RRP: A Register Mechanism Routing Protocol in Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) are event-based systems that rely on the collective effort of several micro-sensor nodes. Reliable event detection at the sink is based on collective information provided by source nodes. When data needs to be gathered from a selected set of nodes and transmit to sink in the network. However the sensor nodes often face the critical challenge among all is the constraint on limited battery energy. Therefore, how to minimize the energy consumption while maintaining an extended network lifetime becomes the most critical issue in the WSNs. We present a routing protocol in cluster-based WSNs called the Register mechanism Routing Protocol (RRP). The RRP protocol is attempted to resolve the above issue. The performance of RRP is then compared to routing protocol such as HCDD (Hierarchical Cluster-based Data Dissemination in WSNs) and TTDD (Two-tier Data Dissemination Model for Large scale WSNs). The simulation results demonstrate that RRP may reach energy savings up to 21%~50%.

***Key Words*:** Wireless Sensor Networks, Energy-Efficiency, Cluster-Based Routing, Mobile Sink

1. Introduction

In the development of wireless dissemination technology [1], WSNs have become the most popular research area. The compact size of the micro sensors and the unique characteristics of communications among those sensor nodes used in the WSNs substantiate the highly applicable role of such networks in fields such as military, business, medical treatments, environmental protection, the disaster assistance & rescue, and so on. Typical applications of WSNs include monitoring and tracking because of their many inherent advantages. Numerous examples have shown that, in recent years of research and development, WSNs are employed in place of human labor for tasks that either require a long period of monitoring or involve high risks. Each wireless sensor node features data processing, wireless communication, and data sensibility. In addition, all WSNs comprised of the said wireless sensor nodes acquire features related to rapid construction, easy operation, self-organization or mobility [2], and so on. Hence, all relevant study results have always been deemed with great importance.

Traditional aggregate data of nodes use a routing protocol to sink. In general increase the traffic load that cause the interference and reduce packet delivery ratio that energy consumption of nodes in wireless network. Therefore main objective of this paper is to design a mobile sink routing protocol which can be applied to cluster-based WSNs [3]. It is expected that, with such protocol, evenly distributed energy consumption among all sensor nodes can be achieved, and consequently the overall life time of the WSNs will be improved.

The RRP proposed by this paper is aimed at improving the network lifetime. The major designing concepts are shown as follows:

1. Eliminate complicated computation upon operation.
2. Reduce electric energy consumption while improving overall network lifetime.

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3. Decrease relay frequency of sensor nodes nearby the sink to prevent failure in sensing data dissemination.

The paper is organized as follows. Section 2, related work is outlined. Section 3, we provide applicable methods and the detailed description of mobile sink routing protocol used in the cluster-based wireless sensor network. Section 4, there is comparable and analytical description for the simulation results. The last section is conclusion and future works.

2. Related Work

2.1 Hierarchical Cluster-Based Data Dissemination

Hierarchical Cluster-based Data Dissemination in WSNs with Mobile Sink (HCDD) [4] is a routing protocol, and, it is also a clustering type routing protocol. The HCDD protocol presented a new concept of the mobility and hierarchy. Mobile sink nodes, rather than merely static sensor nodes, are used in HCDD. In addition, the nodes in a wireless sensor network are first grouped into various cluster groups, and the cluster head nodes from each cluster group will then form layers to establish a fully hierarchical architecture. Under this structure, each cluster is able to communicate with one another.

The cluster head node, on the other hand, is in charge of the communication with the mobile sink nodes. Through the hierarchical structures, the cluster head node is able to track down the mobile sink nodes. This protocol also successfully minimizes the power consumption of the entire sensor network by means of mobile type sink nodes and multi-layer routing.

2.2 Two-Tier Data Dissemination Model

A Two-tier Data Dissemination Model for Large scale Wireless Sensor Networks (TTDD) [5] proposed by Haiyun Luo et al., belongs to the Grid-Based routing protocol. This routing algorithm will first partition the network into several grid units consisting of a number of nodes. In this architecture, the location information of nodes can only be managed by those sensor nodes which also serve as dissemination nodes. It should be noted that the data source has to be one of the dissemination nodes configured within this architecture. When a sink node requests for data, it sends out a query message, which can only be disseminated among dissemination nodes, to the data source nodes. Upon receipt of such query message, the data source nodes will then send back the relevant data to sink nodes via a reverse path.

In TTDD, however, each data source must form its own grid unit, which consumes a lot of energy, and the result is not efficient. Even if the data is only disseminated within the same grid unit, the amount of energy consumption is too much to use practically.

3. Register Mechanism Routing Protocol

Each sensor node in the network will exchange information regarding its own geographical address and the status of energy supply with one another, save all relevant information, and establish a *Neighbor Information Table* (*NIT*), which will then be utilized for future operations, such as the selection of cluster head nodes and data dissemination, in the initialization stage of the network. The proposed method will have four main phase as follows: Clustering Phase (CP), Register Phase (RP), Data Dissemination Phase (DDP) and Maintenance Phase (MP).

3.1 Clustering Phase (CP)

After all sensor nodes are properly configured, each one of them will start building its own *Neighbor Information Table* (*NIT*) and be divided into clusters. The size of each cluster called Cluster Radius (CR) that expressed by hop count. Each sensor node has dependence on value of CR, which keep the information of neighbor to CR + 1. For example, if CR = 3 that express the radius size, which representative the most far length is 3 hop count. Then each node will maintain 4 hop count of neighbor information. Every node broadcast "Hello" message to neighbor node and exchange information that contain ID, address and remain of energy etc. And store this exchange information of neighbor nodes, which have CR + 1 of neighbor nodes. The Table1 presents the information of the neighbor node for each node.

The *Seq_No* present to a serial number. And the

Table 1. Neighbor information table (NIT)

Seq_No	Hop_Count	Neighbor_ID	Address	Distance	Remain_Energy

Hop_Count is saving from node to neighbor node of distance that had passed through the number of nodes. The neighbor node uses an *Neighbor_ID* of value to express. The graphic location of neighbor node has store to *Address* field. To calculate the distance from node (A) to node (B) by formula (1) and the values save to *Distance* field.

$$\overline{AB} = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \tag{1}$$

Finally, the residual energy of neighbor node has presented the *Remain_Energy*. After all sensor nodes are properly configured, each one of them will start building its own *Neighbor Information Table* (*NIT*) and be divided into clusters. Each node is entry to wait time status. And the X_{node_ID} parameter is setting that the each node will put own serial number into *node_ID*. Formula (2), the value calculated between [0,1] of value. According to the negative exponential distribution design a $t_{\text{node\_ID}}$ timer, which calculated by formula (3).

$$X_{node\_ID} = \lambda_{\text{node\_ID}} e^{-\lambda_{node\_ID} t_{node\_ID}} \tag{2}$$

$$\lambda_{node\_ID} = \lambda_0 \frac{E_{res}^{node\_ID}}{E_{\max}} \tag{3}$$

where the $E_{res}^{node\_ID}$ is residual energy of node, the $E_{\max}$ is initial energy of node, the λ_0 is a constant that describe residual energy of node. The $\lambda_{\text{node\_ID}}$ and λ_0 of ratio is decided on $E_{res}^{node\_ID}$ of values. Therefore above formula use negative exponential distribution, mainly have performance in dynamical load balanced.

Corollary 1. The algorithm develops useful residual energy for load balance, which the more residual energies of sensor node has more opportunity to become cluster head. Also the residual energy of node has less chance than wait time status is longer. Therefore the algorithm may guarantee the load balance in wireless sensor network. Since the formulation (2), the increase reduce of wait time will accord with $\lambda_{\text{node\_ID}}$ of value, it may guarantee the feasibility. We obtained the $t_{\text{node\_ID}}$ of value from the $\lambda_{\text{node\_ID}}$ and can be written as

$$t_{node\_ID} = -\frac{1}{\lambda_{node\_ID}} \ln \frac{X_{node\_ID}}{\lambda_{node\_ID}} \tag{4}$$

The $\lambda_{\text{node\_ID}}$ function of first derivatives such as:

$$\frac{dt_{node\_ID}}{d\lambda_{node\_ID}} = \frac{1}{\lambda_{node\_ID}^2}(1 - \ln \frac{\lambda_{node\_ID}}{X_{node\_ID}}), X_{node\_ID} \in [0,1] \tag{5}$$

If $\frac{dt_{node\_ID}}{d\lambda_{node\_ID}} \le 0$ then $\lambda_{node\_ID} \ge X_{node\_ID}*e$, namely the function $t_{\text{node\_ID}}(\lambda_{\text{node\_ID}})$ is monotonically decreasing between [0,1]. Therefore, when we elected the $\lambda_{node\_ID} \ge \max(X_{node\_ID}, e) = e$, then the $t_{\text{node\_ID}}$ and $\lambda_{\text{node\_ID}}$ have become inverse proportion. According to the formulation (3), the $\lambda_{\text{node\_ID}}$ is monotonically increasing function by residual energies E_{res}. Therefore we may prove the nodes, has more residual energies then it hold a shorter wait time, which has more opportunity to become cluster head. Thus guarantees the load balance in the networks. According to precede the formulation that is designed a timer. Thus the node has more residual energies while has a shorter wait time, may contend with high priority in the channel. After the competition channel success, will be change the status to cluster head and broadcast an ADV-CH message to notify the neighbor nodes at the NIT. When the neighbor nodes receive the *ADV-CH* message, it will stop the timer and join into this cluster head. If a node receives several *ADV-CH* messages at the same time, it has decided to join the cluster head by closest to its location, which judge from the signal strength. If a node receives several *ADV-CH* messages at the same time, it has decided to join the cluster head by closest to its location, which judge from the signal strength. And the node will reply to a *JOIN* (*Node_ID*, *t*) message, where the *Node_ID* express the *ID* of node and the t is delivery time of this *JOIN* message.

During the clustering phase, we will design a *tCF* parameter that the time spent on the cluster division. If a *tCF* of value is count down to reach 0, then the rest nodes are not yet decided to join any cluster. These nodes will transmit the *JOIN* (*Node_ID*, *t*) message to neighboring nodes at its *NIT* listed, and to request for joining this cluster with neighbor nodes. Finally, the completion cluster division in the network while each cluster head will establish an *Intra-Cluster Schedule Table* (*IACST*) as shown Table 2.

3.2 Register Phase (RP)

The WSNs enter the Register Phase (RP) upon com-

Table 2. Intra-cluster schedule table (IACST)

Cluster_ID	Member_ID	Address	Remain_Energy	Time to be a Header (minute)

pletion of the clustering process described in the previous section. During this phase, the mobile sink starts to move around in the network according to the movement pattern calculated based on the Hidden Markov Model (HMM) [6] of the Random Waypoint [7]. Meanwhile, all sensor nodes and the cluster head node, depending on its current state out of the possible three register, transmission, and sleep which define the three primary aspects of its tasks, will also start their own tasks respectively.

The sink node, as it moves around in the network, sends out a *Search_CH* message containing information of its moving velocity, v. When the mobile sink node enters the valid dissemination range of some cluster head node, and the *Search_CH* message is intercepted by such head node, the cluster head node starts measuring the stationary time, *Ts*, of the mobile sink node within its valid dissemination range.

In addition, it sends out a *Request To Register* (*RTR*) message with its address information included to the mobile sink node requesting for registration. The sink node, once accepts the *RTR* message packet, stops sending out the *Search_CH* message and instead sends an *Agree To Register* (*ATR*) message packet back to the node whose address information is provided in the *RTR* message packet to allow data transmission from that node. The *RTR* and *ATR* message format as follows. Mobil sink aggregate information from cluster head and registration process, like Figure 1. When cluster head 31 has to listen a *Search_CH* message from the mobile sink to transmit.

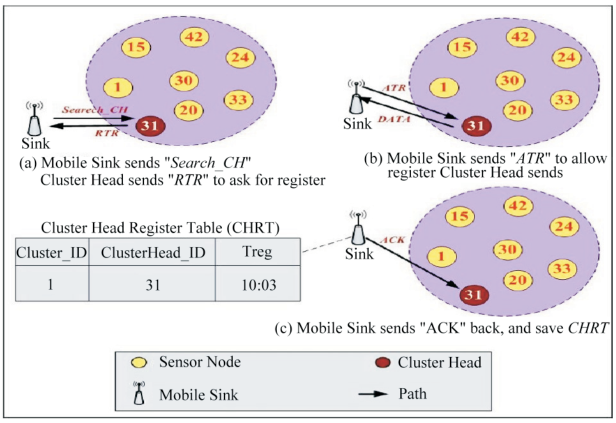

Figure 1. Mobil sink aggregate information from cluster head and registration process.

Then this cluster head 31 will transmit a *RTR* message to mobile sink and request a registration, like Figure 1(a). After the mobile sink receive a RTR message while reply *ATR* message to this cluster head, and then is included the speed rate of mobile sink. Finish the registration of cluster head 31 and received the *ATR* message. Therefore the aggregate data from nodes in this cluster can begin delivery to mobile sink, like Figure 1(b). Finally the mobile sink node, upon receipt of all sensed data from the cluster head node, sends out an *ACK* message to confirm the receipt of the data and records the relevant information of the cluster head node (as Figure 1(c)) in its *Cluster head Register Table* (*CHRT*).

3.3 Data Dissemination Phase (DDP)

After the registering phase, the wireless sensor network enters its next phase, Data Dissemination Phase (DDP). We will split our discussion into two parts the data dissemination inside the cluster and the data dissemination outside the cluster. According to Greedy Algorithm, the most favorable choice should be made at each selection step. Therefore, when designing our routing protocol for data dissemination inside the cluster, we adopt this greedy concept, using the remaining energy capacity as the indicator, to select our most favorable path, which in turn minimizes the overall energy consumption, evenly distributes and balances loads among the sensor nodes, and thereby extends the lifetime of the entire network. We will illustrate our path selection for data dissemination inside the cluster using Figure 2. If node 42 within a cluster needs to disseminate sensed data

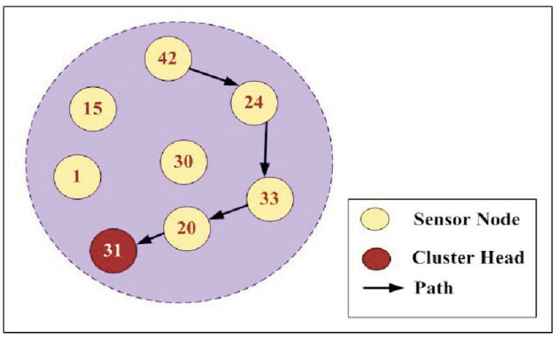

Figure 2. Example for data dissemination route inside the cluster.

to the cluster head node 31, node 42 will inspect *NIT* in advance and then select a neighbor node closest to itself, having the highest electric power capacity, as the next relay node.

In this example, the neighbor node 24 is closest to node 42 and, therefore, will receive all sensed data along with related data required for the cluster head node 31 from node 42. Once node 24 receives relay data from node 42, node 24 will then inspect its *NIT* to select the next relay node. Since node 33 is the closest to node 24, node 24 will disseminate all related data to its neighbor, node 33. Node 33, upon receipt of data from node 24, checks its *NIT* to select the next relay node. In this case, two closest neighbor nodes, node 20 and node 30, are found. Node 30, hence, re-inspects its *NIT* for higher remaining energy capacity between the two. Node 20 is found to have higher electric power capacity and, thus, is selected as the next relay node. At this point, node 20 checks its *NIT* and finds that the cluster head node 31 is the closest neighbor node and relay is no longer necessary. It then disseminates all related data to cluster head node 31 directly. Once the cluster head node registers with the mobile sink node, the mobile sink node receives a confirmation form cluster head node stating that cluster head node is ready to disseminate data, through the exchange of the *RTR* and *ATR* data packet. If the mobile sink node moves to the cluster containing cluster head node and finds that the cluster has been registered before and that cluster head node has been saved into its *Cluster head Register Table* (*CHRT*), it, after reconfirming that cluster head node is the cluster head node of the cluster based on the previous *IACST*, sends *Request To Send* (*RTS*) message packet asking cluster head node to disseminate sensed data. Upon receipt of the *RTS* message packet, cluster head node disseminates data to mobile sink. If the mobile sink node does not receive any message from the cluster head node after certain wait time, T_{next}, it moves to the next cluster according to its planned path for the operation of receiving related data shown in Figure 3.

3.4 Maintenance Phase (MP)

On the maintenance of clusters, if a new sensor node is to join the network, it will send out the *JOIN*(*Node_ID*, *t*) message with its own *ID* number and the message send time included. In addition, it will set a certain wait time for the available clusters to respond. If responses are received from the cluster head nodes within the wait time, it will join the cluster, of which the cluster head node is closest to itself. If, however, no reply is received within the set wait time, it will resend the *JOIN*(*Node_ID*, *t*) message again up to a total of three times. Upon failure of all three attempts, it will update its own status and become a cluster head node itself. Meanwhile, the new cluster head node will send out the *ADV-CH* message informing all nearby neighbors and start forming its own cluster.

Another important issue to be addressed about the maintenance of cluster architecture is the replacement of the cluster head node. A competition mechanism is activated based on *IACST* prior to the replacement of the cluster head node so as to create a buckup_head. The current cluster head node will then compare the energy capacity of itself with that of the buckup_head. If the energy capacity of such buckup_head is higher than that of the cluster head node with a difference of more than a threshold, then the buckup_head will be reserved as the cluster head node in the next operation, and the current cluster head node soon to be replaced will be moved to the end of the *IACST*. Changes in the schedule list of the current cluster head node will trigger the dispatch of the updated *IACST* and an update on *NIT*; otherwise, only the *NIT* is updated. The RRP protocol proposed in this paper is based on a cluster-based architecture. The algorithm, as described in this document, is capable of efficiently distributing the energy consumption in different phases of operations. It is able to not only extend the lifetime of the entire sensor network, but also improve the efficiency of the whole routing protocol.

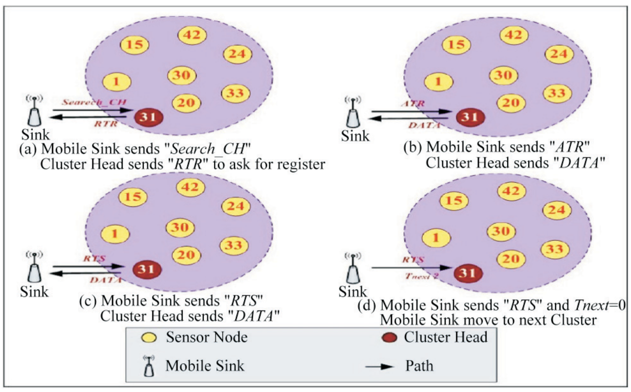

Figure 3. Example for data dissemination route outside the cluster.

3.5 Fault Tolerance

Since the threshold of energy for a node that causes the path changes show in Figure 4. If the node 33 is non-transmit of state that delivery the *Stop_T* message to its neighbor node 20, node 24 and node 30. After this node change its status to stop delivery and only responsible for its interest of information. But if the node 33 is found its energy smaller than threshold energy, then transmits the *Stop_T* message to its neighbor node 20, node 24 and node 30. And this node will reserve the transmit information of node 24 until receive the *Change_Path* message from node 24, and then lose data packet. Finally, the node 24 will transmit data to node 31 through node 30.

4. Simulation Results

We use GloMoSim [8], which is developed primarily for wireless mobile network by University of California Los Angels (UCLA), as our simulation tool, GloMoSim is implemented based on ParseC and is able to perform simulation tests for large-scale wireless communication network.

The parameters and environmental settings for our simulations are as follows: (1) the sensing area is 500 m × 500 m; (2) 1000 sensor nodes are deployed randomly, but evenly and equally densely, in the network; (3) the size of the dissemination packet is 100 bytes; (4) the sensing radius for the sensor nodes is 25 m; sensor nodes are randomly selected acting as the data source nodes; (5) the movement of the mobile sink is computed based on the Hidden Markov Model (HMM) of Random Waypoint. In regards to the similarity between the proposed mobile sink routing protocol with registering mechanism and two other well-known routing methods TTDD and HCDD on the concept of mobile data sink, we will compare the performance of our protocol with that of TTDD and HCDD and perform an in-depth analysis on the various features of the three protocols and the goals they achieve respectively.

First, we observe the energy consumption of the entire WSNs using different routing methods in the simulation process. The results are shown in Figure 5. As shown in the comparison chart, the routing algorithm presented has a lower energy consumption than the other two methods. A further analysis of the simulation results shows that a similar outcome is observed because HCDD, like the algorithm presented in this thesis, is also based on the concept of clustering. However, due to the additional overhead affixed to the maintenance of the hierarchical structure every time a new layer is added, the overall energy consumption of HCDD is increased accordingly. Furthermore, the potential overhead makes it almost impossible to monitor the energy consumption of the wireless network. Based on this observation, it is apparent that our algorithm indeed has a superior performance in terms of managing the energy consumption for the entire network.

The average energy consumption of TTDD, on the other hand, is almost 50% higher than that of our algorithm. In setting up the architecture TTDD requires more energy in order for each dissemination node to establish its own grid unit. Additionally, each dissemination node is subject to high energy consumption for handling the data dissemination within its own grid unit. As a result, the performance in terms of reserving energy for the entire network is highly compromised. The simulation results of the different routing methods on the network

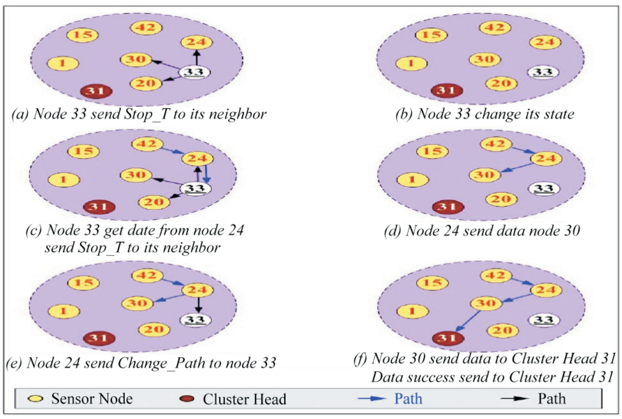

Figure 4. Fault tolerance.

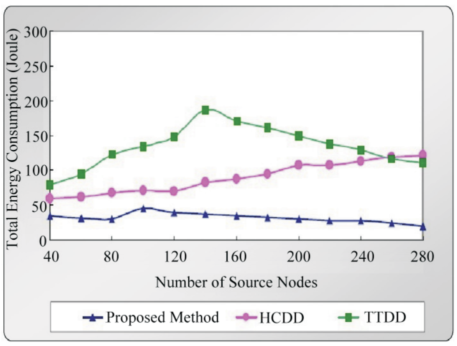

Figure 5. The comparison chart showing the energy consumption of network.

lifetime are shown in Figure 6.

Based on the simulation results, our algorithm preserves a longer network lifetime when having the same number of data source nodes. In comparison with HCDD, our algorithm results in an average of nearly 23% increase in the overall network lifetime. This analytical result proves that the cluster head replacement mechanism used in our algorithm can truly perform the function of load balancing among nodes and effectively manage the electric energy consumption in each cluster. HCDD, however, with its hierarchical clustering architecture, has the worst performance in terms of the overall network lifetime among all three routing methods. This observation can result from the higher fail rate of the cluster head nodes in the upper hierarchy. As the number of data source node in the network increases, the number of data relay operations performed by the cluster head nodes in each layer increases as well, particularly, the ones in the upper layers.

Additional loads are forced on those cluster head nodes because they are higher up in the hierarchy. The constant and long-distance data relay operations lead to rapid energy consumption; and, as a result, a higher fail rate of the cluster head nodes. Our algorithm, when compared with TTDD, has, on average, about 14% increase in the overall network lifetime. The analysis shows that TTDD, a Grid-based routing algorithm, fixes the position of each dissemination node via GPS when configuring the grid unit. Since the location of any given node is fixed and known in advance, the energy spent on network maintenance is relatively less than HCDD. Its performance in terms of network lifetime is, therefore, better than that of HCDD.

Nevertheless, the dissemination of related data relies heavily on these fixed nodes; and as the number of data source node increases, the data dissemination volume and the data relay operations increase as well. These are the primary sources of energy consumption for using TTDD. Additionally, with the cluster head node replacement mechanism our algorithm is able to successfully balance loads among all dissemination nodes. It is also able to prevent the cluster head nodes from wasting energy by utilizing mobile sink nodes to actively communicate with the cluster head nodes. Taken as a whole, our algorithm results in a better performance in terms of overall network life time than what TTDD is able to achieve.

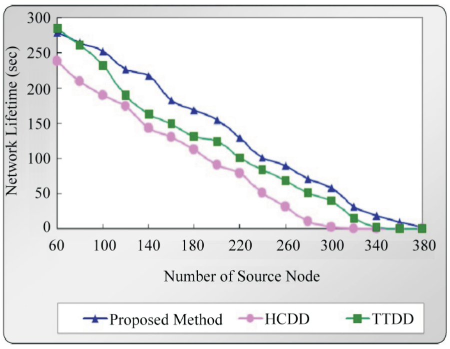

Figure 6. The comparison chart showing the lifetime of network.

According to the analysis of the simulation results, it is apparent that our algorithm indeed has a greater performance in terms of either the energy consumption or the overall lifetime of the entire network when compared with the other two routing protocols of different architectures. Particularly, the electric power and energy consumption of the entire network is evenly distributed across the network and, base on the simulation results, not seriously impacted by the increase in number of data source nodes. Hence, the overall performance of our algorithm on extending the network lifetime is more outstanding than the other two routing methods.

5. Conclusion and Future Works

In this thesis study, we propose a mobile routing algorithm with registering in the cluster-based architecture. During the initializing phase of the sensor network, we introduce path competition and scheduling mechanism, using the remaining energy capability as the indicator, to ensure that sensor nodes with more energy capability will have a greater chance of being selected as cluster head node. By doing so, the load balancing in the system is ensured. Furthermore, the location information of mobile sink node is recorded and retained through the registration procedure between the cluster head node and the mobile sink node. In order to enhance the mobility of the sink node, we adopt the Hidden Markov Model (HMM) to compute its moving path and use random waypoint as its moving method.

In simulation analysis, we test our algorithm using the simulation tool and then compare the result to that of TTDD and HCDD two well-known protocols. According to the simulation results, our algorithm has a better performance on overall lifetime and electric power and energy consumption for the entire network. The delay of data transmissions and use multiple mobile sinks will be the concerned in the future.

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