A Hierarchical Routing Protocol for Improving the Quality of Service in Wireless Sensor Network

Seyed Ahmad Soleymani[1], Abdul Hanan Abdullah[2], Satria Mandala[3], Mir Ali Rezazadeh Baee[4], Shidrokh Goudarzi[5]

[1.] Ph.D. Student of Computer Science, Faculty of Computing, Universiti Teknologi Malaysia, Johor, Malaysia
[2.] Professor, Faculty of Computing, Universiti Teknologi Malaysia, Johor, Malaysia
[3.] Lecturer, Faculty of Computing, Universiti Teknologi Malaysia, Johor, Malaysia
[4.] M.A. Student of Information Security, Faculty of Computing, Universiti Teknologi Malaysia, Johor, Malaysia
[5.] M.A in IT Management, Faculty of Computing, Universiti Teknologi Malaysia, Johor, Malaysia
ahmad.soleymani@gmail.com

Abstract: In wireless sensor networks, routing protocols play a crucial role to specify how the communication among nodes in the network can be established. Therefore, the protocols must enable nodes to choose the best routing path between source and destination nodes by considering different parameters, such as communication range, memory, CPU and battery resources. Unfortunately, most of the existing routing designs in the networks disregard the parameters. As a consequence, the protocols are inefficient and wasteful energy resources. This paper presents a development of a new routing protocol for wireless sensor networks that conforms to all aforementioned parameters. The protocol implements a new efficient algorithm for selecting the next hop to solve inefficient and wasteful energy problems. It also implements quality of service (QoS) by prioritizing data flows for guaranteeing level of performance of data transmission in the networks. Rigorous tests and comparisons to an existing protocol, well known as Optimized Energy-Delay Sub-network Routing (OESDR) protocol, were done in a network simulator. Several performance data were used in the evaluation and analysis of both protocols. The results show that the proposed protocol outperforms OESDR. The proposed protocol is 50% more energy-efficient and increases the network longevity if compared to OESDR. Moreover, the number of reported and missed events of both protocols are almost similar.

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1. Introduction

Wireless sensor network (WSN) refers to a network of wireless sensors that are self-directed and self-organized that to measure a certain physical parameters or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants, at different locations are used. These types of networks have changed to the appropriate tools for data gathering and monitoring of phenomena and events from the environment and their applications are increasing in some areas such as industry, military and habitat day by day (Akkaya and Younis 2005). Advances in radio technology and electric and electronic industry, has led to building small and relatively cheaper sensors which are communicating with each other by a wireless sensor network. However, there are limitations and problems to this type of networks.

The most important problem in wireless sensor network is energy and power consumption. So, at the time of planning a routing protocol for wireless sensor networks, the power consumption should be considered because the power consumption has a directly related to the network's lifetime. As previously mentioned, WSNs suffer from resource constraints for example, energy, bandwidth, central processing unit, and storage. So, Due to these limitations, the designs of routing protocols are faced with a serious challenge. Moreover, routing in WSNs with conventional routing in fixed networks is different. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements (Misra, Misra et al. 2009). Generally, for this type of network many routing protocols have been developed. Routing in WSNs base on the network structure can be categorized into flat-based routing, hierarchical-based routing, and location-based routing. In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. Furthermore, these protocols base on the protocol operation can be divided into multipath-based, query-based, and negotiation-based, QoS-based, or coherent-based routing techniques (Al-Karaki and Kamal 2004).

Classification of routing protocols in WSN based on network structure and protocol operation is shown in Figure 1. Many studies about clustering in wireless sensor networks have been done from various perspectives (Singh, Singh et al. 2010). Clustering is an energy-efficient communication protocol that can be used by the sensors to report the event to the base station. A clustering based network is combined of some clusters of sensors. Each cluster with a specific node which called cluster head is managed that it has the task of coordination between nodes for data transmission. Nodes are divided into several clusters with a cluster head that has the task of routing from the cluster to the other cluster heads or base stations. Data transmit from a lower clustered layer to a higher one. Clustering provides inherent optimization capabilities at the cluster heads.

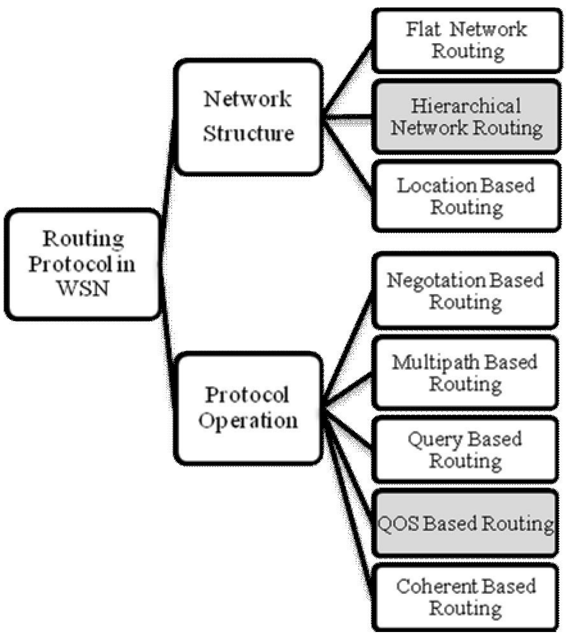

Figure 1. Classification of routing protocols in WSN

In addition to clustering to minimizing energy consumption, it is also important to consider the QOS requirements in terms of delay, reliability, and fault tolerance in routing in WSNs. There is no clear definition of QOS in wireless sensor networks, but some of the definitions which are presented are such as network coverage, the number of active nodes in each time, the receiving information accuracy in central node and the time of transmitting information to a central node. Some of these definitions like network coverage and the number of active nodes depend on the application of that time and other definitions are related to network features. According to our definition of QOS and due to the constraints of wireless sensor networks we have considered the following objectives:

1- Reduce the consumption of energy that it leads to increase the network lifetime
2- Create dynamic reconfiguration and increase the reliability of the network
3- Create the balance between the energy and distance
4- Reduce the end-to-end delay

In this paper, we provide a routing protocol for wireless sensor networks to improve QOS and increase the network's lifetime. To achieve these goals, our protocol tries to select appropriate intermediate nodes in the main route. Selected relay nodes based on the type of service desired user, energy, distance, or a combination of both. On the other hand, increase the number of hops in the path cause increase delay and decrease the number of hops cause increase the communication distance for transmitting information. As a result, we must create the balance between these two parameters and we define a function to create the balance between power consumption and end-to-end delay.

The rest of this paper is structured as follows: the next section reviews the related works in a hierarchical-based routing protocols and Qos-based protocols in WSNs. Third section explains the new hierarchical routing protocol in details. The fourth section OEDSR protocol is briefly described. At the end, we present a comparison between the proposed protocol in this paper and OEDSR.

2. Related Work

According to the protocol presented in this research, in this section, we review a sample of hierarchical-based routing protocols and Qos-based protocols in WSNs. One of the most popular hierarchical clustering protocol for WSNs that was proposed for reducing power consumption. In this protocol, based on duration the clustering task is turned among the nodes. Each cluster head with using direct communication send or forward data to the base station. LEACH uses a randomize rotation of high-energy cluster head position rather than selecting in a static manner, to give a chance to all sensors to act as cluster heads and avoid the battery discharge of an individual sensor and dying quickly (Heinzelman, Chandrakasan et al. 2000).

Lindsey and Raghavendra (2002) proposed the PEGASIS. This protocol is an extension of the LEACH protocol, which forms chains from sensor nodes so that each node transmits and receives from a neighbour and only one node is selected from that chain to transmit to the base station. HEED extends the basic scheme of LEACH by using residual energy and node degree or density as a factor for cluster selection to achieve power balancing. It can operate in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. In this protocol periodically selects cluster heads according to a combination of their residual energy of each sensor node and intra-cluster communication cost as a function of cluster density or node degree (Younis and Fahmy 2004).

According to another study, Manjeshwar and Agrawal (2001) proposed the TEEN. It is a hierarchical clustering protocol, which groups sensors into clusters with each led by a cluster head. The sensors within a cluster report their sensed data to their cluster head. It sends aggregated data to higher level cluster head until the data reaches the base station. Thus, the sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes from clusters and this process goes on the second level to the base station is reached. SAR is one of the first routing protocols for WSNs that introduces the notion of QoS in the routing decisions. Routing decision in SAR is dependent on three factors: energy resources, QoS on each path, and the priority level of each packet (Akyildiz, Su et al. 2002). He, Stankovic et al. (2003) proposed SPEED. It is another QoS routing protocol for sensor networks that provides soft real-time end-to-end guarantees. The protocol requires each node to maintain information about its neighbors and uses geographic forwarding to find the paths.

Although in previous research, energy and distance are considered as two main parameters but the creating balance between them is important. So, in our protocol, we create the balance between energy, distance node to base station and distance node to the event. Moreover, reliability and trust between nodes in data transmission is a main concern. Therefore, in this protocol election the cluster head is based on trust but in previous research, these issues have not been studied together. The simulation results of this protocol indicate the importance of this issue.

3. Materials and Methods

In this section, we present a new routing protocol. It is based on clustering that the following have described it in detail.

3.1. Network Structure

The protocol in terms of network structure is hierarchical categories. Sensors have different functions in the protocol hierarchy. Means that some sensors have the task of data collection and some of them have the task of data transmission. In this protocol, because the energy of cluster heads is higher than other sensors, data transmission and data forwarding to the base station is the task of cluster head. More hierarchical routing protocols are composed of two main phases:

- Setup phase: In this phase, cluster heads and cluster members are selected.
- Steady state phase: in this phase. Data collection is done.

In this structure, it isn't necessary that all nodes have a communication with the base station. So, in order to reduce the data transmission from the nodes to the base station and as a result increase network energy efficiency, cluster heads have the task of routing and forwarding data to the base station.

3.2. Initial Setup Network

For initial setup the network, the base station sends the START message to all the network's nodes. After that, each node sends the HELLO message to adjacent nodes and by receiving a response from them will be aware of the status of its neighbors. In addition, according to the same status of nodes in terms of energy in the initial setup network, accidentally, some nodes as cluster heads are elected by the base station.

3.3. Trust aware Election the Cluster Head

After a period of network activity, cluster heads will be changed. For this purpose, some of the nodes will be a candidate for electing the cluster head. To avoid increasing the number of candidates the threshold will be considered. So, only those nodes that their residual energy more than a critical threshold, $E_{threshold}$, can be a candidate. Moreover, each candidate node must compete within their own competing radius with other candidates. Thus, for candidate nodes will calculate the competition radius which the following Eq. (1) can be used for this purpose:

$$R_{comp} = \frac{d_{2BS} - d_{Min}}{d_{Max} - d_{Min}} \times R_{Max} \qquad (1)$$

In Eq. (1), d_{2BS} is the distance of candidate's node to base station and d_{Min}, d_{Max} are the minimum and maximum, respectively. R_{Max} is the most of the communication range of each node. Thus nodes that are farther from the base station will have larger competition radius. As shown in Figure 2 and as consequence, large clusters and certainly the number of nodes in each cluster are more. This will lead to more competition among the nodes for electing the cluster head.

In this protocol, the election of cluster heads is based on two factors, waiting time and trust value of candidate nodes. As mentioned above, each candidate node base on these parameters will compete with other candidates within their own competing radius.

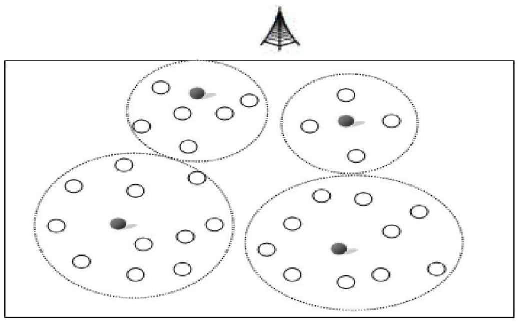

Figure 2. Clusters in regions away from the central station are larger

3.4. Trust.

In this protocol, to improve security and avoid malicious nodes in the network and also avoid choosing this type of nodes as the cluster head, the trust value as one of the parameters used to select the cluster head. In the real world, the trust between people is based on services that are offered. Also, based on the level of trust between them; the people will decide how to communicate with others. This issue also can be applied in wireless sensor networks. So, the level of trust and provide a service between two nodes is based on the number of positive and negative interactions between them which in the following way, will explain how to calculate it. As mentioned above, trust value between two nodes is based on the number of positive and negative interactions between them and by the Beta Reputation in (Jsang and Ismail 2002) will be calculated as follows:

$$f\left(p \middle| M_{a,b}+1, S_{a,b}+1\right)=\frac{\Gamma\left(M_{a,b}+S_{a,b}+2\right)}{\Gamma\left(M_{a,b}+1\right)\Gamma\left(S_{a,b}+1\right)} \times P^{M_{a,b}}(1-P)^{S_{a,b}} \quad (2)$$

In Eq. (2), $M_{a,b}, S_{a,b}$ indicate the number of positive and negative interactions between two nodes (a and b) in the past, respectively. Where $0 \le P \le 1$, $M_{a,b} \ge 0, S_{a,b} \ge 0$.

By calculating the expected value of Eq. (2), we have:

$$T_{a,b} = \mathrm{E}(f(P|M_{a,b}, S_{a,b})) = \frac{M_{a,b}+1}{M_{a,b}+S_{a,b}+2} \quad (3)$$

Where $T_{a,b}$ is in the range between 0 and 1 and it indicates the trust value between **node a** and **node b**. Thus, the level of trust between the candidate node and current cluster head is $T_{CCH,Candid}$.

Each candidate node which its trust value is more than other candidates has more chance of electing as the cluster head.

3.5. Waiting Time.

In addition, the waiting time for each node is based on the amount of primary energy and the remaining energy of each node which it has been described in the following way. The based on initial energy and remaining energy, a waiting time will be allocated to each node. After the end of this time, each candidate node should send the message to the current cluster head. According to the Eq. (4), each node which has more energy than other nodes will introduce itself as a cluster head node sooner and so other candidates which are in its competition radius are called losers. The waiting time for each candidate node is calculated as follows:

$$T_{Wait} = \frac{E_{init} - E_s}{E_{init}} \times T_c \quad (4)$$

In Eq. (4), E_{init} and E_s is the initial energy and the remaining energy of a node, respectively, and T_c is the maximum waiting time. So, each node that has more trust value and lowest waiting time immediately announces itself as the cluster head and will be called the winner in this competition. When winner nodes are selected as the cluster head, each of them broadcast a message to neighbor's nodes that are within their competition radius and other nodes according to its signal strength select the closest winner node as the cluster head. In this protocol, as shown in Figure 3, in order to avoid waste of energy, the operational range of nodes is divided into three areas, left, right and center. By default, all nodes are in sleep mode unless an event occurred in their area or the base station being sent a query message to their area.

In order to gather information about a specific area the base station will send a query message to that area of the network for example left area and just the nodes which are within that area has the task sending the report of the event, if it happened, to the base station and other nodes in other area are inactive. Also, when an event is detected routing and data transmission is performed only by that area's node. Each sensor has a sensing range and the communication range and when an event will be detected by the sense that it is located in the sensing range of sensor. So any event that happens in the sensing area of sensor, it will be detected and record that event. But only the nodes that are located in the place of the event have the task of report to cluster head or base station.

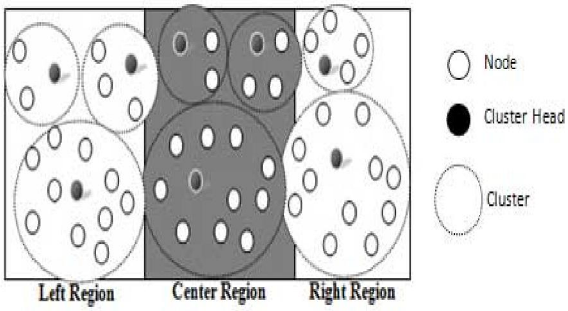

Figure 3. Division's operational area

3.6. Select the Node for Send to Cluster Head

In this protocol, we have assumed that all nodes are aware of the status of neighboring nodes and Information related to its neighbors is stored in their table. In addition, an event may be detected by some nodes and nodes must report it to the cluster heads. But which node has the task of sending the report within a cluster. In order to save energy, only one of them for this purpose is enough.

So in this part we prioritize nodes based on three criteria:

- Higher residual energy
- Closer distance to the event
- Closer distance to the cluster head

According to these three criteria, and after check the relevant table, each node that earns more points has the task of sending the report to the cluster head. To calculate the point of each node, e.g. node a, the following equation is used:

$$Score_a = \alpha E_s + \beta G_{d2event} + \gamma G_{d2CH} \quad (5)$$

In Eq. (5), E_s is the residual energy of node, $G_{d2event}$ is the distance of node to event and G_{d2CH} is the distance of node to cluster head. Where α, β and γ represent the significance of energy, distance to the event and distance to the cluster head, respectively, with α + β+ γ =1. Moreover, after a period of network activity and when change cluster head, the information stored in table of nodes will update.

3.7. Select the Next Hop

According to the this protocol is based on the query from the base station, so after broadcast the query message in the entire network, Cluster heads which detect the occurrence of an event by the other nodes have the task to send reports to the base station. For this purpose, and to select the next hop (next cluster head) for data transmission, prioritization is done according to two factors, energies and distance to the base station. This prioritization is based on a function of energy and distance which you can see in equations (6) and (7) respectively:

$$F_{energy} = \frac{E_{init} - E_s}{E_{init}} \quad (6)$$

$$G_{distance} = \frac{d_{2BS} - d_{Min}}{d_{Max} - d_{Min}} \quad (7)$$

To calculate degree of cluster head node based on the coefficient of the two above functions:

$$Degree = (\alpha F_{energy} + \beta G_{distance})^{-1} \quad (8)$$

Which in Eq. (8), Degree calculated based on Based on the obtained values of Eq. (6) and Eq. (7) and also, Where α and β represent the significance of energy and distance, respectively, with α + β = 1.

According to this equation, each node that has higher energy and less distance to the base station will have more degrees and higher priority. So, each cluster head which detects the occurrence of an event if the base station is not within the its communication range given the report to the next cluster head which is in higher priority and that node to the next cluster head, similarly, until it reach to the base station. Finally, at the end of a period of time and in order to create the kind of balance in energy consumption of nodes all above operations will be repeated for all alive nodes in the network. In continue the pseudo-code for these operations is presented.

```
Select Next Hop ()
{
for each Cluster-head (f, g)
{
Calculate Cluster-head . Degree
if Cluster-head . Degree > Max
Max-Cluster. ID = Cluster-head. ID
}//end for

Next-Hop = Max-Cluster. ID

}//end function
```

Send packet to next hop

3.8. Optimized Energy_Delay Sub_Network Routing (OEDSR)

Optimized Energy-Delay Sub-network Routing (OEDSR) protocol is a hierarchy based structure protocol (Ratnaraj, Jagannathan et al. 2006). It is an extension of Optimized Energy-Delay Routing (OEDR) protocol (Regatte and Jagannathan 2005). Where, only sub-networks are formed around an event/fault and elsewhere in the network nodes are left in sleep mode. OEDSR borrows the concept of relay-nodes (next hop node) selection from OEDR. In OEDR, relay node selection is based on maximizing the number of two hop neighbors. Whereas, the selection in OEDSR is based on maximizing the link cost factor. OEDSR assumes that the base station has a sufficient power supply, thus a high power beacon from the base station is sent to all nodes on the network. This assumption makes all nodes know their distance to the base station, which the link cost factor formula relies on this assumption.

4. Results

In this section and based on the similarity of OEDSR and our proposed protocol we present a comparison between them. A comparison between them was done in cases of total energy network, active nodes, the number of missing events and reporting nodes. In shapes we've named the proposed protocol as My Protocol. These two protocols have stimulated by the help of MATLAB. In this simulation, it is assumed that an event occurs in the network in each period. Simulation parameters are shown in Table 1.

Table 1. Simulation parameters

Parameter	***Value***
Network's Size	$100 \times 100\ m^2$
Number of initial Sensors	200
Initial energy of Network	0.5 J
A	0.5
B	0.5
T_c	0.1
R_{Max}	100
d_{Max}	158
d_{Min}	50

4.1. Reduced rate of network's energy

The reduced rate of energy from the entire network can be considered as a factor for comparing the energy efficiency of two protocols. The gentle slope of the graph means that energy consumption is more balanced. As shown in Figure 4, Energy diagram of My Protocol towards OEDSR has a gentle slope, which indicates optimal energy efficiency is in this protocol.

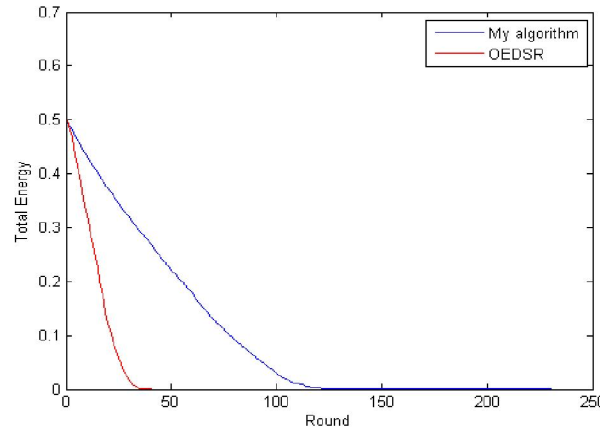

Figure 4. Reduced rate of network's energy

4.2. Network lifetime

In wireless sensor networks, the network lifetime is one of the most important parameters. It is clear that the network lifetime is dependent on the active node and by reducing the number of active nodes Network performance will decrease. One of our objectives in this paper increases the network lifetime and as can be seen in Figure 5, the offered protocol in this study has increased the network lifetime significantly compared to other protocol.

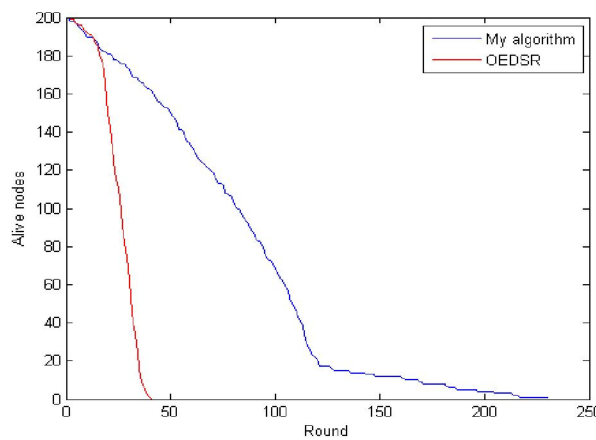

Figure 5. Network lifetime

4.3. Reported events

Comparison between two protocols in the number of detecting events and the number of reported events show that the prepared protocol in this paper reports greater number of events comparing to base station. According to Figure 6, it can realize that in 100 beginning periods of the Network, the protocol in this paper reports nearly all discovered events and then by the gradual decline of network nodes, detection and reporting of events declined over time but this operation in 20 beginning periods of network in OEDSR is done well.

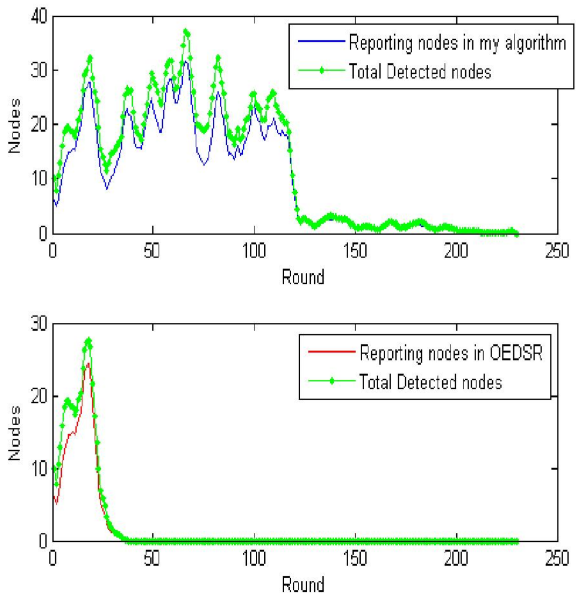

Figure 6. The number of reported events

4.4. Number of missed events

One of the main parameters in wireless sensor networks based on event occurrence is network's reliability. A network that is able to report more events has the more reliability. In Figure 7, we've done a Comparison between the two protocols in terms of the number of missed events. It is clear that Chart below proves that fewer events from the point of view of sensors which are organized by prepared Protocol in this paper have remained secret. According to the two forms, it is clear that My Protocol in comparison with OEDSR has more reliability in detection of the events.

5. Conclusion

In this paper, by considering the network's lifetime as a type of quality service and in order to improve it, we provided a routing protocol based on the hierarchical and multi-hop structure. At first, some of nodes candidate to get the cluster head and after the competition with together in competition radius based on trust value and time waiting. After the election of cluster head and introduce to neighboring nodes, the network activity begins.

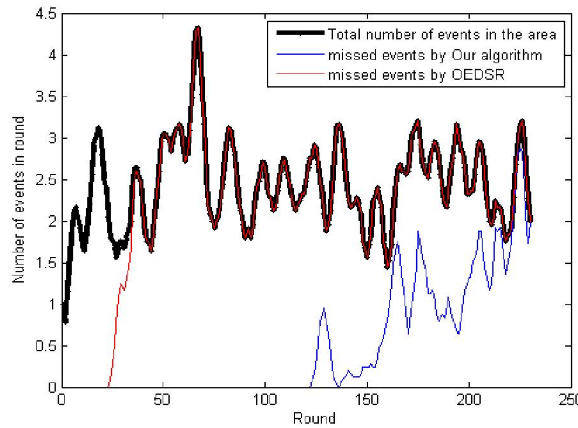

Figure 7. Number of missed events

The main task of cluster head is the selecting the best route to send or forward a report of an event to base station. In addition, in this protocol and in order to save energy, if an event is detected by some nodes, only one of them will send the report of event to its cluster head and also the cluster head in order to transmit the report of event to the base station select the next cluster head. Until the report of event reaches to the base station, this process will be continued. Election of the next cluster head is based on the residual energy and distance to the base station. Moreover, in order to avoid waste of energy, the operational range of nodes is divided into three areas, left, right and center. If an event occurred in an area, just the nodes which are within that area has the task sending the report of the event to the cluster head or base station and other nodes in other area are in sleep mode. The above operation for balance of energy consumption among all nodes in the network is repeated after a period of time. At the end, we have compared between the presented protocol in this paper and OEDSR protocol. A comparison between them was done in cases of network energy, the number of active nodes, the number of reported events and the numbers of missed events were placed on analysis and evaluation. The results of simulation show an impressive performance in presented protocol compared with the OEDSR. So, by considering the appropriate criteria and parameters for prioritization and selection of cluster head, the protocol can be improved and ultimately increase the network lifetime.

Corresponding Author:
Seyed Ahmad Soleymai
Universiti Teknologi Malaysia (UTM)

Johor
Malaysia
E-mail: ahmad.soleymani@gmail.com

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