A Clustering Protocol with Mode Selection for Wireless Sensor Network

Aries Kusdaryono* and Kyung Oh Lee*

Abstract—Wireless sensor networks are composed of a large number of sensor nodes with limited energy resources. One critical issue in wireless sensor networks is how to gather sensed information in an energy efficient way, since their energy is limited. The clustering algorithm is a technique used to reduce energy consumption. It can improve the scalability and lifetime of wireless sensor networks. In this paper, we introduce a clustering protocol with mode selection (CPMS) for wireless sensor networks. Our scheme improves the performance of BCDCP (Base Station Controlled Dynamic Clustering Protocol) and BIDRP (Base Station Initiated Dynamic Routing Protocol) routing protocol. In CPMS, the base station constructs clusters and makes the head node with the highest residual energy send data to the base station. Furthermore, we can save the energy of head nodes by using the modes selection method. The simulation results show that CPMS achieves longer lifetime and more data message transmissions than current important clustering protocols in wireless sensor networks.

Keywords—Ad Hoc Network, Wireless Sensor Networks, Clustering, Routing Protocol

1. INTRODUCTION

Wireless sensor networks have been widely used in many different areas of application such as military, health care and monitoring environments. The main ability of wireless sensor networks is communicating and sensing between nodes, which are deployed in a wide area with a large number of nodes. In order to increase the utilization of wireless sensor networks, many researchers have developed efficient ways to increase the usability of a single node. For increasing network lifetime it is essential to make the most efficient use of every node since each node of wireless sensor networks has limited energy resources. One of the important key points in utilizing a network is to increase the network's performance by constructing an efficient routing protocol. The most popular routing protocol that has been used in many applications is clustering. Many different methods of clustering have been developed to increase network lifetime in wireless sensor networks. Each clustering method has been used and proven to reduce the energy consumption of each node.

In this paper, we introduce an enhanced clustering method based on well proven clustering schemes - BCDCP (Base Station Controlled Dynamic Clustering Protocol) and BIDRP (Base

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Station Initiated Dynamic Routing Protocol). One of the head nodes is selected as a leader node to send messages to the base station and this leader node can vary according to the residual energy of cluster heads. Constructing an efficient routing path in clusters is very crucial to decrease dissipating energy of cluster heads. In our scheme, named "clustering protocol with mode selection" (CPMS), we use clustering and leveling methods to construct a network. The base station will collect data of each node and process the data to construct the clusters of the whole network. Each node will receive information from the base station about the clusters and energy levels. In order to save the energy of cluster heads, message transmission should be delayed if possible.

The whole paper is organized as follows: section 2 presents related work on clustering methods, section 3 provides the proposed algorithm, section 4 discusses the simulation, and section 5 describes the conclusion of the work.

2. Related Work

In wireless sensor networks the routing construction methods are very important to decrease energy dissipations. The clustering scheme has been used and proven to decrease the energy consumption of sensor nodes since it groups several nodes that are close together. In the clustering scheme, one of the nodes is appointed as a cluster head, which usually, has the highest power in that cluster. The key point of the clustering scheme is to make the cluster heads collect data in their own cluster and send them to the other cluster heads or base station. In this way, each member node can save the energy required for transmission and so they can survive longer.

2.1 BCDCP (Base Station Controlled Dynamic Clustering Protocol)

Siva D. Muganathan et al. [6] propose a centralized routing protocol called Base Station Controlled Dynamic Clustering Protocol (BCDCP), which distributes the energy dissipation evenly among all sensor nodes to improve network lifetime and average energy savings. The method assumes that the properties of a given sensor network model are a fixed base station, sensor

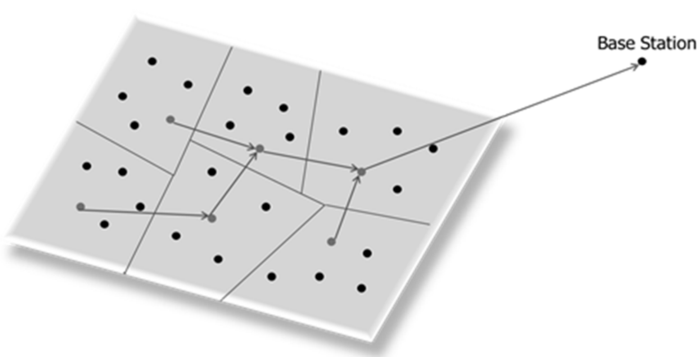

Fig. 1. Centralized base routing protocol Base Station Controlled Dynamic Clustering Protocol (BCDCP) routing path

nodes with energy constraints, nodes equipped with power control capabilities, and stationary nodes. It operates in two major phases, i.e., the setup phase and data communication phase. BCDCP uses class based addressing which gives identifications to each node in a network.

In the setup phase of BCDCP, the main activities are cluster setup, cluster heads selection, cluster head-to-cluster head (CH-to-CH) routing path formation, and schedule creation for each cluster. During each setup phase, the base station receives information on the current energy status from all the nodes in the network. The base station computes the average energy level after receiving information from each node and decides which nodes are appointed as cluster heads. The base station sends information back to the nodes which include identification for each node. Each node holds two identifications which represent the identification for each node and identification of cluster head. Each cluster head is connected to the other cluster heads and uses a minimum spanning tree to create a routing path.

In the transmission phase, each sensor node transmits the sensed information to its cluster head. Since sensor nodes are geographically grouped into clusters, these transmissions consume minimal energy due to small spatial separations between the cluster head and the sensing nodes. Once the data from all sensor nodes has been received, the cluster head performs data fusion on the collected data, and reduces the amount of raw data that needs to be sent to the base station.

2.2 BIDRP (Base Station Initiated Dynamic Routing Protocol)

An enhancement on clustering protocol was proposed in [5]. The protocol, called Base Station Initiated Dynamic Routing Protocol (BIDRP), is based on clustering and signal range initiated by the base station to increase the network lifetime.

In BIDRP, the method to choose the cluster head is the same as in Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C) [10] or BCDCP. It is initiated by the base station when each node sends its data to the base station for the initial creation. BIDRP uses a layer to send data from each cluster head to the base station while creating clusters. The base station

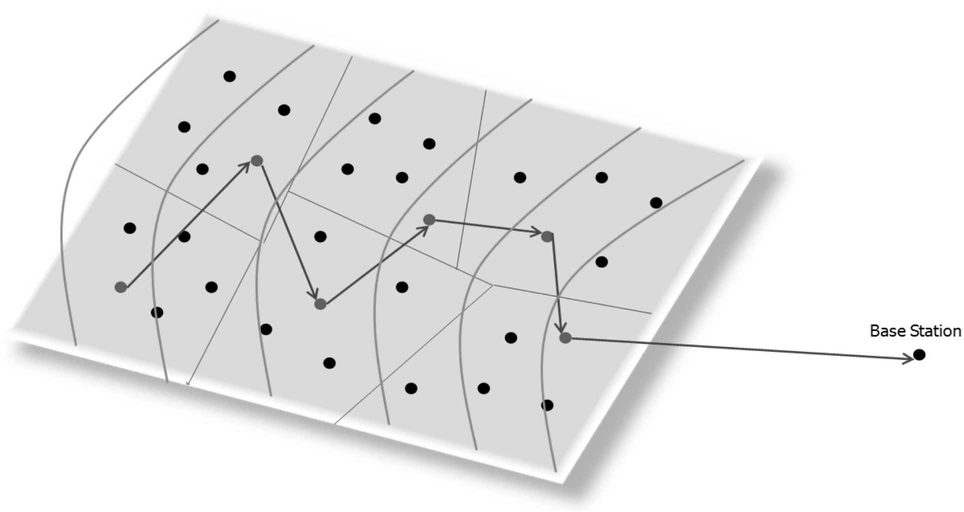

Fig. 2. Base Station Initiated Dynamic Routing Protocol (BIDRP)

sends signal levels to the cluster heads; the closest cluster head to the base station has the lowest level and the farthest one to the base station has the highest level. The farthest cluster head sends its data to the neighbouring cluster head. Thus, it creates a chain of cluster heads from the highest level to the lowest level. Then the cluster head in the lowest level (leader node) will send aggregated data to the base station. In this scheme, the leader node will dissipate energy much faster, since sending data to the base station requires a large amount of energy. Even though, the leader node has the highest energy among all other nodes, it will die quickly. In our scheme, we also use the signal level to route, but we improve the problem of the leader node's fast death.

3. Clustering Protocol with Mode Selection

We adopt the basic mechanism of BCDCP and BIDRP but we improve the performance of network lifetime - by choosing the leader node, which sends final data to the base station, considering not only the energy transmission but the energy level as well. To reduce the energy dissipation, we also introduce two modes of operation - ON and Standby.

Our scheme starts with the initialization phase in which each node sends data of energy level and location to the base station. The base station computes the values and sends a message to each node. The message contains the following data:

- ID of node,
- ID of cluster head,
- ID of level,
- ID of layer,
- Mode of operation

The next step is the formation phase. In this phase we organize clusters with ID of nodes and ID of cluster heads first and then build the energy layer's level. Finally, the leader node which will send the final aggregated data to the base station is determined.

The final step is the transmission phase, where all nodes will send data to a designated node. The prefix of each node can be assigned as follows:

- Regular node
- Cluster head
- Layer center
- Leader node

The formation phase is described in more detail in the proceeding sections.

3.1 Forming Clusters

In our scheme, we use the similar approach as in BCDCP to create the clusters utilizing the high energy base station. Since the base station has an unlimited energy source, the location of all the nodes in a network is calculated and updated by the base station. The base station performs the formation of balanced clustering, where each cluster head serves an approximately

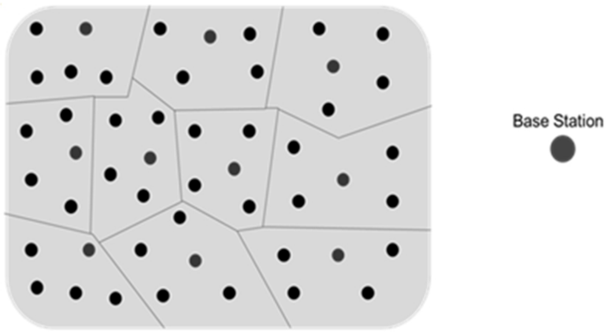

Fig. 3. The forming clusters with appointed cluster heads (the red dots are the cluster heads)

equal number of member nodes to avoid cluster head overload. At the initialization phase, each node sends the information of energy status and its location in the network to the base station. The base station executes the cluster splitting process and cluster head selection by computing their energy levels and performing a balanced clustering technique [12] in order to distribute evenly the number of nodes in each cluster as well as the load on all cluster heads. The base station sends the required information to all the nodes. The information includes the ID of node to distinguish in which cluster the node resides, and the ID of the cluster head appointed as cluster head. The creation of clusters and the selection of cluster head are identical to the scheme in BCDCP. Figure 3 shows the process of cluster formation.

3.2 Forming Layers of a Level

The focus of forming layers of a level is finding the appropriate node to send the final aggregated data to the base station, i.e., finding the leader node of all clusters. Since the energy consumption of the leader node is quite significant, we have to choose the leader node very carefully. We should not select a node just because it has the highest energy (as in BCDCP) or just because it is situated at the shortest distance from the base station (as in BIDRP), but we must consider energy and distance at the same time.

3.2.1 Creating Levels

In order to select the leader node, considering distance and energy, we have to divide the sensor field into several levels. As in BIDRP, the base station computes the signal strength from the nodes and creates an energy level hierarchy, that is, the distance to the base station becomes one of the major factors in deciding the leader node. In BIDRP, the cluster head in the lower level (i.e., the shortest distance to the base station) becomes the leader node which aggregates the sensed data and relays it to the base station. However in our algorithm, we also consider the energy status of each cluster head node in selecting the leader node.

Each cluster head will receive its ID of level denoted such as $Level_n$. Figure 4 shows the distribution of levels. The level and energy of cluster heads are used to find the appropriate leader node, and this will be described in the next section.

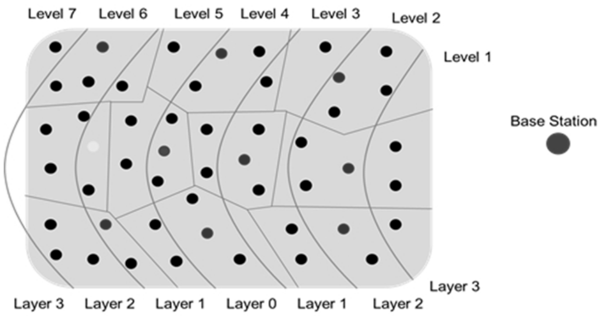

Fig. 4. Forming layer's levels

- Red dots are the cluster heads
- A Yellow dot is the cluster head with highest energy remaining
- A Green dot is the cluster head with highest energy-distance ratio and becomes the leader node

3.2.2 Calculating energy-distance ratio

In order to select the best leader node, we consider not only the remaining energy of the cluster head but also energy levels (hence the distance to the base station). The energy-distance ratio can be calculated as in formula (1):

$$R_{ED} = E_{Rm} / Level_n \quad (1)$$

In formula (1), E_{Rm} (Energy Remaining) denotes the energy remaining s in the cluster head node and $Level_n$ denotes the level where the cluster head node is located. The base station will choose the cluster head node which has the largest R_{ED} (Ratio of Energy-Distance) as the leader

Table 1. Calculation of energy ratio remaining

Level	Cluster Head	E_{Rem}	R_{ED}
1	-	-	-
2	CH_1	1	0.5
2	CH_2	1.1	0.55
2	CH_3	0.9	0.45
3	CH_4	1.4	0.467
4	CH_5	1.9	0.475
4	CH_6 (green dot)	2.5	0.625
4	CH_7	2.1	0.525
5	CH_8	1.7	0.34
5	CH_9 (yellow dot)	2.9	0.58
6	CH_{10}	2.3	0.38

node.

In figure 4, the yellow dot (CH_9) in level 5 has the highest energy (2.9 J) and the green dot (CH_6) in level 4 has the largest R_{ED}. BCDCP takes CH_9 as the leader node, BIDRP takes a node in level 2 (CH_2), since there is no cluster head in level 1, but we choose CH_6 as the leader node.

3.2.3 Creating Layers

The purpose of creating layers is to determine the direction of data transmission of cluster heads. When we decide on the leader node, we create the layer using the level of information and location of the leader node. The level where the leader node is situated becomes level 0 and the adjacent levels to layer 0 become layer 1 - there are usually two layers with value 1. The distance from layer 0 becomes the value of that layer.

The data will always be transferred from the head node in a higher layer to the head node in a lower layer. Finally, the cluster head node in layer 0, hence the leader node, will send the aggregated data to the base station. Therefore, this method will decrease the energy dissipation of each cluster head node thereby increasing the network lifetime.

3.3 Modes of Operation

In the formation phase, the modes of operation are defined to decrease energy consumption and increase the network lifetime. The modes of operation are only used for cluster heads and there are two modes.

3.3.1 ON - in this mode, the operations of cluster heads are as follows:

- Cluster head receives and aggregates data from the surrounding member nodes in a cluster.
- Cluster head can receive data from cluster heads in the same layer or upper layer.
- Cluster head cannot receive data from cluster heads in the lower layer.
- Cluster head can send data to cluster heads in the same layer or upper layer.
- Cluster head cannot send data to the cluster heads in a lower layer.
- Cluster head enters standby mode when there is no transmission of data from the member nodes for a pre-defined time.

3.3.2 Standby - in this mode, the operation of cluster heads are as follows:

- Cluster head sends a message to cluster heads in the same layer or a lower layer to be notified that this cluster head will not send data until there are changes in the data of member nodes (sensing that events occurred). Therefore, this method will reduce the waiting time in the Time Division Multiple Access (TDMA) schedule.
- Cluster head receives sensing data from surrounding node in the cluster, but does not send data to other cluster head. Once changes have occurred in the sensing data, cluster head switches to ON mode.
- A cluster head (which has the highest energy in one level) should receive data from the same layer or upper layer and send data to the lower layer, if all cluster heads in one layer are in Standby mode.
- Cluster heads that have been selected as leader node must switch to ON mode.
- Cluster heads that have new data changes in the sensing field will join the TDMA schedule by sending one message to the cluster head in the same layer or lower layer.

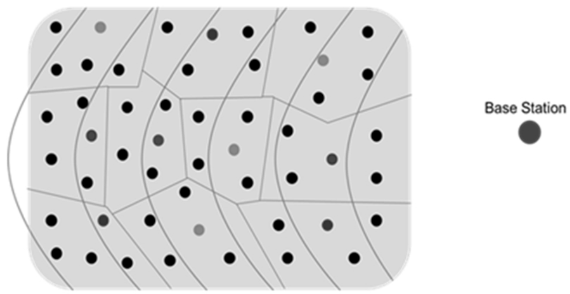

Fig. 5. Deciding the modes of operation for cluster heads

- A Green dot represents the leader node
- A Purple dots represent layer center node
- Red dots represent cluster heads in On mode
- Blue dots represent cluster heads in Standby mode
- Black dots represent regular nodes

In case there are several cluster heads in ON mode in the same layer, one of the cluster heads must be selected to be the layer's center node. The role of a layer's center node is collecting data from cluster heads which reside in the same layer. It also receives data from the upper layer of the layer center node or cluster head, and finally sends to the lower layer of the layer center node. It is elected in a similar way as leader node, by finding the highest energy ratio among cluster heads in the current layer. The highest energy ratio is computed as follows:

$$R_{ELC} = E_{Rm} / (d_{CH} - d_{LC(L)}) \tag{2}$$

The highest energy ratio of the layer center Node denoted as R_{ELC} (Ratio Energy of Layer Center) is calculated using the energy remaining of the cluster head (E_{Rm}) divided by the difference of the distance from the cluster head (d_{CH}) and layer center node in the lower layer ($d_{LC(L)}$). Once the highest energy ratio is discovered then the cluster head can be appointed as the layer center node.

The maintenance of the routing protocol in the mode operation step of the formation phase does not need to reconstruct the entire routing. The changes will only occur in the layer where each cluster head can notify its changes to the lower layer level or the upper layer cluster heads.

3.4 Construction of Routing Path

In this step, schedule creation is required to allocate the time slot in order to transmit data from a certain node to an intended node without any data collision in the receiving node. In our algorithm, we adopt a scheduling technique in BCDCP utilizing the time division multiple access (TDMA) schedule. The benefit of using the TDMA scheduling technique in our algorithm is to avoid data collision at every receiving node and decrease energy consumption. The base station assigns the identification of time slots to all nodes. The purpose of identification of time slots is to identify the time slot of each node to send its data.

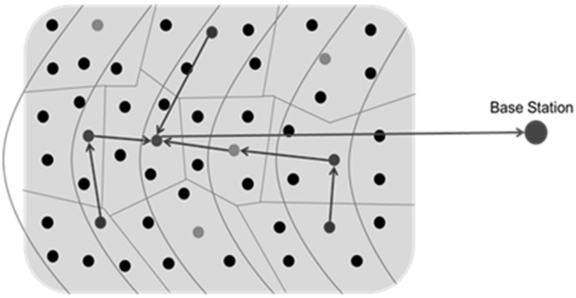

Fig. 6. Final routing example in CPMS

Each node is assigned identification for a specific time slot sent by the base station - ID of time slot. In each cluster, member nodes have the task of sending their data to the cluster head according to the assigned time as noted in the ID of the time node. Each cluster head is also assigned identification for specific time slot noted as the ID of the cluster head node (ID of CH node). In each layer, cluster heads have the task of sending their data aggregate to the layer center node according to the assigned time as the noted ID of a CH node.

In the operation mode selection step, each cluster head which is in Standby mode sends a message to the layer center node which indicates that it will not join the TDMA scheduling. Cluster heads which are changed to ON mode should send a message to the layer center node to notify that they will join the TDMA scheduling. We can run the TDMA scheduling more efficiently using the operation mode. Therefore, CPMS is more efficient than BCDCP and BIDRP regarding TDMA scheduling.

After the formation phase, the data transmission phase takes place. The data transmission phase starts by sensing the surrounding area then it sends the data to the cluster head. The cluster heads construct a cluster chain from the highest layer level to the lowest layer level then send the data through this chain. Finally, the leader node which is in the lowest layer level sends all the aggregated data to the base station.

The leader node (green dot) in figure 6 drains the energy rapidly since its role of data collection and transmission to the base station consumes a lot of energy. To avoid the leader's quick death, if the energy-distance ratio of the leader node becomes smaller than a pre-determined value, we have to change the leader node with the head node which has the largest energy-distance ratio in that status. As a result, the energy spent on the cluster heads is spread evenly throughout the network.

4. SIMULATION

To assess the performance of CPMS, we simulated CPMS performance using Network Simulator 2 (NS2) and compared its performance with the other clustering-based routing protocols such as BCDCP and BIDRP. The performance is measured by the quantitative metrics of average energy dissipation, system lifetime, total data messages delivered successfully, and number of nodes alive.

Table 2. Simulation Parameters

- Network field : 100m × 100m
- Number of nodes : n = 100
- Initial energy : E_{Init} = 3 J
- Data packet size : 4000 bits
- Energy transmit : E_{Tx} = 50 nJ/bit
- Energy transmit : E_{Rx} = 50 nJ/bit
- Energy transmit dissipation for free space : E_{fs} = 10 pJ/bit/m^2
- Energy transmit dissipation for two ray model : E_{rs} = 0.0013 pJ/bit/m^4
- Energy Aggregation Data : E_{AD} = 5 nJ/bit/message

In the experiment, the nodes are deployed in an area with the base station located far from the sensor field. The initial energy of each node is 3J and the nodes are placed in the same coordinates for each simulation. We simulate 100 m × 100 m network topologies with the base station located at least 75 m away from the nearest node. Figure 7 shows the average energy dissipation of the protocols under the study observation over the number of rounds of operation. This plot clearly shows that CPMS has a much more desirable energy expenditure curve than those of BCDCP and BIDRP. On the average, CPMS exhibits a reduction in energy consumption of 12% and 17% over BCDCP and BIDRP, respectively.

Next we analyzed the number of data messages received by the base station for the three routing protocols under consideration. For this experiment, we again simulated 100 m × 100 m network topologies where each node begins with an initial energy of 3J. Figure 8 shows the average number of data messages received by the base station over the number of rounds of activities. The plot clearly illustrates the effectiveness of CPMS in delivering significantly more data messages than its counterparts. BCDCP offers improvements in data delivery by factors of 33% and

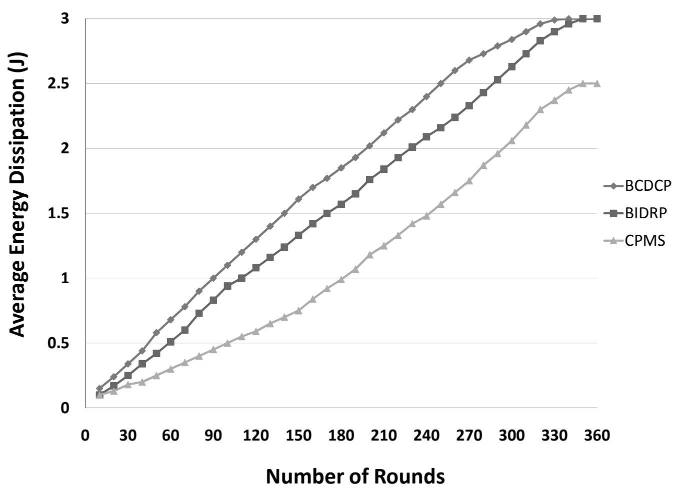

Fig. 7. Comparison between CPMS with BCDCP and BIDRP

44% over BCDCP and BIDRP, respectively.

The improvement gained through BCDCP is further exemplified by the system lifetime graph in figure 9. This plot shows the number of nodes that remain alive over the number of rounds of activities for the 100 m × 100 m network scenario. With CPMS, all the nodes remain alive for 1290 rounds, while the corresponding numbers of rounds for BCDCP and BIDRP are 678 and 777, respectively.

Figure 10, shows similar results with a different network area size of 50 m × 50 m network scenario. With CPMS, all the nodes remain alive for 2490 rounds, while the corresponding number of rounds for BCDCP and BIDRP are 1920 and 2130, respectively.

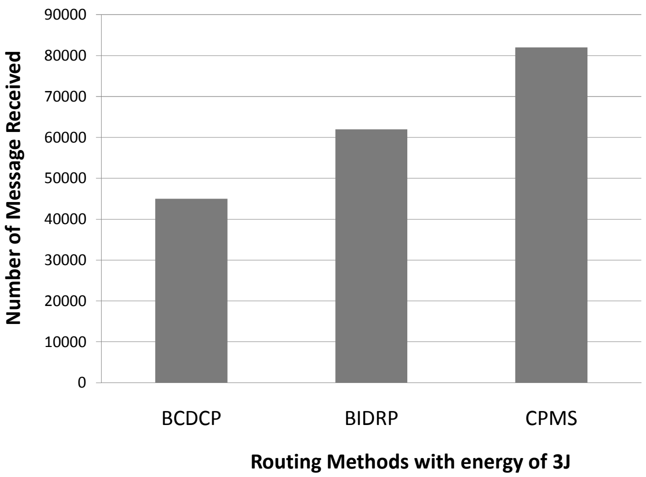

Fig. 8. Comparison of average number of data messages received at the base station

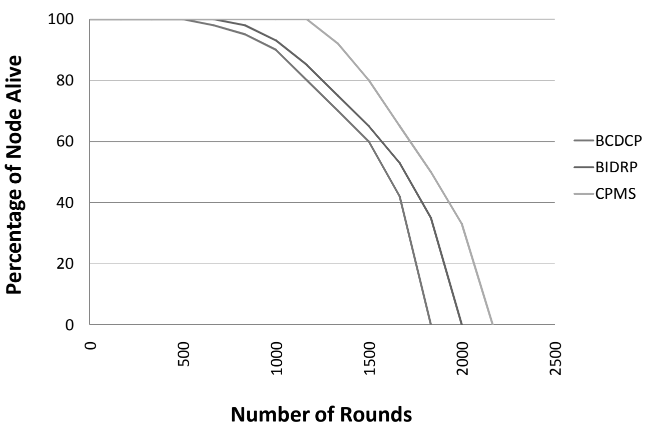

Fig. 9. Performance result for 100m x 100m

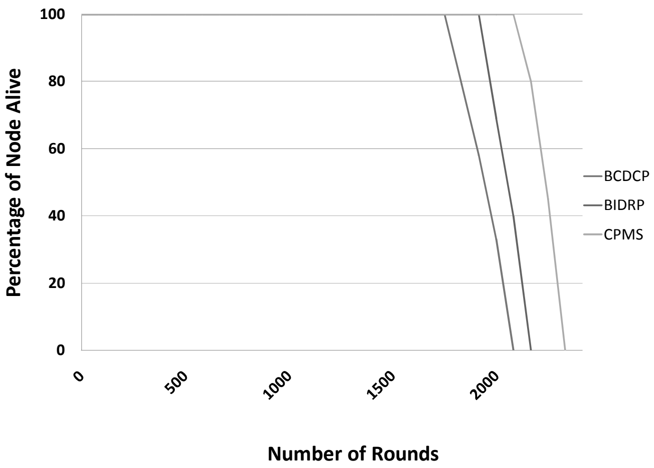

Fig. 10. Performance result for 50m x 50m with initial energy. 5J/node

5. Conclusion

In this paper we propose an enhanced centralized clustering-based routing protocol, CPMS (Clustering Protocol with Mode Selection), that utilizes high-energy base stations to perform the most energy-intensive tasks. BCDCP and BIDRP are energy efficient centralized clustering-based routing protocols. However, BCDCP chooses the leader node only based on the energy of head nodes and BIDRP chooses the leader node only focusing on its distance. Since CPMS considers the energy of cluster head nodes *and* the distance, it outperforms BCDCP and BIDRP. Furthermore, CPMS introduces modes of operation and this increases the lifetime of cluster heads.

Performance of the proposed CPMS protocol is assessed by simulation and compared to other clustering-based protocols (BCDCP and BIDRP). The simulation results show that CPMS outperforms its comparatives since it adopts the energy status of cluster heads and the relative distance between the cluster heads and the base station. It is also observed that the performance gain of CPMS over its counterparts increases with the area of the sensor field. Therefore, it is concluded that CPMS provides an energy-efficient routing scheme suitable for a vast range of sensing applications.

As future work, we will refine the formula for deciding the leader node considering more complicated factors and we will enhance the algorithm to provide better quality of service and security to guarantee access to the base station.

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