_039	83.92	A_039←A_010←A_048

After the filtering process, the source node uses an internal sorting algorithm to find the best-hop node. Sorting algorithm is explained in algorithm 2. These steps will be repeated until the message reaches the sink.

Algorithm 2. Sorting at Source Node

1. **Input:** A Queue list 'L' contains {{Receiver ID, /* Optional */Intermittent ID}+Power}
2. **Pre-condition:** An unsorted queue list 'L'
3. **Loop Invariant:** Identify MAX={{Receiver ID, /* Optional */Intermittent ID}+Power}
4. **Assume:** i, j, n, MIN: float variables.
5. Calculate n = Number of elements in Queue list 'L'
6. for(j=0;j <n; j++) {
7. MIN=j;
8. for(i=j+1, i <n; i++) {

9. if(Queue[i] < Queue[MIN]) {
10. MIN=i;} }
11. If(MIN!=j)
12. { swap(Queue[j], Queue[MIN]) }
13. **Select:** Best-hop = Queue[n]
14. **Post-condition:** A list 'L' contains sorted { {Power}, Receiver ID,/* Optional *//Intermittent ID }
15. End algorithm.

The sorted values are shown in table 3. As per our work, A_072 is selected as the best-hop and the intermittent node as A_09. It is necessary to take an intermittent node here; otherwise source node cannot reach best-hop.

Table 3. Source data after executing an algorithm 2

Source ID (10.58,14.21)	Receiver ID	Power	Appended Node(s)
(A_018)	A_028	48.46	A_028
(A_018)	A_021	53.91	A_021←A_082←A_089
(A_018)	A_039	83.92	A_039←A_010←A_048
(A_018)	A_026	84.93	A_026←A_020
(A_018)	A_072	96.74	A_072←A_09

5. Simulation and Analysis of the Proposed Protocol

In this section, we analyze our proposed protocol based on the simplified MAC considering zero packet loss, zero greedy failure and non-uniform node deployment in unit disk graph model.

5.1 Definition of Progress and Advance

Progress and *advance* [32] are used to distinguish different routing schemes in WSN. Suppose that data is forwarded from source node u to hop-node v towards the sink s . Progress is denoted as $Progress(u,v)$ and is defined as the distance of node u and v on the straight line that passes through node u and sink s . Advance is denoted by $Advance(u,v)$, which is the difference between $|us|$ and $|vs|$.

$$Progress(u,v) = |uv| \cos(\angle uvs) \quad (5)$$

$$Advance(u,v) = |us| - |vs| \quad (6)$$

We use energy consumption on progress ratio and advance ratio to measure the energy consumption of our proposed protocol. Let $\eta_{Progress}(u,v)$ and $\eta_{Advance}(u,v)$ be the energy consumption on progress ratio and the energy consumption on advance ratio for forwarding 1-bit data from node u to v , respectively. These are defined as,

$$\begin{aligned} \eta_{Progress}(u,v) &= \frac{E_{transmit}(v \leftarrow u) + E_{receive}(v \leftarrow u) + E_{intermittent}(v \leftarrow u)}{Progress(u,v)} \\ &= \frac{x_1 + x_2 |uv|^k}{|uv| \cos(\angle uvs)} + intermittent(u \leftarrow v) \end{aligned} \quad (7)$$

$$\begin{aligned} \eta_{Advance}(u,v) &= \frac{E_{transmit}(v \leftarrow u) + E_{receive}(v \leftarrow u) + E_{intermittent}(v \leftarrow u)}{Advance(u,v)} \\ &= \frac{x_1 + x_2 |uv|^k}{|us| - |vs|} + intermittent(v \leftarrow u) \end{aligned} \quad (8)$$

5.2 Guaranteed Data Delivery from Source – to – Sink

As shown in figure 4, let us denote the shortest distance between source u and sink s as $|us|$. If a hop-node $v \in R_u$, then $|vs| < |us|$ because no nodes are located at the same location. Therefore, $Advance(u,v) = |us| - |vs| > 0$ means that each node is gets some positive advance. Let $\overrightarrow{u_0 u_1 u_2 \dots u_m \dots u_{n-1} u_n}$ be the routing path to reach packets from u_0 to u_n . For any intermediate node u_m advance can be calculated as $Advance(u_m, u_n) = |u_n s| - |u_m s| < 0$, which means that u_m cannot forward its packet to u_n meaning that guaranteed data delivery holds.

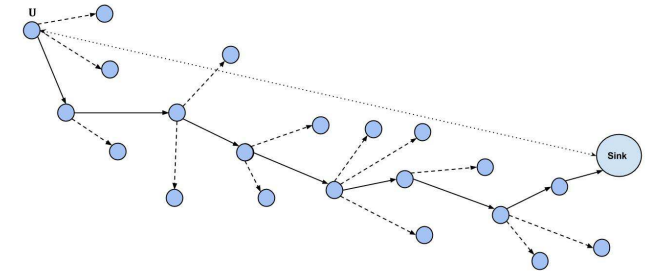


Figure 4. Illustration of loop-free forwarding in the proposed protocol

5.3 Extension to Lossy Sensor Networks

Packets may be lost due to many reasons such as collision, data error or reduction of signal strength in the receiver end. To analyze the behavior of data loss, *packet reception rate* (PRR) is used to measure the quality of unreliable communication links. PRR can be defined as the ratio of the measure of successful transmissions from u to v to the total measure of transmissions from u to v . Let $PRR(u,v)$ be the packet reception rate for the communication link from $u \rightarrow v$. The expected success rate of successful packet transmission is $[PRR(u,v)]^{-1}$. If a packet is lost before reaching the receiver antenna, the same amount of energy is dissipated by the receiver. Therefore, the relay process of 1-bit data from $u \rightarrow v$ can be modeled as,

$$E_{total}(u \rightarrow v) \approx \frac{E_{transmit}(v \leftarrow u) + E_{receive}(v \leftarrow u) + E_{intermittent}(v \leftarrow u)}{PRR(u,v)} \quad (9)$$

As per energy consumption over advance ratio which is denoted by $\eta_{Advance}(u,v)$, the above equation can be remodeled as,

$$E(\eta_{Advance}(u,v)) \approx \frac{E_{transmit}(v \leftarrow u) + E_{receive}(v \leftarrow u) + E_{intermittent}(v \leftarrow u)}{PRR(u,v) * Advance(u,v)} \quad (10)$$

$$\approx PRR(u,v)^{-1} * \frac{E_{transmit}(v \leftarrow u) + E_{receive}(v \leftarrow u) + E_{intermittent}(v \leftarrow u)}{Advance(u,v)} \quad (11)$$

As per Equation (11), energy consumption over advance ratio is highly reliable in lossy sensor networks. To look the reality, we adopt this motivation in the simulation of random walk and random sleep analysis.

5.4 Simulation Settings

As per radio frequency communication law, we have designed a WHSN package based on NS2 [33]. In our simulation, 500 independent sensor nodes are randomly deployed in 5000 $m \times 1500 m$ area. Each sensor node can have different transmission ranges varying from 10m to 25m. The sink is placed at the center of the test bed. We have used three different scenarios to evaluate the performance of the proposed work. The data transmission rate of nodes is in the range of 250 *kbps* and is disseminated in ISM band. The sink is assumed to have an infinite power supply. A single source node can generate one packet per second. Packet size is 80 *bytes*, and the overall simulation setup time is 50 *minutes*. We use the modified first order radio model to compute energy consumption. The parameter values used in the simulations are presented in table 4.

Table 4. Simulation settings

Network Area	5000 $m \times 1500 m$
Total Number of Sensor Nodes	500
Data Rate at MAC layer	250 <i>kbps</i>
Topology Configuration	Randomized
Overall Simulation Time	50 <i>minutes</i>
Transmission Range	10 <i>m</i> to 25 <i>m</i>

- **Varying Active Nodes Scenario:** Here we introduced a method that each sensor node is either in active or inactive mode. The probability of active mode and inactive mode is ρ and $1-\rho$ respectively. The major consideration here is every sensor node cannot be active throughout the simulation.
- **Random Walk Scenario:** Every sensor node takes a new location in a Euclidean plane according to Random Walk Mobility Model. A sensor can select its own new location by choosing its speed and direction from the range [*minimum speed: 0, maximum speed: 2π*]. Every node movement continues for an interval time of 10 seconds. New speed and direction can be recorded at the end of each interval time.
- **Random Sleep Wake up Scenario:** A Random Independent Sleeping (RIS) [34] scheme proposed in is hired in our work to extend the overall network lifetime. This RIS scheme splits the entire simulation time into ζ_{sleep} intervals. At the beginning of each interval, each node works actively with probability value ρ and sleeps with a probability $1 - \rho$. This sleep and wake up cycle is decided by ρ .

For performance analysis, in addition to our proposed protocol, we have implemented two more routing protocols used in WHSN: ProHet and EBGR. ProHet is a two-way communication model based probabilistic routing protocol which uses periodic beacon messages to forward data from a source node to sink. It handles asymmetric links that exist in the heterogeneous network by finding a reverse path. Flooding is a major problem in ProHet caused by periodic beacon messages. EBGR is a beaconless energy efficient protocol which uses an optimum relay region to find its best-hop. EBGR protocol uses location information to represent its optimum relay region. If no forward nodes are available in a source's optimum relay region, then this protocol uses a time stamp called T_{max} , to enter into recovery mode. In our

analysis, beaconless greedy forwarding mode is denoted as EBGR-1 and beaconless recovery mode is denoted as EBGR-2. The principal MAC protocol is IEEE 802.11, and the outline of the MAC protocol is defined as follows: For ProHet, the handshake function between source and hop is established by a beacon frame. Our proposed protocol uses location broadcast/reply handshaking for selecting and reducing packet collisions. The beacon message is set to 20 *bytes*. The location message length is 15 *bytes* and the reply message length is 20 *bytes*. The length of RTS message in EBGR is 25 *bytes* and CTS message is 20 *bytes*. For the parameter settings in our proposed protocol, the delay slot (δ_{slot}) is calculated by using Equation (4). For the energy model which is described in the preliminary, the energy consumed by the transmitter source on transmitting or receiving 1-bit data (i.e., x_{11} and x_{12}) is set to 50 *nJ/bit*, the transmitting amplifier (x_2) is set to 10 *pJ/bit/m²*, and the propagation loss exponent (k) is set to 2. The energy spent by the intermittent nodes x_{13} is 1 *nJ/bit*. In each simulation, 20 nodes are selected as source nodes. The simulation does not complete until the sink accepts all data packets generated in the network, and the simulation results are an average of 50 independent runs.

5.5 Performance Analysis of Proposed Protocol under Varying Active Nodes

In this simulation, sensor node is able to send and receive messages only if the node is in active mode ρ . We first analyze the delivery ratio of the above mentioned protocols. As can be seen from Figure 5(a), the delivery ratio of our proposed protocol is better than ProHet and EBGR 1 and 2. ProHet struggles to make its two-way communication model (p_1, p_2) because of low number of active nodes at the initial level. When the number of active nodes is increases, the delivery ratios of both the protocols are increasing. When the number of active nodes is greater than 60%, both protocols are getting almost same delivery ratio. EBGR-1 shows low delivery ratio at initial and better performance at the end. It shows that, EBGR is completely relying on the number of active nodes in its optimum relay region. Anyhow EBGR-2 tends to reduce forwarder node selection time by protesting a node to become a hop-node. This hop-node may not be a best-hop always. So as far as low active nodes and minimum turnaround time, EBGR-2 is working better than EBGR-1. In contrast, our proposed protocol collects individual node power value from various neighbor nodes using delay factor. It ensures minimum level of collision at the source level. So source node easily identifies its best-hop and forwards the data. The average packet delivery ratio of EBGR-1, EBGR-2, ProHet and our proposed protocol is 86.49, 89.19, 91.98 and 92.72 in terms of percentage.

Latency of the proposed protocol is analyzed in terms of seconds and shown in Figure 5(b). Comparative analysis shows that, our proposed protocol and ProHet gives minimum latency than EBGR-1 and 2. The major reason is, EBGR-1 does not get sufficient hop-nodes inside the optimum relay region. EBGR-2 selects some unqualified nodes as its best-hop, but connectivity problem arises due to heterogeneous hop-nodes. So EBGR-1 and EBGR-2 shows maximum and more over same latency in this analysis. Our proposed protocol and ProHet shows more delay at the beginning, but later it reduced because of available active

hop-nodes. The average latency of EBGR-1, EBGR-2, ProHet and our proposed protocol is 37.77, 37.77, 37.62 and 37.59 in terms of seconds.

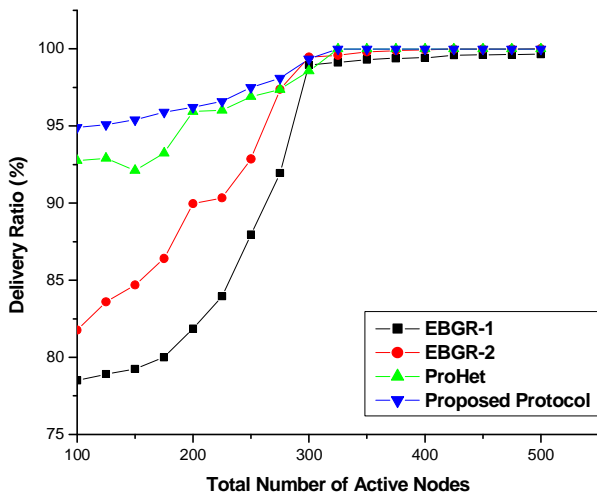


Figure 5(a). Delivery ratio analysis of proposed protocol under varying active nodes

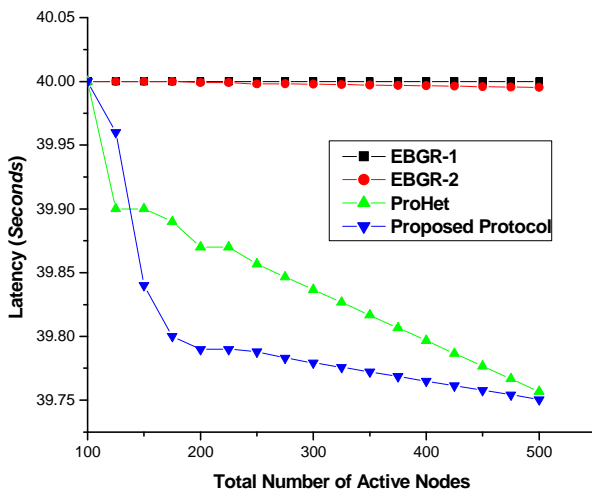


Figure 5(b). Latency analysis of proposed protocol under varying active nodes

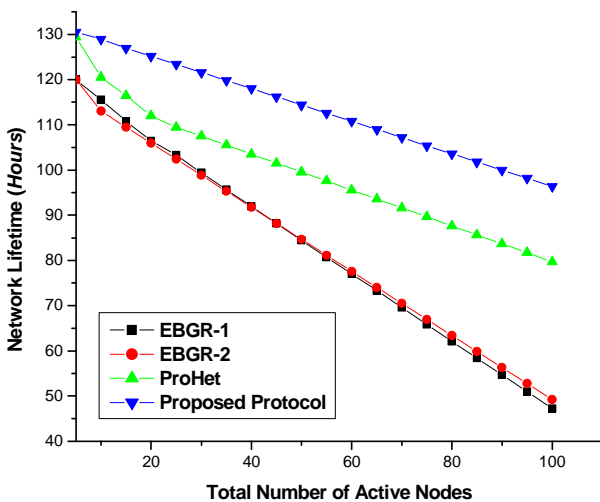


Figure 5(c). Lifetime analysis of proposed protocol under varying active nodes

Lifetime analysis is shown in Figure 5 (c). Here we are varying the total number of active nodes from 0 to 100. Due to heterogenic nodes in a Euclidean plane, EBGR-1 and 2

loses their energy at the initial time. So the overall lifetime of EBGR-1 and 2 is low than ProHet and our proposed protocol. ProHet forwards the same copy of data to two receivers. Beacon messages are also becoming a major energy conserving factor. Thus ProHet utilizes more energy than our proposed protocol.

5.6 Performance analysis of proposed protocol under random walk

In this simulation, we set the dynamic network topology by setting random walk in the euclidean plane. The parameters of the Random Walk Mobility Model are set as follows: *minspeed* is set to 0.0 *meter/second*, and *maxspeed* is 5.0 *meter/second* to provide different levels of mobility. Figure 6(a) shows the packet delivery ratio which is the sum of the total number of packets received against total number of packets propagated. When the node movement greater than 70% *i.e.* approximately 3.50 *meter/second*, all the protocols are showing low packet delivery ratio. EBGR-1 is showing better delivery ratio against EBGR-2, because EBGR-1 chooses a best-hop in its relay region. Our proposed protocol and ProHet shows closely related data delivery in random node movement. At high node movement speed, beacon and location messages are outdated quickly. This is reflected in delivery ratio and latency analysis (Figure 6 (b)).

Total lifetime of a network is analyzed in Figure 6 (c). The RTS/CTS frames of EBGR-1 and EBGR-2 is becoming useless at high node movement speed. So EBGR protocol spends more power to establish some reliable routes. This makes minimum lifetime at the end. Periodic beacon frames in ProHet consumes more power than our proposed protocol. It uses beacon-flood to identify a probabilistic best-hop node. If the node movement is greater than 35 *meter/second*, the collected neighborhood information becomes outdated. The reason is that most of the beacon messages are not received by some of the suitable forwarder nodes. So establishment of data-path becomes more critical in ProHet. Better lifetime is obtained from our proposed protocol in random walk scenario. Our protocol only uses a single-hop communication instead of two receivers in ProHet. Our approach uses unicast forward scheme instead of multicast in ProHet. So lifetime of our protocol is better than ProHet.

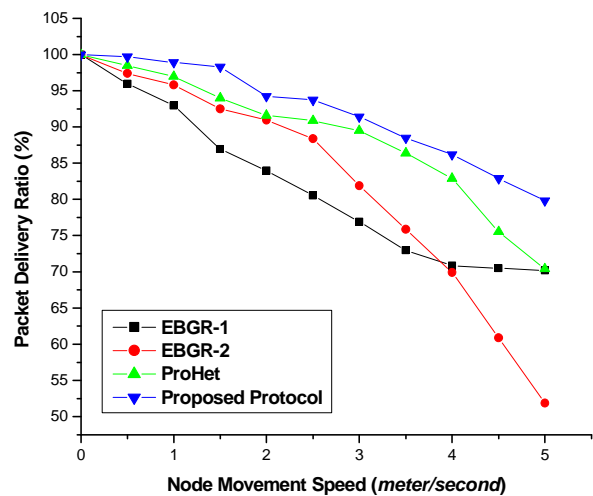


Figure 6(a). Delivery ratio analysis of proposed protocol under random walk

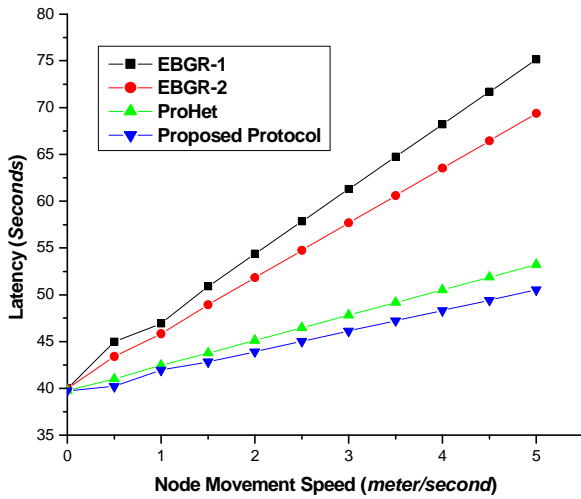


Figure 6(b). Latency analysis of proposed protocol under random walk

5.7 Performance of proposed protocol under random sleep

Random Sleep and Wake up (RIS) is integrated in order to measure the performance of simulated protocols (T_{shift}). As per this scenario, ProHet broadcasts a beacon message only when it shifts between *sleep* and *active* state. For EBGR and our proposed protocol, each node broadcasts the RTS / CTS / location messages when it works in an *active* state. Neighbor node will be active in the selection process if its remaining active time is large enough to complete forwarding a data packet.

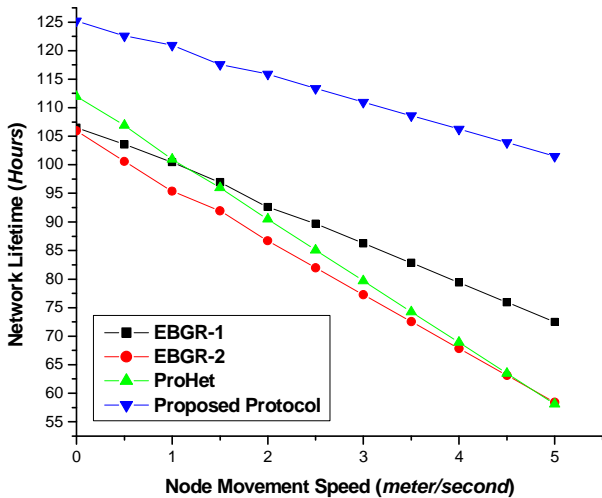


Figure 6(c). Lifetime analysis of proposed protocol under random walk

Figure 7 (a) shows the delivery ratio of all the mentioned protocols. When the sleeping probability is less than 60% the proposed protocol performs well, because most of the nodes work in an active state. At higher sleeping probability, EBGR and ProHet shows higher packet loss rate. If the node sleeping probability is more than 60%, the latency (Figure 7 (b)) and surprisingly lifetime (Figure 7 (c)) of all the protocol increases rapidly. It doesn't mean that latency is directly propositional to network lifetime. Because sleeping probability is inversely proportional to the active state of nodes. Whenever more nodes are in sleeping state, EBGR-1 uses very minimal energy. The reason is most of its forwarder nodes are in sleeping state. So conservation of energy in EBGR-1 is lower than other protocols. ProHet struggles more

in provisional loops, because of its two-hop receiver identification process. At the end, our protocol shows better lifetime in random sleep because of the following reason. Individual delay based response system employed in our proposed system provides limited responses from suitable active hop-nodes. This system makes consumption of low power than all the other protocols.

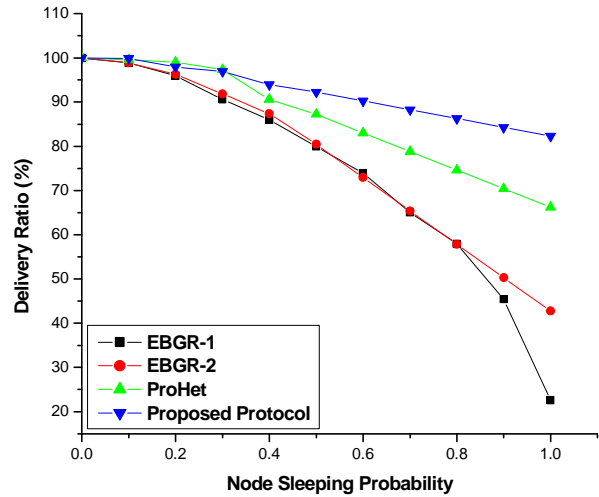


Figure 7(a). Delivery ratio analysis of proposed protocol under random sleep

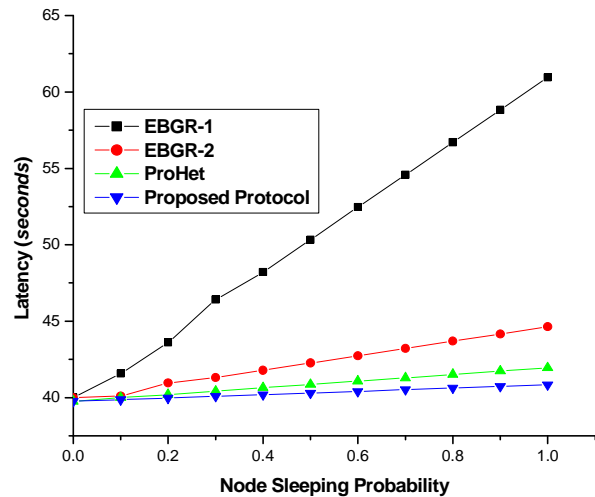


Figure 7(b). Latency analysis of proposed protocol under random sleep

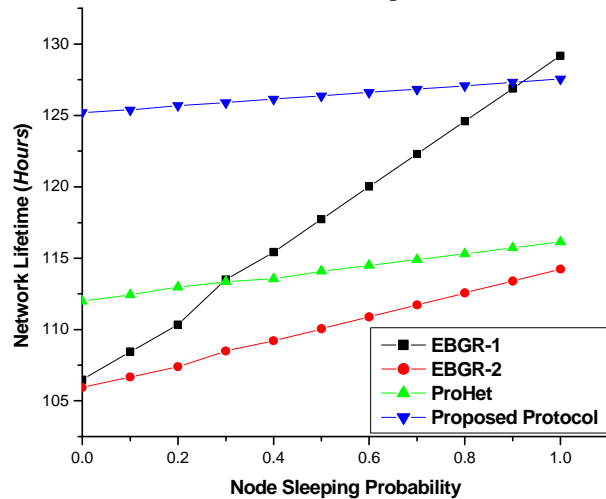


Figure 7(c). Lifetime analysis of proposed protocol under random sleep

6. Conclusion and Future Work

Power aware routing is a hot research aspect in WSNs. In this work, we concentrate on the problem of asymmetric links in WSNs and propose a novel power aware geographic routing which makes an efficient power aware routing to provide energy efficient, loop-free, stateless sensor-to-sink routing in highly unstable asymmetric scenarios. The performance of the proposed protocol is evaluated under different cases. Simulation results show that our protocol outperforms well in all the three scenarios and consumes less power than the other protocols based on the collected neighborhood information in highly dynamic scenarios. Congestion control is mainly achieved in this heterogeneous architecture by delay slot based reply scheme, which is a major contribution in this work. But if we look closer, we can understand that all the neighbor nodes that take part in the contention process waste their energy because of delay based individual reply. Our future work is that, if some improvement is adopted in this reply system, then it would be much more efficient.

References

- [1] S. Ben Alla, A. Ezzati, Beni Hasane, M. L. Hasnaoui, "Hierarchical Adaptive Balanced Energy Efficient Routing Protocol (HABRP) for Heterogeneous Wireless Sensor Networks", Proceedings of International Conference on Multimedia Computer Systems. Morocco, pp. 67-72, 2011.
- [2] M. Perillo, Z. Cheng, W. Heinzelman, "An Analysis of Strategies for Mitigating the Sensor Network Hot Spot Problem", Proceedings of International Conference on Collaborative Communications, USA, pp. 474-478, 2005.
- [3] W. Y. Zhang, X. J. Du, J. Wu, S. D. Soysa, Y. Liu, "Near-minimum-energy routing in heterogeneous sensor networks", Proceedings of International Conference on IEEE GLOBECOM, USA, pp. 1-5, 2010.
- [4] I. Stojmenovic, X. Lin, "Power-Aware Localized Routing in Wireless Networks", IEEE Transactions on Parallel and Distributed Systems, Vol. 12, No. 11, pp. 1122-1133, 2001.
- [5] Ana Maria Popescu, Gabriel Ion Tudorache, Bo Peng, Andrew H. Kemp, "Surveying Position Based Routing Protocols for Wireless Sensor and Ad hoc Networks", International Journal of Communication Networks and Information Security, Vol. 4, No. 1, pp. 41-67, 2012.
- [6] K. Kalpakis, K. Dasgupta, P. Namjoshi, "Efficient Algorithms for Maximum Lifetime Data Gathering and Aggregation in Wireless Sensor Networks", Computer Networks, Vol. 42, No. 6, pp. 697-716, 2003.
- [7] Haibo Zhang, Hong Shen, "Energy-efficient beaconless Geographic Routing in Wireless Sensor Networks", IEEE Transactions on Parallel and Distributed Systems. Vol. 21, No. 6, pp. 881-896, 2010.
- [8] H. Takagi, L. Kleinrock, "Optimal Transmission Ranges for Randomly Distributed Packet Radio Terminals", IEEE Transactions on Communications, Vol. 32, No. 3, pp. 246-257, 1984.
- [9] S. Wu, K. S. Candan, "GPER: Geographic Power Efficient Routing in Sensor Networks", Proceedings of IEEE International Conference in Network Protocols, USA, pp. 161-172, 2004.
- [10] J. Kuruvila, A. Nayak, I. Stojmenovic, "Hop Count Optimal Position Based Packet Routing Algorithms for Ad Hoc Wireless Networks with a Realistic Physical Layer", IEEE Journal on Selected areas in Communications, Vol. 23, No. 6, 1267-1275, 2006.
- [11] K. Gagneja, E. Nygard, "A QoS based Heuristics for Clustering in Two-Tier Sensor Networks", Proceedings of the Federated Conference on Computer Science and Information Systems, USA, pp. 779-784, 2012.
- [12] M. Heissenbuttel, T. Braun, T. Bernoulli, M. Walchli, "BLR: Beacon-Less Routing Algorithm for Mobile Ad Hoc Networks", Elsevier Journal of Computer Communications, Vol. 11, No. 1, pp. 1076-1086, 2004.
- [13] H. Fußler, J. Widmer, M. Kasemann, M. Mauve, H. Hartenstein, "Contention-Based Forwarding for Mobile Ad Hoc Networks", Ad Hoc Networks, Vol. 1, No. 4, pp. 351-369, 2003.
- [14] B. Blum, T. He, S. Son, J. Stankovic, "IGF: A State-Free Robust Communication Protocol for Wireless Sensor Networks", Technical Report CS-2003-11, University of Virginia, UAS, 2003.
- [15] I. S. P. Bose, P. Morin, J. Urrutia, "Routing with Guaranteed Delivery in Ad Hoc Wireless Networks", Proceedings of Third ACM International Workshop Discrete Algorithms and Methods for Mobile Computing and Communications, USA, pp. 48-55, 1999.
- [16] Brad Karp, H. T. Kung, "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks", Proceedings of ACM Annual International Conference on Mobile Computing and Networking, USA, pp. 243-254, 2000.
- [17] F. Kuhn, R. Wattenhofer, A. Zollinger, "Worst-Case Optimal and Average-Case Efficient Geometric Ad-Hoc Routing", Proceedings of ACM MobiCom, USA, pp. 267-278, 2003.
- [18] Al-Sakib Khan Pathan, Nadjib Badache, Samira Moussaoui, "Strengths and Weakness of Prominent Data Dissemination techniques in Wireless Sensor Networks", International Journal of Communication Networks and Information Security Vol. 5, No. 3, pp. 158-177, 2013.
- [19] L. Barriere, P. Fraigniaud, L. Narayanan, J. Opatrny, "Robust Position-Based Routing in Wireless Ad Hoc Networks with Irregular Transmission Ranges", Wireless Communications and Mobile Computing, Vol. 3, No. 2, pp. 141-153, 2003.
- [20] J. Al-Karaki, E. Ahmed Kamal, "Routing techniques in Wireless Sensor Networks: A Survey", IEEE Transactions on Wireless Communications, Vol. 11, No. 6, pp. 06-28, 2004.
- [21] H. Frey, I. Stojmenovic, "On Delivery Guarantees of Face and Combined Greedy-Face Routing in Ad Hoc and Sensor Networks", Proceedings of ACM MobiCom, USA, pp. 390-401, 2006.
- [22] B. Elbhirri, R. Saadane, D. Aboutajdine, "Stochastic Distributed Energy-Efficient Clustering for Heterogeneous Wireless Sensor Networks", ICGST International Journal Computers Networks and Internet Research, Vol. 9, No. 2, pp. 11-17, 2009.
- [23] X. Chen, W. Y. Qu, M. L. Ma, K. Q. Li, "A Geography-based Heterogeneous Hierarchy Routing Protocol for Wireless Sensor Networks", IEEE International Conference on High Performance Computing and Communications, China, pp. 767-774, 2008.
- [24] X. Du, F. Lin, "Improving Routing in Sensor Networks with Heterogeneous Sensor Nodes", Proceedings of IEEE 61st Vehicular Technology Conference, USA, Vol. 4, pp. 2528-2532, 2005.
- [25] A. Behzadan, A. Anpalagan, B. Ma, "Prolonging Network Lifetime via Nodal Energy Balancing in Wireless Heterogeneous Sensor Networks", Proceedings of IEEE International Conference on Communications, Japan, pp. 01-05, 2011.
- [26] D. L. Guidoni, A. Boukerche, L. A. Villas, F. S. H. Souza, R. A. H. Mini, A. A. F. Loureiro, "A Framework based on Small World Features to Design HSNS Topologies with QoS", IEEE Symposium on Computers and Communications, Turkey, pp. 732-737, 2012.

- [27] K. K. Gagneja, Xiaojiang Du, K. Nygard, "Enhanced Routing in Heterogeneous Sensor Networks", IEEE International conference on Future Computing, Service Computation, Cognitive, Adaptive, Content, Patterns, Greece, pp. 569-574, 2009.
- [28] Xiaojiang Du, Fengjing Lin, "Improving Routing in Sensor Networks with Heterogeneous Sensor Nodes", IEEE Vehicular Technology Conference, USA, pp. 2528-2532, 2005.
- [29] Xiao Chen, Zanzun Dai, Wenzhong Li, Yuefei Hu, Jie Wu, Hongchi Shi, Sanglu Lu, "ProHet: A Probabilistic Routing Protocol with Assured Delivery Rate in Wireless Heterogeneous Sensor Networks", IEEE Transactions on wireless communications, Vol. 12, No. 4, pp. 1524-1531, 2013.
- [30] Y. F. Hu, W. Z. Li, X. Chen, S. L. Lu, J. Wu, "A Probabilistic Routing Protocol for Heterogeneous Sensor Networks", IEEE International Conference on Networking, Architecture and Storage, China, pp. 19-27, 2010.
- [31] W. R. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Micro-sensor Networks", Proceedings of 33rd Hawaii International Conference on System Sciences, Hawaii, pp. 04-07. 2000.
- [32] T. Melodia, D. Pompili, I. F. Akyildiz, "Optimal Local Topology Knowledge for Energy Efficient Geographical Routing in Sensor Networks", Proceedings of IEEE INFOCOM, pp. 1705-1716, Hong Kong, 2004.
- [33] www.isi.edu/nsnam/ns/ns-documentation.html
- [34] S. Kumar, T. H. Lai, J. Balogh, "On K-coverage in a Mostly Sleeping Sensor Network," Proceedings of ACM MobiCom, USA, pp. 144 – 158, 2004.