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A Mobile sinks based Data Collection Scheme for Isolated Wireless Sensor Networks

Sunil Kumar Singh and Prabhat Kumar

Computer Science and Engineering, National Institute of Technology Patna, Patna-800005, Bihar, India
(sunil.cse14, prabhat)@nitp.ac.in

Absract: This paper considers a group of isolated heterogeneous Wireless sensor networks. Each isolated network consists of sensor nodes, a mobile sink and a commonly fixed base station (BS). Our work mainly focuses on how to minimize the energy consumption and reduce transmission delay during the data collection without negotiation on the consistency constraints of the networks. The randomly deployed sensor nodes are static and periodically send sensed data to their nearest nodes towards the mobile sink. The sensor nodes transfer their sensed data to the sink node via several intermediate nodes in the form of a tree. Here root node of the tree is considered as the sink that transfers aggregated data to the BS. Here network faces an additional problem called hot spot, where the nodes near to the BS have heavier data traffic load and they consume more energy as compared to other nodes. This results in the early death of these nodes and degradation of the overall network performance. Therefore, this paper addresses the four crucial problems related to the performance of isolated networks: (i) how sensor nodes send their sensed data to the mobile sink node? (ii) how to deal with hot spot problem that arises due to the single sink in an isolated wireless Sensor Network (WSN)? (iii) how sinks transfer their aggregated data to the BS without compromising with consistency of the network? (iv) How multi-paths data forwarding technique ensure connectivity all the time in all sinks and the BS?. In order to deal with these problems, we propose a distributed scheme for finding next location movement of the sink and formulate a graph-based problem and try to find out the shortest path with maximum data flow to the BS. Immense simulations have been performed, which indicate that the proposed scheme normally deliver better performance than existing similar type of schemes.

Keywords: Isolated WSN, Mobile sink, Hot spot problem, Data collection, Energy efficient.

1. Introduction

A Wireless Sensor Network (WSN) is a collection of sensor nodes that can sense their surrounding environmental phenomena like temperature, pressure, humidity, pollutions, etc. (Akyildiz et al., 2002). Sensors are tiny electronic devices, they can communicate with each other and form a large network. A sensor node has three main tasks sense the data, process the data and transmit the data to the BS directly or through other intermediate nodes. Among these three jobs, the maximum energy is consume in sharing the information to their neighboring nodes in the network. Communication block of a sensor consumes maximum energy in a WSN, which comprises of transmitter, receiver and power amplifier (Ahmad Abed and Baicher, 2012). Sensor nodes are mostly battery operated device and therefore energy efficient operations need to be developed. In most of the cases, sensor nodes are deployed randomly by dropping them from plane or helicopters in harsh environment. It is really tough job and costly to recharge or replace the battery of sensor nodes in such scenario. Uniform load distribution in entire network is one important way of energy conservation. In large WSN, multihop routing is more expedient as compared to single hop routing because the energy dissipation of a node is directly proportional to the distance (Prabhat Kumar and U.S.Triar, 2012) (Singh et al., 2017a). Though multihop routing is good for large area network, it has a critical issue called as hot spot problem. In hot spot problem, nearby nodes of the BS/sink die quickly because these nodes have more data traffic compared to distant nodes from the BS. The nearby nodes act as a bridge through which distant nodes transmit their data and as a consequence they suffer from hot spot problem Olariu and Stojmenovic (2006),(Singh et al., 2016),Singh et al. (2017b). If any portion of the network suffers from an hot spot problem, the whole network gets affected and network may get partitioned.

We are concerned about the data gathering issues of isolated WSNs (Tseng et al., 2013) that are detached into several disconnected subnetworks and not connected to the outside world. Here we are considering a group of isolated WSN of a limited geographical area like a Zoo, park, etc. These isolated networks are separated due to cost constraints, physical constraints, fire, node failure and natural disasters. Even if the sensor nodes are initially randomly deployed, it is not necessarily connected. Therefore, these types of isolated WSNs emerge in many practical applications. Thus, communication among these separated WSNs is essential. Most of the articles related to an isolated WSN or disconnected WSN considered the geographical area very large and they have used mobile data sinks for collecting data from these networks. A single data sink is always not sufficient to collect data efficiently due to the large area and isolated network. It causes a long delay which results in dropping packets due to buffer overflow of the node. For instance, in paper (Wu and Tseng, 2013) authors have considered a helicopter as a mobile data sink (Mule) to communicate among large isolated WSNs, which is very costly and not suitable for all networks. In order to reduce these types of issues, we have used mobile sink (MS) in each isolated WSN and these MSs having abilities to communicate with each other and also with the distant BS. Using mobile elements as the mechanical data sink is considered as a major approach to extend the network lifetime and also to gather data from isolated networks. The mobile elements travel throughout the network and collect the sensor data, store it, and drop off to access point or sink. The mobile element moves in two different approaches, predefined path and randomly selected path.

In our paper, we are using a group of heterogeneous isolated WSN where a large number of sensors are deployed randomly and after deployment, nodes are static. A mobility controlled MS is also present in each isolated network which has no resource issues. A fixed BS is located outside the whole isolated WSN. Sensor nodes sense environmental events and transmit to their sink via some intermediate node and the sink node aggregates these received packets before reporting to the BS. We address the main issues arising in our network to send data from a sensor node to the BS. Initially, we discuss how trees are formed for data collection at the sink. Next, we address how network lifetime can be enhanced by controlling the movement of the sink. We can reduce the hot spot problem in all isolated networks using the mobile sink and changing its place at a regular interval. The reliability (R) of the sink's communications have been computed for an aggregated packet to enhance the network lifetime.

The rest of the paper is organized as follows: In section 2 related research works are discussed. Then, in section 3, the network model and assumptions of this work are described. The problem statement with some sub-problems and their solutions are presented in section 4. Section 5 presents the simulation results with performance comparisons. Lastly, section 6 concludes the paper with some future works.

2. Related Work

In this section, we discuss some recent literature related to data collection by mobile elements (MEs) in two categories based on the node and ME communication.

i) Direct (one-hop) data collection: Each sensor node visited by one or more MEs and collect data directly in a one-hop communication. This type of data collection is suitable for small area networks. In large areas, individual data collection by MEs is not feasible because of more delay and energy consumption.

ii) Multi-hop Data collection: The MEs only need to visit a predefined place or a designated sensor nodes like cluster head or relay nodes and only these nodes send collected data to ME. In the multi-hop data collection, the major issues are packets delivery delay, schedule to visit nodes and hot spot.

In mobile sinks scenarios, the main concern of the researchers are extra overhead in the network due to locating the ME by the nodes and finding the most efficient location of Mobile sink. In (Shah et al., 2003) the authors explored a three-tier architecture for sparse sensor networks, known as MULE. Mules act as mobile gateways, which visit the network in an unplanned fashion. which works as mobile transport agents, for instance, humans, animals, or vehicles. The main concept of this approach is to pick up data from bottom layer(sensors), buffer it, and unload the data to the top layer (access points). Further, this work is extended by including the mule to mule communication to enhance system performance (Jain et al., 2006). Luo et al. discussed the joint mobility and routing problem with single MS, which has unlimited mobility (J. Luo, 2005). This is the best mobility scheme for collection of data in a dense network. A WSN with the single MS is considered in (Yanzhong Bi and Chen, 2007) to balance energy consumption, using proactive movement in the direction of the node that has the maximum remaining energy. Mobile sink broadcasts a notification message when it reaches a new place and through multi-hop communication, it collected data from sensor node. Hamida et al. (Hamida and Chelius, 2008) analyzes data dissemination protocols using sink mobility. In this article, sink mobility is analysed, along with its impact on energy consumption and network connectivity. Pantziou et al. (Pantziou et al., 2009) have proposed a novel scheme named MobiCluster, here sink are fitted with city vehicles and it moves with a predefined path. It is a cluster based scheme where MS collects data from rendezvous sensor nodes located nearby the periphery of the sink path. In a network, cluster head collects data from its member nodes and transfers the aggregated packets to the rendezvous nodes. The proposed protocols reduce the message overhead but the main drawbacks are network delay and hot-spot. Zhao et al. (Zhao and Yang, 2010) presented a data gathering schemes with the help of multiple mobile sinks called SenCar. Each SenCar collects data from sensor nodes when they come in their ranges. In this scheme, data gathering is high but it suffers from high overheads and delay. In paper (Luo and Hubaux, 2010), Luo et al. extended their earlier work (J. Luo, 2005) by using multiple sinks. They explored some primary issues of this joint sink mobility and routing problem by developing an optimization framework. Based on the primal-dual algorithm, authors have developed an approximate algorithm and mathematically formulated this problem. Maia et al. (Maia et al., 2013) addressed a distributed data storage protocol called ProFlex for large-scale heterogeneous WSNs with mobile sinks. ProFlex intelligently manages data collection in selected storage node to reduce the message overhead and minimizes the occurrence of hotspot problem. In (Chu and Ssu, 2014), a cluster-based mobile sink exploration (CMSE) protocol is proposed which directs messages efficiently to mobile sinks. In this scheme, multiple routing paths are set up from a sensor to sink, without knowledge of node locations to enhance network lifetime. The CMSE approach facilitates successful packet delivery to the sink, using the intersection of registration web and exploration path. In paper (Zhao et al., 2015) authors have mentioned the problem of data gathering with a mobile sink in a predefined path in a large scale WSNs to prolong the lifetime of the network. Authors have proposed a heuristic topology control algorithm by using a greedy algorithm and dynamic programming to allow the efficient data gathering.

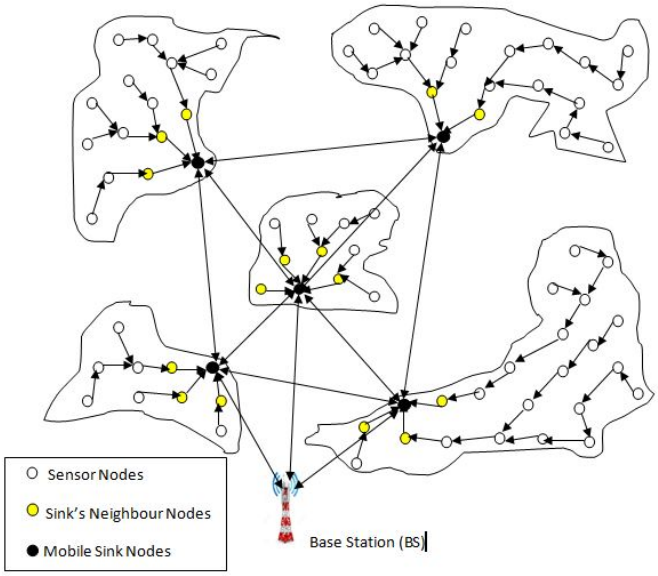

Figure 1: proposed Model Network Scenario

3. Network Model and assumptions

In this paper, we consider a group of isolated WSNs consisting of static sensors, mobile sinks and a remote fixed BS. In this heterogeneous WSN, each isolated WSN continuously observes the surroundings and sensor nodes generates packets at a regular interval. There are four different types of data communications in our network model: (i) Inter-node communication within an isolated WSN, (ii) sensor nodes to sink communication, (iii) sink to sink communication, (iv) sinks to BS communication. The BS is connected with the outside world, so our main objective is to transfer sensing data to the BS. Figure 1 illustrates the network model of our system. The assumptions regarding our network model are as follows:

- Sensor nodes are homogeneous and randomly deployed.
- Each isolated WSN is assigned a mobile sink that collects sensed data from its neighbouring nodes and sends it to the remote BS.
- The sink nodes are more powerful in terms of storage space, energy, and computation power. The sink nodes keep records of sensor node ID, location information and residual energy. Two different radios are used by each sink for communicating with the sensors and the other sinks.
- The BS is fixed and deployed far from the isolated WSN.

4. Problem Statement and Proposed Solutions

4.1. Problem definition

The paper proposes a data transmission scheme for a group of isolated WSNs where nodes are randomly deployed with mobile sinks. each isolated WSN has a mobile sinks and the BS is positioned remotely.
We classify this problem into the subsequent sub-problems:

- How do nodes send their data to the sink in an isolated network?
- How to decide, whether a sink will move to a new location or not?
- How do the sinks and the BS communicate with each other?
- How multi-path data forwarding technique ensure connectivity all the time in all sinks and the BS?

4.2. How do sensor nodes forward sense data to the sink in an isolated network?

In isolated WSN, sensor nodes forward their sensed information to the mobile sink by forming a tree-like structure (Boukerche et al., 2006). The tree formation process starts whenever the sink moves to a new location. The scheme allows each sensor node to find out the total hop levels from the sink. The tree formation for routing the packets to the sink is based on flooding method and it is started by the sink of each isolated WSN. In this way, all nodes transmit their packets to the sink till the sink does not change its place. Here in the tree structure, sink node is considered as a root node and other nodes are its child nodes. Figure 2, illustrates the formation of tree for the data collection initiated by the MS.
Initially, at the time of tree formation, sink node transmits a tree update packet (TRUD) to its one-hop sensor nodes. It contains sink id and hops count (HC) values. The total levels of hop from a source node to the sink node can be designated by this HC. The levels of hop required to reach the packet from nodes to the sink are fetched from hop table (HT), which is

maintained by each node. Initially, all sensor nodes are initialized to 0 in their HT. Whenever a sensor node receives the TRUD packet, it stores the HC value in its HT and after incrementing the HC value by 1, it forwards the packets to its neighbour. When a sensor node receives multiple TRUD packets from the sink or its neighbour, the node containing the least HC value is selected and copied into HT. This process will go on until the whole isolated WSN is not configured with the different set of hops. When all nodes get their hop levels, the sink starts gathering data from the sensor nodes in each isolated WSN. The HT maintains the previous hop sensor node id from which it received the TRUD packet. It permits uni-casting of sensed packets in the reverse path to the sink or root of the tree. After tree formation, each sensor node begins the transmission of the sensed packets at regular intervals to its root or sink. The residual energy and the HT of the nodes are also sent with sensed packets through piggybacking. The sink combines the sensed packets into a single packet and transmits these aggregated packets to the BS. At the completion of each round, a sink makes a decision for moving to a new place, based on its one-hop sensor nodes energy levels.

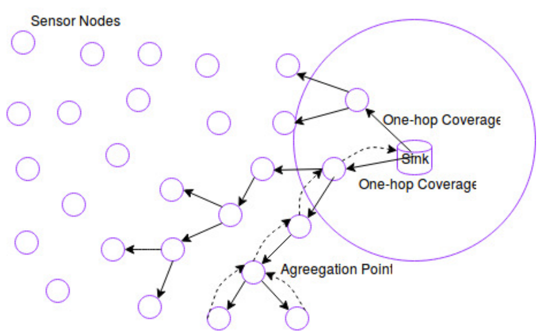

Figure 2: Tree formation for data collection by sink

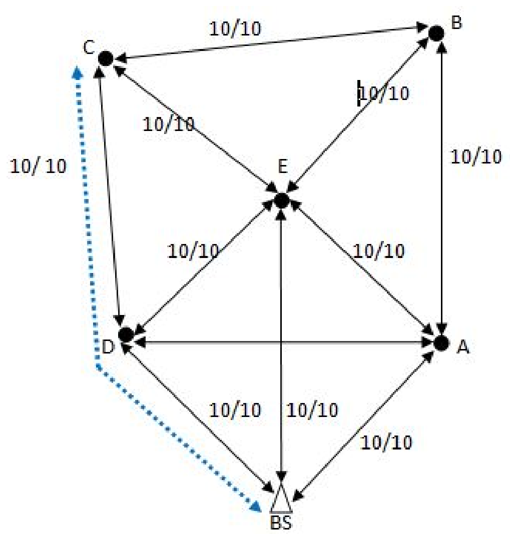

Figure 3: Sinks:A,B,C,D,E Uniform weight 10, C-D-BS one shortest path and max flow=30 computed by Edmonds-Karp algorithm.

4.3. How to decide, whether a sink will move to a new location or not?

The Data gathering by tree formation technique suffers from hot spot problem because the one hop sensor nodes from the root node consume more energy as compared to farther hop nodes. The main reason for this uneven energy consumption is that these sensor nodes have to forward the other sensor nodes packets to the sink. Hence, the sink has to change its place periodically to minimize the hot spot problem. But frequently changing the place of sink in each round consumes more energy in a new tree formation. Therefore, the sink does not change its place in each round and saves a significant amount of energy. In each round, it checks the $E_{one-hop}$, if it is below the pre-defined threshold it starts searching for new location.

$$E_{one-hop} = \frac{\sum_{i=1}^{N^{one-hop}} E_R}{N^{one-hop}} \tag{1}$$

$$E_{Net-Avg} = \frac{\sum_{i=1}^{N} E_R}{N} \tag{2}$$

$E_{one-hop}$ and $E_{Net-Avg}$ denote the average remaining energy of one-hop sensor nodes from the sink and average residual energy of the whole isolated network respectively. $N^{one-hop}$ denotes the number of neighbours of a particular node and E_R is the residual energy of each node. Equations 1 and 2 are calculated by the sink which helps to find the new location for it. The process to find sink's new location is explained in algorithm 1, which is performed by the sink.

Algorithm 1:
Carrier Movement to New Location

Step 1: Sink calculates the residual energy of $E_{one-hop}$ and $E_{Net-Avg}$.
Step 2: if ($E_{one-hop} <= \frac{E_{Net-Avg}}{2}$)
    sink looks for a new place.
Step 3: new place = max ($E_{one-hop}, N_{one-hop}$)
Step 4: if new place ≠ 0 then
    sink will go to new place
Step 5: else if sink continue with current one hop neighbours
Step 6: else isolated network dead
    endif.
    endif.
Step 7: Stop.

At the end of each round sensor nodes that are one hop away from the sink transmit their current residual energy levels to the sink. If the $E_{one-hop}$ is below the half of $E_{Net-Avg}$, then the sink looks for new location having higher $E_{one-hop}$ and maximum number of one-hop neighbours nodes $N_{one-hop}$.

4.4. How do sinks and the BS communicate with each other?

In order to achieve better throughput in terms of data transmission by the sink node to the BS, we have used two different antennas in all sinks. One low power antenna to communicate with sensor nodes and another to communicate with neighbouring sinks and the BS. Sensor nodes transmit their sensed data to the sink and the carrier sends these aggregated data to the BS, both transmissions are performed using multi-hop communication. We assume that each sink can communicate up to R distance and they know their present location. A sink explores its neighbourhood sinks by interchanging echo packets with small TTL.

After exploring all sinks of isolated WSNs, a directed graph G is constructed. In G, sinks represent vertices (V) and edges (E) are assumed between two sinks if the distance is less than or equal to R. Figure 3 illustrates a weighted directed graph with 5 sinks and a BS. There are several algorithms available for finding the shortest path with the maximum data flow. In this paper, Edmonds-Karp algorithm (Edmonds and Karp, 1972) is used due to its dual properties: always gives minimum hop path from sink to the BS with the maximum data flow. Since the sinks are located in different isolated networks, this algorithm is most suitable in terms of running time also which is $O(VE^2)$. Edmonds-Karp algorithm helps all sinks to remain connected all the time due to breadth-first search (BFS) technique used in the first step of the algorithm. When a sink is moving to a new location, it starts BFS algorithm to ensure if it is still connected to the graph G or not.

4.5. How multi-paths data forwarding technique ensure connectivity all the time in all sinks and the BS?

To ensure the connectivity all the time between sinks and BS, multiple paths are formed from sink to the BS. In order to conserve resources of each node, packet header keeps essential information required for forwarding decisions. The sink nodes ready to forward multiple copies of echo packets through multiple paths, based on few local information like (channel error, hop counts, outdegree, etc.). Before reaching the BS, this information is updated at each forwarding node. The sink nodes and the BS are connected in this way after exchanging the echo packets and Acknowledgement (ACK) packets as shown in the Figure 3. When a connection has been established, each sink has multiple paths to send its aggregated sensed data collected from the sensor nodes. The sinks transmitted their data in shortest paths with maximum bandwidth using the Edmonds-Karp algorithm as discussed in Section 4.3. We can compute reliability (R_n) (Deb et al., 2003) for a data packet from sink to the BS based on the number of multiple paths M_p of disjoint edge to the BS. We also require local channel error E_r and the number of hops from sink to the BS H_s. The R_n can be calculated using Equation 3.

$$R_n = 1 - (1 - (1 - E_r)^{H_s})^{M_p} \tag{3}$$

The Edmonds-Karp algorithm calculates the maximum flow between any two vertices for given directed weighted graph. The edges are connected based on the connectivity among sinks and the BS. A uniform weighted value 10 is assign to each edge. Using Equation 4 a sink can compute the required reliability r_n of the forwarding packets.

$$r_n = 1 - \sum_{i=1}^{p} (1 - (1 - E_r)^{H_s}) \tag{4}$$

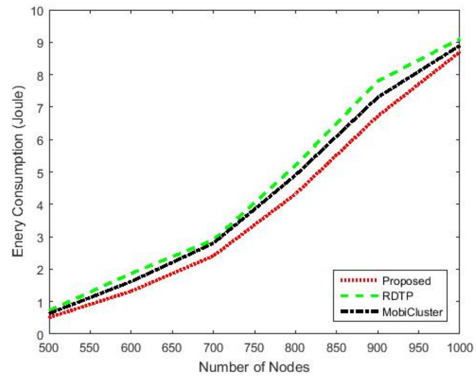

Figure 4: Energy Consumption vs Number of Nodes

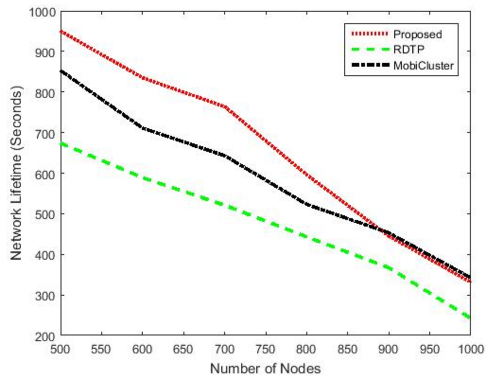

Figure 5: Network Lifetime vs Number of Nodes

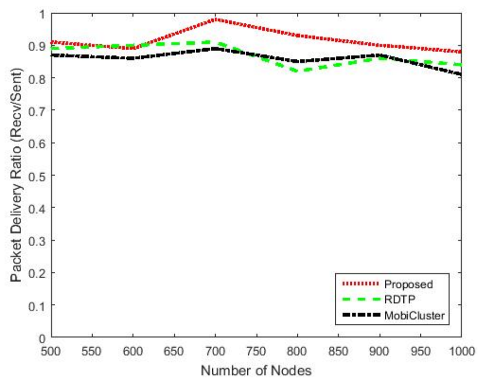

Figure 6: Packet Delivery Ratio vs Number of Nodes

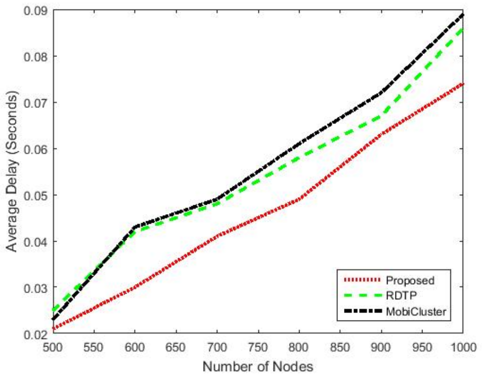

Figure 7: Average delay vs Number of Nodes

5. Simulation Results and Analysis

To evaluate the proposed scheme, this has been simulated in Matlab R2015a on Windows 10 platform with Intel Core i7 3.6 GHz CPU and 8GB RAM. For the simulations, we have taken ($1000X1000$) square meter deployment area and further this field is divided into five isolated grids by deploying the sensor nodes randomly. The size of the isolated grid is $150X150$ m^2. The nodes have an initial energy of 10 Joules. The length of packet size was 512 bytes. The wireless radio ranges of sensor nodes and sink are 50 m and 100 m respectively. In our scheme, we are using an omnidirectional antenna and IEEE 802.11 MAC protocol with CBR traffic. The constant $e_{mpfading}$, $e_{freespc}$ and E_{elect} have values 50 mJ/bit, 10 mJ/bit/m^2 and 0.0013 pJ/bit/m^4 respectively. We have simulated the proposed protocol making different scenarios by taking different positions of mobile sinks. All those scenarios are examined by deploying 500 to 1000 sensor nodes. The simulation results are discussed in the following section. Our proposed scheme is evaluated based on the several performance parameters. We have compared this scheme with the two similar algorithms (Pantziou et al., 2009) and (Zhao and Yang, 2010) discussed in section 2. The simulation graphs plotted on the average results of the 25 simulations with different deployment scenarios.

Performance metrics

The proposed scheme has been compared with the following performance metrics:

1. ***Network Lifetime***: Time till the network is alive and it is measured by the energy level of the network.
2. ***Network Consumption***: It is the average energy dissipation by the network in each round.
3. ***Packet Delivery Ratio***: The ratio between the data packets received by the BS and data packets generated by the sensor nodes.
4. ***Average Delay***: Total required time to reach the sensed data to the BS after its generation at nodes.

Figure 4 illustrates the total energy consumption by the sensor nodes and it is clearly observed that our proposed protocol has least energy dissipation as compared to RDTP and MobiCluster schemes. This is because of load balancing routing during data collection by MS using the tree structure. RDTP has more overheads due to multiple sinks synchronization and MobiCluster has a major issue to find the relay nodes for multi-hop communication which consumes a significant amount of energy. From Figure 5, an enormous divergence has been shown in terms of network life at a different set of nodes. It is mainly due to the minimum hot-spot problem in our protocol whereas MobiCluster has more hot-spot due to the fixed path for data collection. Figure 6 shows the packet delivery ratio of the network in a different set of sensor nodes. We can observe that the success ratio of the packet delivery is always more than 80%, even in the higher number of nodes also it maintains this high success ratio. This clearly proves the reliability satisfaction of our scheme. The main reason for the reliability is the sinks communication between them and also with the BS using the Edmonds-Karp algorithm, which ensured the multi-path data forwarding to the BS. Other two schemes perform poorly as compared to our scheme in terms of packet delivery ratio. The total average delay of the network is plotted in Figure 7 with respect to the number of nodes. From this graph, it is clearly shown that our scheme has less delay as compared to others. This is mainly because of all time connectivity between sinks and the BS through the Edmonds-Karp algorithm.

6. Conclusions

This paper addresses the data collection issues in an isolated WSN, where several isolated sub-networks are separated from each other. Each isolated network has a mobile sink, which collects data from sensor nodes. In this model, we have considered direct communication among all sinks with an assumption that the isolated networks are not very far. Here, the main issues that we have discussed are when and how sink nodes change their location, how all sinks and the BS are communicated with each other and how sinks transmit aggregated data to the BS via the shortest path with the Maximum flow. The sensed packets have Routed to the root or MS with the help of tree form which is simple and less complex. By changing the places of each sink periodically, we have reduced the occurrence of hot spot problem as shown in the simulation results. We also showed how sinks send maximum data to the BS through shortest path every time using the Edmonds-Karp max flow algorithm. The simulation results showed that our scheme is energy efficient and more reliable as compared to the others. In future, we will use some more network flow and data collection algorithm and compare them.

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