PERFORMANCE ANALYSIS OF ENERGY EFFICIENT CLUSTERING SCHEMES FOR WSN

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Abstract

Clustering enables energy constrained wireless sensor networks to consume less battery power for routing the data packets. In order to achieve the key goal of prolonging the lifetime of sensor nodes besides avoiding undesired frequent topological changes, support from clustering mechanism is much appreciable. While proposing clustering mechanisms, attention is needed the way by which the sensor nodes are deployed over the field of interest. The energy consumed by cluster heads of various clusters to collect and aggregate the sensed data from the non-CH members should be balanced over the network to the possible extent. This can not only overcome faster energy depletion of a certain number of cluster heads and improve the performance of wireless sensor networks. Instead of random selection of cluster heads, it is essential to consider the current status of nodes after each round of data transfer to assign the role of cluster heads. The key factor considered for this is the residual energy of sensor nodes. Besides this approach, uniform sensor node deployment is achievable through grid based clustering techniques. This paper is an attempt to analyze the energy efficiency perspectives of a link quality cum residual energy based clustering mechanism and a virtual-grid based clustering mechanism for efficient routing in energy constrained wireless sensor networks.

Keywords: cluster heads; energy depletion; link quality; residual energy; grid.

1. Introduction

Low power and low cost sensor nodes [1] constitute special type of ad hoc network called wireless sensor networks. One or more sensors, a processor, a radio transceiver and a battery are the principal components of a sensor node. The physical environment of interest is continuously monitored by random and wide sensor node deployment. As this network does not require any predetermined infrastructure, effective cooperation is required among these sensor nodes i.e. they need to self organize them to exchange sensed data and after dissemination of this sensed data it needs to be communicated to an external sink.

The radio range of these sensor nodes is restricted, due to limited battery power, so that it can communicate either directly to the sink or to its neighboring nodes for data forwarding. Through an appropriate routing protocol, the sensor nodes should cooperate among themselves to forward the sensed data to their destinations for multi hop communications. Exploiting adequate energy efficient communication strategies can prolong the lifetime of these battery operated sensor nodes and thus frequent topological changes can be mitigated.

The success of multi hop communication in WSN is possible through energy aware routing techniques [2]. Traditional routing schemes with a focus on optimized data transmission in terms of delay and packet loss are inadequate for WSN due to their application specific requirements. Due to this new energy efficient routing approaches are proposed for WSN with the prime goals of, finding optimal routes in terms of power consumption and balancing energy consumption among sensor nodes.

One of the effective approaches to optimize energy conserving multi hop data transmission is clustering i.e. grouping sensor nodes and assigning a cluster head which should be responsible for coordinating the sensor nodes to forward their sensed to their sink nodes in an energy efficient way.

Random cluster head selection without considering the status of the sensor node is an inappropriate approach in the sense that the selected Cluster Head may lose its energy than the predicted time and die before the task of that particular route establishment is achieved. By considering this, a derivative of passive clustering (PC) mechanism [3], link-aware clustering mechanism (LCM) is proposed in [4] to consider the residual energy of sensor nodes after each round together with the status of the link with their neighboring nodes is proposed and a comparative analysis is done. This protocol is claimed to provide better energy efficiency than the previously proposed passive clustering technique i.e. it is proved to be an energy efficient derivative of passive clustering (PC) technique.

Uneven distribution of nodes after the deployment leads to energy imbalance among the selected cluster heads. This should also be considered seriously towards the energy efficient routing performance of the energy constrained wireless sensor networks. The proposed distributed uniform clustering algorithm (DUCA) in [5] is with the aim of deploying the sensor nodes over the sensing field and then clustering them through a centralized sink. This approach ensures almost equal number of cluster members in each cluster. This helps the selected cluster heads to consume almost equal amount of battery power for their data collection and aggregation.

The rest of this paper is organized as follows: Chapter 2 gives an overview of existing energy efficient clustering mechanisms, Chapter 3 describes the various performance metrics used for performance analysis, Chapter 4 gives the details on simulation scenario and results and Chapter 5 concludes this paper.

2. Existing energy efficient clustering mechanisms – an overview

2.1 LCM – link aware clustering mechanism

Expected Transmission Count (ETX) is a metric used in [6], [7]

$$ETX_{ab} = 1 / (p_{ab}(f).\ p_{ab}(r) \qquad (1)$$

where, $p_{ab}(f)$ and $p_{ab}(r)$ are the forward and reverse delivery ratios from node s_a to s_b, respectively and used to measure the bi-directional transmission over any particular link. This metric is extended and a new metric, Predicted Transmission Count (PTX) is used in this algorithm,

$$PTX_{ab} = E_a(res) / (ETX_{ab} .\ E^{tx}(n, d_{ab}) \qquad (2)$$

where, $E_a(res)$ is the residual energy of s_a, d_{ab} is the distance between s_a to s_b and $E^{tx}(n,d_{ab})$ is the energy consumption for s_a to transmit a n-bit message over a distance d_{ab}. And $E^{tx}(n,d_{ab})$ comprises of two sub-components $E_e^{tx}(n)$, energy consumed by the transceiver and $E_{pa}^{tx}(n,d_{ab})$ is the power amplifier energy consumption transmit a n-bit message over a distance d_{ab}.

$$\text{i.e. } E^{tx}(n, d_{ab}) = E_e^{tx}(n) + E_{pa}^{tx}(n, d_{ab}) \qquad (3)$$

According to eq. (3), first order model for power consumed by transceiver is considered with reference to [8]. The evaluation of $E^{tx}(n, d_{ab})$ is based on the comparison of distance between these two nodes with a predefined distance threshold. Based on this, the channel to be used is also selected between free-space fading model and multipath fading model.

The novel metric PTX gives a clear idea on the internal state of the sensor nodes such that whether to continue with the current internal state or to change the same after each round of data transfer. LCM enables the sensor nodes to take part in energy efficient cluster based routing in an effective way.

2.1.1 Pros and Cons

It is an effective clustering mechanism as random selection of cluster heads is avoided by considering not only the residual energy of sensor nodes but also the link status. Sensor nodes contribute for energy efficient routing of data packets in the network by consuming their limited battery power according to their current internal state only i.e. nodes are not forced to take up their internal state.

But, as sensor nodes are assigned with multiple internal states, clear distinction is needed. This keeps the algorithm comparatively complex and its performance is not much suited for wide variety of scenarios. As all the nodes get involved in this routing methodology, at least in the beginning, the wastage of battery power is unavoidable. This reduces the lifetime of the network or disturbs the topology frequently.

A centralized cluster head selection mechanism may be considered to overcome the above mentioned limitations of LCM. In that sense, DUCA, a Distributed Uniform Clustering Algorithm can be considered.

2.2 DUCA – Distributed Uniform Clustering Algorithm

At the beginning, sparsely deployed sensor nodes are assigned with a virtual-grid such that, Number of grids is approximately equal to the Number of cluster heads. Each grid is assigned with an ID and the sensor nodes covered by each CH is informed about the grid ID. The network area is divided such that,

$$C \approx GT \quad (4)$$

where, C is the required number of CHs and GT is the number of grids. This facilitates the network to have almost uniform distribution of sensor nodes.

The 1st phase of CH election phase is similar to LEACH with the aim of getting a fair selection of CHs to balance the energy consumption among the sensor nodes. For each round of CH election, nodes generate a random number between 0 and 1 and when it is less than predefined threshold value, that node is elected as CH for that round. This CH selection is based on the number of times it has been selected in the previous rounds.

The goal of even distribution of CHs elected in phase 1 is achieved through the following steps in phase 2:

Step 1: The residual energy level of CHs selected in phase 1 is broadcasted by them along with their corresponding grid IDs and grid region.

Step 2: When it is found that there is more than one CH in the same grid, the one with the highest residual energy elects itself as the CH. The remaining nodes act as normal sensor nodes for that round.

Step 3: In order to get $C \approx GT$ instead of $C = GT$, the elected CHs should advertise their elections by increasing the broadcast range so as to cover the nodes in the adjacent grids also i.e. there is less possibility in few rounds that there exists a grid without CH. The nodes in the grid without a CH can associate themselves with the closest CH in adjacent grid by using Threshold Sensing Range (TRs). By this way, the number of CHs elected becomes almost equal to the number of grids in the region.

The associated nodes are driven between ACTIVE STATE and SLEEP STATE based on TRs. By this way, the number of CHs elected becomes almost equal to the number of grids in the region. TDMA schedule is assigned only for the nodes in ACTIVE STATE. SLEEP STATE is to avoid redundancy among sensor nodes.

3. Performance metrics

The following are the different metrics used for analyzing the performance of these two clustering mechanisms:

(1)Throughput – a measure of rate of successful data reception within the specified time.

$$\text{i.e. Throughput (bits/sec.)} = \frac{\text{Number of packets received successfully at the receiver}}{\text{Time duration of data transmission}} \quad (5)$$

(2) End to end delay – a measure of time taken by a data packet to reach the destination after delivered into the channel by the source

$$\text{i.e. End to end delay(sec.)} = \sum \frac{\text{(Time to receive data packets – Time to transmit data packets)}}{\text{Total number of data packets}} \quad (6)$$

(3) Transmission Cost – a measure of the required number of successful data transmissions from the source to destination

$$\text{i.e. Transmission Cost} = \sum \frac{\text{Total number of transmissions}}{\text{Total number of data packets}} \quad (7)$$

(4) Packet Delivery Ratio or Reliability – a ratio between the number of packets received by the destination and the number of data packets transmitted by the source

$$\text{i.e. Packet Delivery Ratio} = \frac{\text{Number of data packets received}}{\text{Number of packets transmitted}} \quad (8)$$

(5) Overhead – a measure of amount of control overhead required for efficient clustering and data forwarding

4. Simulation

4.1 *Simulation Scenario*

The performance of these two clustering mechanisms is analyzed using a simulation model developed in ns-2. Sensor nodes are deployed in random over an area of 600 X 600 meters. The total number of nodes is fed before start of the simulation. This number is varied between 40 and 70. Simulation is done for100 time units.

One of the nodes is assigned as a stationary sink for simulating DUCA.

4.2 *Simulation results*

Fig.1 shows the performance in terms of throughput of the deployed sensor network using LCM and DUCA clustering algorithms.

DUCA outperforms LCM in terms of throughput. To be specific, the average throughput for DUCA is for better and almost constant irrespective of the number of sensor nodes. The throughput is very poor in LCM, especially when the number of sensor nodes is less.

This is because, according to LCM, a considerable number of sensor nodes are involved with clustering process as the cluster formation is initiated and completed by nodes themselves. And as sensor nodes need to maintain several internal states, instead of being idle when they are not needed to get involved in the clustering process, considerable amount of energy is wasted rather than saving the same.

Simply, nodes do not have much clarity about their internal state or it needs considerable amount of time to decide on their internal state. This increases the time required for complete transmission of a set of data packets and thus reduces the throughput.

Even though sensor nodes are uniformly deployed based on a virtual-grid structure, there are chances of some grids with only one or two sensor nodes. As the single node cannot act as a cluster head, it has to associate itself with a neighboring cluster for its data forwarding requirements. At the same time, it increases the hop distance as it is a single hop communication.

Even when there are two nodes in a grid, it is difficult task to prioritize a node for cluster head. In this case also, support of neighboring cluster is solicited. This increases the time required for the receiver to receive the data packets as it is a long haul communication rather than forwarding it through its own cluster head. But in case of LCM, it is a direct communication between source and destination and it strictly get involved with cluster heads throughout the routing path. Due to this, there is a drastic reduction in the time required to receive the packets at the destination node.

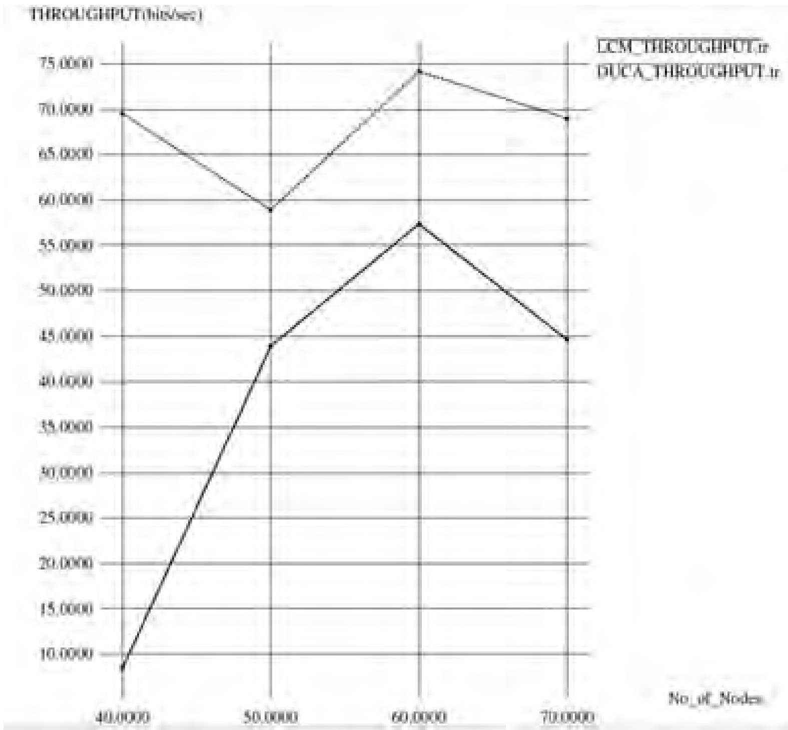

Fig.1 Performance comparison between LCM and DUCA for network throughput

The performance of the deployed sensor network in terms of end to end delay with reference to LCM and DUCA mechanisms is as shown in Fig.2. As shown, LCM outperforms DUCA in terms of delay in the reception of data packets at the destination node.

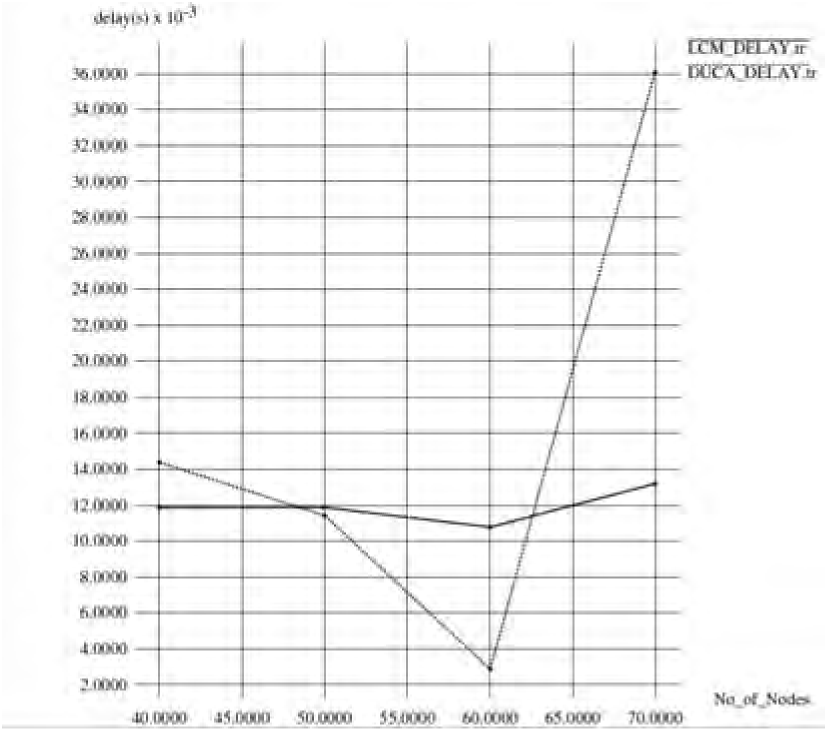

Fig.2 Performance comparison between LCM and DUCA in terms of end to end delay

Delay gets increased with the number of sensor nodes because according to DUCA, the total deployment area should be divided preferably with equal number of virtual grids in rows and columns. This is possible only when the deployment is square in structure. But whenever it is not feasible, due to non-square deployment area, the number of grids cannot be a square number as preferred by DUCA. This leads to uneven distribution of nodes and thus fails to allocate a cluster head for each grid.

The next simulation is done to compare the performance in terms of transmission cost, which is as shown in Fig.3. According to DUCA, the percentage of successful reception of data packets is appreciably good when compared to that with reference to LCM. The amount of interference is much reduced in DUCA when compared with LCM.

As the formation of clusters in LCM is completely under the control of sensor nodes, it is not done in an organized manner, even though it is claimed to have reduced control overhead for cluster formation, cluster head assignment and data forwarding. This difficulty is overcome in DUCA, as a centrally located sink initiates cluster formation and attention is given for the data forwarding task of sensor nodes without cluster head.

Even though, the transmission cost is more for less number of sensor nodes, DUCA gets stabilized with the transmission cost with the increase in the number of sensor nodes. But in case of LCM, it is opposite i.e. even though the transmission cost is less for less number of sensor nodes, it increases with the number of sensor nodes. In short, the average transmission cost involved with LCM is comparatively much higher than that for DUCA.

When the number of sensor nodes gets increased, cluster formation itself takes much more time and as the clusters are not distributed evenly, there is no uniformity in the lengths of several data forwarding paths. And moreover, congestion and data redundancy become more with increased number of sensor nodes, which are overcome to a greater extent according to DUCA.

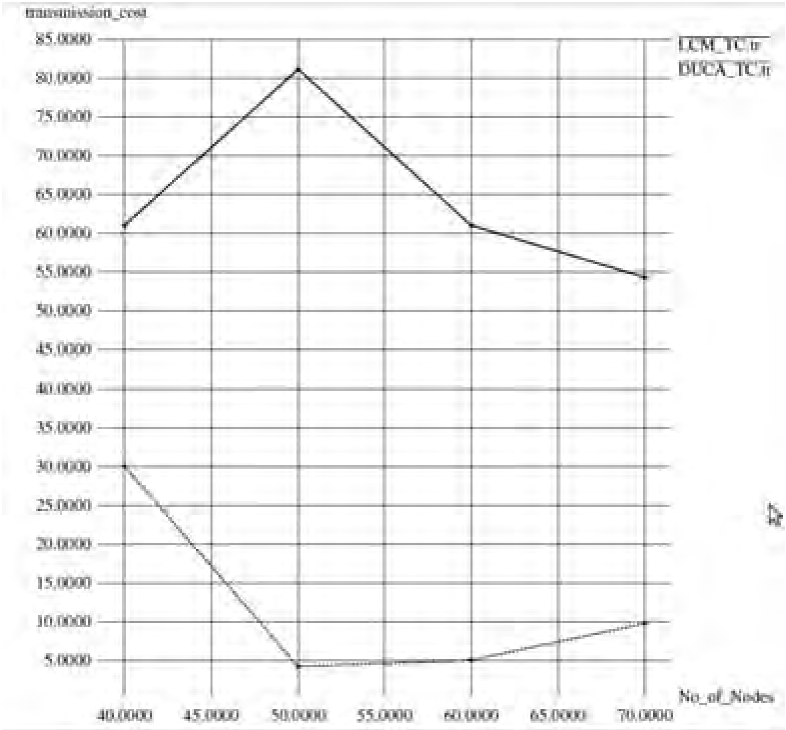

Fig.3 Performance comparison between LCM and DUCA in terms of transmission cost

The performance of the network for its reliability i.e. Packet delivery ratio under LCM and DUCA is the next simulation scenario. Even though LCM is designed with a goal of reducing the number of control overhead packets required by the sensor nodes when compare to passive clustering technique, still as the clustering and data forwarding tasks are assigned to the sensor nodes themselves, sensor nodes need to deal with considerable amount of control overhead packets. Moreover, each sensor node is assigned with a list of internal states and for each state they need to spend their energy differently. But the case is different for DUCA. As the formation of clusters, enabling nodes in virtual-grid without cluster head are controlled by a sink, the sensor nodes require less number of control overhead packets.

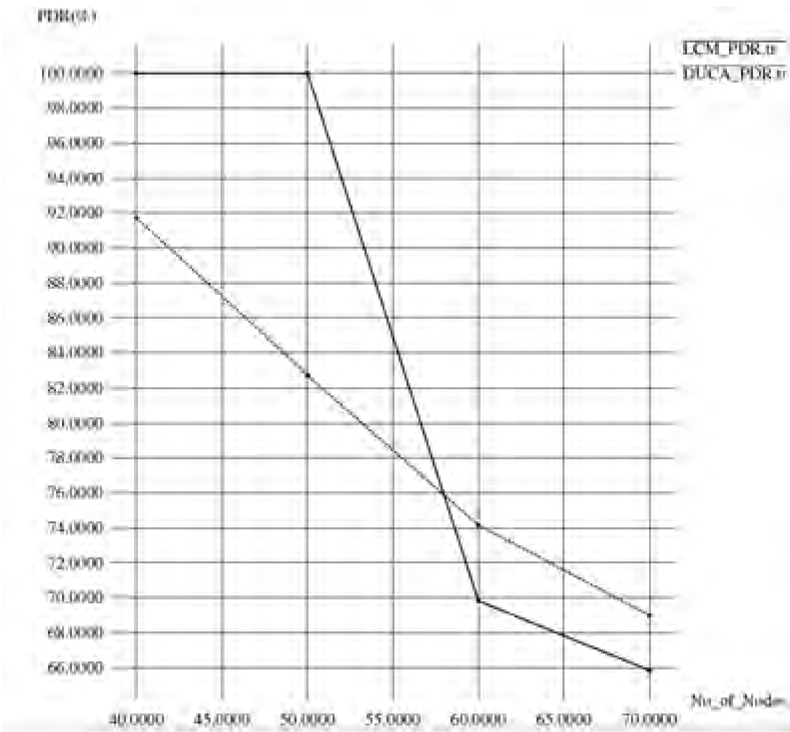

Fig.4 Performance comparison between LCM and DUCA in terms of packet delivery ratio

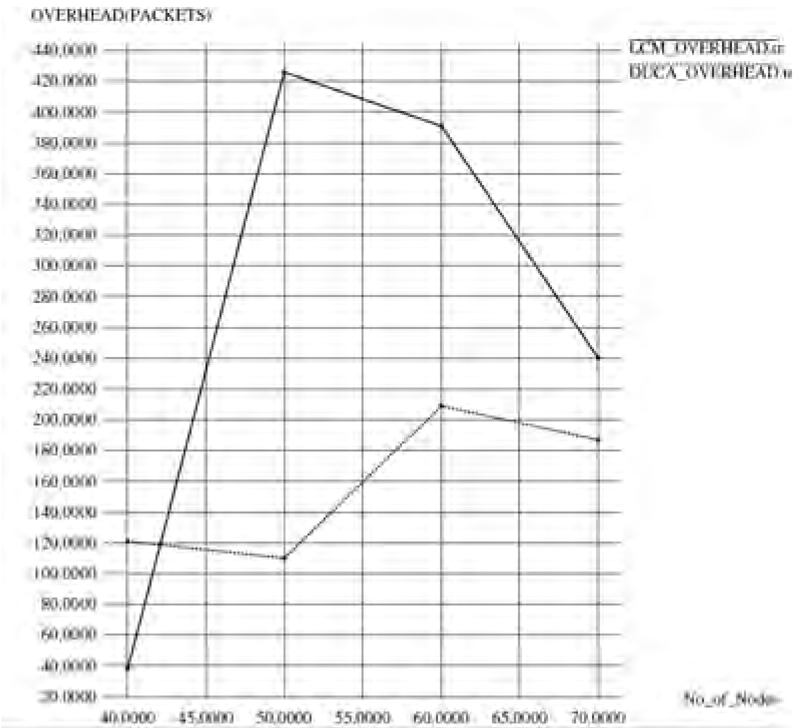

Fig.5 Performance comparison between LCM and DUCA in terms of control overhead packets

As shown in Fig.5, the average control overhead packets required for DUCA is much less than that required for LCM. As shown, LCM requires less control overhead packets than DUCA when there are less number of sensor nodes in the network as it is much easier to form the cluster and enabling the sensor nodes to forward their data without much interference.

But when the number of sensor nodes increases, the number of clusters also increases. This forces the sensor nodes to have more number of control overhead packets so as to forward their data over a much congested environment. Besides this, nodes forward their data based on the quality of link between them. This also requires extra control overhead to monitor the link quality and then data forwarding route is to be established.

5. CONCLUSION

The performance of two energy efficient clustering mechanisms LCM, which considers residual energy of the sensor nodes along with their link quality for cluster formation, is compared with DUCA that enables uniform distribution of sensor nodes based on virtual-grid structure in the formation of clusters. These two clustering mechanisms are applied to the sensor network and the network performance is analyzed in terms of throughput, end to end delay, transmission cost, packet delivery ratio, overhead. Due to its simplicity in cluster formation and maintenance, DUCA gives appreciable performance for almost all the required network performance metrics. However, the problem of keeping only one sensor node in a grid should be overcome. In the future work, defining effective trajectory to move the centrally located sink can be considered for improving energy efficiency.

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