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Mobility and Heterogeneity Aware Cluster-Based Data Aggregation for Wireless Sensor Network

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Abstract Internet of things is the modern era, which offers a variety of novel applications for mobile targets and opens the new domains for the distributed data aggregations using wireless sensor networks. However, low cost tiny sensors used for network formation generate the large amount of redundant sensing data and hence, results in energy and bandwidth constraints. In this context, the paper proposes the sink mobility and nodes heterogeneity aware cluster-based data aggregation algorithm (MHCDA) for efficient bandwidth utilization and an increase in network lifetime. The proposed algorithm uses a predefined region for the aggregation of packets at the cluster head for minimizing computation and communication cost. MHCDA exploits correlation of data packets generated by nodes with a variable packet generation rate to reduce energy consumption by 8.66 %. Also, it prolongs the network life by 23.53 % as compared to with and without mobility of the sink and state of the-art solutions.

Keywords Bandwidth utilization · Data aggregation · Energy consumptions · IoT · Mobility and heterogeneity · Network lifetime · WSN

1 Introduction

Internet of Things (IoT) in correlation with WSN supports for the distributed event based applications that differs from conventional IP application. Emerging technology as wireless communications and IoT has paid attention for device to device communications. The

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low cost sensing devices has further scope in the evolution and applications of WSNs–IoT [1]. WSN based solutions have been designed and applied not only in the monitoring and control applications, but also in diverse areas, including building automation, disaster and waste management, and moving targets [2, 3]. Sensor nodes used in these applications are scarce in terms of resources such as memory, computation power, bandwidth, and energy [4]. In particular, the framework of IoT, with large number of static sensor nodes is deployed for remote monitoring and control applications. A randomly deployed sensor nodes over a large geographical area senses the event and reports the readings to the cluster head (CH). The huge amount of sensed data consumes more bandwidth with possibility of collision before reaching to the sink. The unconditional and random deployment frequently changes the network structure and hence, a topology. A dynamic environment, low bandwidth, limited battery power, and the constrained storage capacity of the nodes, necessitate aggregation of the data. Also, each node must know an energy efficient routing path to forward the aggregated data packets to the sink with low congestion [5]. One of the way to reduce energy consumption is use of cluster-based aggregation on the packets generated by nodes at a variable rate [6]. It is seen that energy consumption in an equal rate of packet generation is less as compared with different rate and is also less by the tree based approach.

Industrial WSN systems are well suited for the environmental data acquisition using smart sensors for IoT representations [7]. Data aggregation algorithms in WSNs–IoT are application specific and export the data to data base as shown in Fig. 1. Wireless sensor networks (WSNs) with IoT provide a dynamic network infrastructure for data aggregation, distribution, and processing. It aims to combine several packets from the sensor nodes in an efficient manner and compress the data [8]. The CH acts as a gateway for receiving information from the nodes and applies the additive and divisible aggregation functions to reduce the packet count. This saves the energy, improves the network lifetime, and bandwidth utilization. In the hierarchical WSN, resource allocation primarily relates to the amount of bandwidth given to the CH.

This paper considers the network model that refers to cluster-based aggregation with node heterogeneity in-terms of energy and sinks mobility. With static environmental conditions, the layered architecture used in cluster-based data aggregation increases the network lifetime and reduces the energy consumption. But with the mobile environment, it

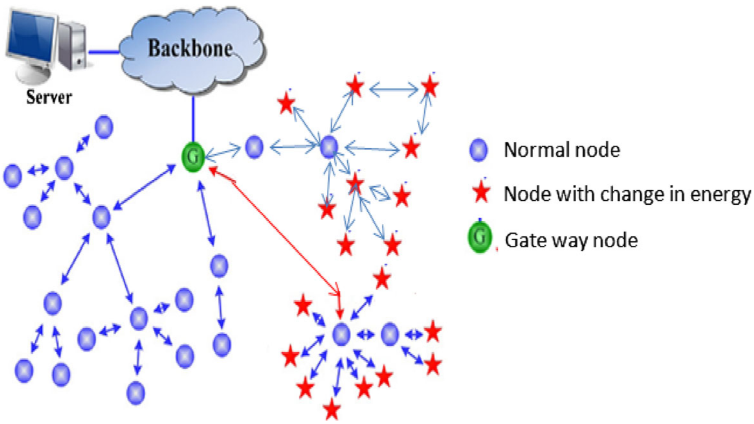

Fig. 1 Heterogeneous network of WSN

is challenging to aggregate the data. The proposed MHCDA uses multi-hop aggregations to reduce the energy consumption and increase the network lifetime. It exploits the aggregation functions by the correlation of number of packets and data generated by the nodes at variable rate. It effectively reduces the packet count reaching to the mobile sink, and hence, improves bandwidth utilization with reduced packet delivery ratio (PDR) and Throughput, while transferring the data to other data bases.

The remainder of the paper is organized in the following sections as Sect. 2 presents a review of the related works. Section 3 describes the assumptions and the proposed network model used for the MHCDA algorithm. Section 4 describes the details about the proposed MHCDA algorithm. Section 5 discusses the simulation setup and results with and without sink mobility and, the finally paper concludes in Sect. 6 with future work.

2 Related Works

The cluster-based aggregation is used to improve the network scalability and energy efficiency. As the sensor node has limited resources, efforts are continued to minimize the required resources, one of the attempt is the use of cluster based aggregation with sink mobility and node heterogeneity. CH receives the number of data packets from the cluster members and performs the additive or divisible aggregation function.

In [9], different cluster-based algorithms are explored for the efficient cluster formation and election of the cluster head, which is further used for aggregating the information. In [10], the topology management protocol has been extended to support event driven data transmissions and dynamic cluster formation. In [11], author used the aggregation principle to reduce the transmission time and active node interval for increase in the network lifetime and channel utilization. In [12], the idea of minimizing energy consumption by use of additive and divisible aggregation function at cluster head and sink is explored. In [13] Cluster Wide Correlated Grouping (CWCG), proposes the hybrid structure for data aggregation. It uses the concept of temporal and spatial grouping of nodes. It provides reduced transmission cost, but increases the latency. In [14], hybrid approach for static and dynamic clustering is presented. The protocol extends towards the adaptive nature based on the velocity of the target. Dynamic clustering shows better performance when the velocity of the target is high. It degrades with imperfect data aggregation. Grouping of Clusters for Efficient Data Aggregation (GCEDA) [15] shows that, energy consumption improves by 14.94 %, if the number of clusters are grouped according to semantic conditions for the inter-cluster aggregations.

In [16], author considers the efficient integer linear program (ILP) formulations in the two-tiered network for assigning sensor nodes into the cluster. The relay nodes act as cluster heads with multi-hop communications. In [17], the effect of nodes mobility in the formation of a cluster and CH election is within the fixed size cluster area is considered. In [18], the channel time allocation approach and energy is used to balance the throughput and energy consumption in multi-rate WSN. In [19], authors consider the heterogeneity of nodes with an advanced and super node, performance of the algorithm is tested for the static nodes and need to consider for the mobile nodes. In [20], performance of WSN for the energy efficiency is measured using static and mobile sink with a duty cycle as the computation metric. In [21], it shows that uniform deployment of static heterogeneous nodes with a separate data collector has the improvement in network lifetime. It avoids the hotspots, but has more energy consumption. In [22], a battery friendly packet aggregation scheme is used to reduce the battery consumption. In [23], management architecture (MARWIS) is presented for the heterogeneous WSNs and the author proposes to subdivide the large network into small subgroups. It contains the sensor node of the same type for improving resource utilization. The clustering algorithm does well for the static conditions but needs special consideration for the changing environmental conditions. The self-configured and heterogeneous nodes in the network ensure the long network lifetime, maximum energy saving, and better bandwidth utilization.

3 Proposed Network Model

The proposed network model uses the heterogeneous nodes in terms of energy and is considered according to the health care applications. The nodes used to generate the number of packets and random data has following assumptions.

3.1 Assumptions

3.1.1 Node Assumptions

All the nodes are heterogeneous in terms of energy and have equal significance. Packet and data generation rate (PGR) of each node is different and not known to each other. All the nodes within the cluster are at one hop for intra-cluster aggregation and have an identification number. Each node generates packet and data using a random function in the range of 0 and 1.

3.1.2 Network Assumptions

All heterogeneous nodes in the network are randomly distributed with equal density in different regions. Each region has one stationary CH that performs the aggregation. Network has single mobile sink. Clusters are considered as multi-hop and have mixed links, unidirectional for intra-cluster and bidirectional for the inter-cluster aggregation in the network. Lifetime of the network is considered up to the first node die.

3.2 Network Model

The network model used for the IoT applications is shown in Fig. 2 that uses WSNs with heterogeneous nodes organized in the clusters. Each cluster represents the identity of a different task and consists of a set of source nodes with different energy levels as normal nodes (NN), advanced nodes (AN), and super nodes (SN) with variable PGR. They are represented as the connecting graph G (V, E) with in cluster region and every sensors is represented by a set of vertices 'V' and wireless connecting edges 'E'. The nodes {S1, S2, …, SV} in the network are randomly distributed and organized into 'n' clusters using a multi-hop clustering algorithm. Some of the nodes'h' is deployed with higher energy (30, 40 J) than the normal nodes 'u' (20 J). Now, consider that each cluster has 'N' nodes out of which 'u' and 'h' nodes '$u, h \in N$' acts as a cluster member and generates the variable number of packets {r_1 (t), r_2 (t), …, $r_{u,h}$ (t)} of fixed size. The CH performs the additive and divisible aggregation function f (A) = {f (S1), f (S2), f (S3), …, f (Su, h)} i.e. on generated packets and data. It considers the spatial and temporal correlation of packets generated by each node within the

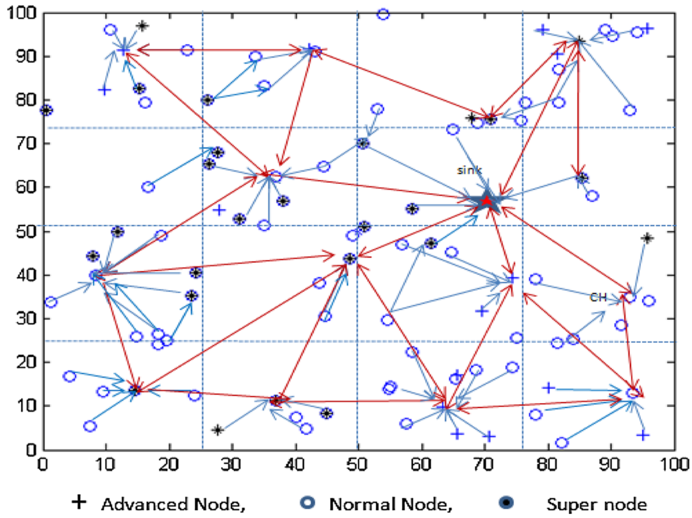

Fig. 2 Proposed network model for MHBCDA

region. Local Aggregator (LA) performs the intra-cluster aggregation of packets and data by applying the aggregation function like sum, count, avg, min, max, and divide. Aggregator/ Gateway (A/G) nodes forward the aggregated data packets from one CH to the other, and to sink. It is assumed that S, LA, and A/G may change over a period of time.

The basic design objectives of the MHCDA for aggregation and bandwidth utilization are:

- Elect the CH and decide the aggregation function.
- Minimize the communication cost with better bandwidth utilization, increase the network lifetime with reduced energy consumption.
- Analyze the effect of mobility of sink on the performance of the algorithm.

3.3 Aggregation Function and Energy Calculations

Abbreviations: K = packets generated at different PGR.

M = packets generated at equal PGR.

X = sum of packets due to different PGR.

Y = average of the number of packets generated by equal PGR.

If X_i and Y_j are two variables that represents the number of packets generated (different and Equal) by the '*u*' *and* '*h*' participating nodes in the cluster, provided that $i = 1 \ldots$K and j = 1…M, then the perfectly compressible aggregation function will be
Additive functions: If each of the heterogeneous node in the specified region of the cluster has variable PGR then the aggregation function is,

$$\begin{cases} Sum = f(A_s) = \sum_{i=1}^{K} (X_i) & for\ \forall (X_i) =\ different\ PGR \\ X_i = (p_{r1} + p_{r2} + \cdots + p_{ru}) & //Sum\ of\ packets\ by\ nodes \end{cases} \tag{1}$$

Divisible aggregation function: If PGR of the entire heterogeneous node is same then the aggregation function is,

$$Average = f(Av) = \frac{1}{M}\sum\nolimits_{j=1}^{M}(Y_j) \quad for\ \forall(Y_j) = equal\ PGR$$
$$Y_j = (p_{r1} + p_{r2} + \cdots + p_{ru})/n_{u,h} \tag{2}$$

The total initial energy in the network is
With the consideration of heterogeneity of nodes in the network, the total initial energy of network is

$$E_i = N(\alpha E_n + \beta E_a + \gamma E_s) \tag{3}$$

α = % normal nodes with E_n = 20 J, β = % advanced node with E_a = 30 J and γ = % super nodes with E_s = 40 J, N = Total number of nodes.
With equal number of nodes in the network $\alpha = \beta = \gamma = 1/3$
The cost of aggregation according to [14] is

$$C_i = \sum\nolimits_{j \in N_i} \cos t(n, CH) + \cos t(CH, \sin k) \tag{4}$$

This indicates the energy consumed by a cluster member 'n' to send a packet to CH and CH to sink.

4 Proposed MHCDA

The MHCDA algorithm for improving bandwidth utilization and a decrease in energy consumption is divided into three phases as cluster formation, intra-cluster aggregation, and inter-cluster aggregation as shown in Fig. 3. In the first phase, all the heterogeneous nodes distribution is random and becomes a member of any one cluster. The whole network area is divided into a small region of 25 × 25 m. From each region, one CH is elected according to the highest energy among the nodes (normal, advanced, or super) and the highest number of average neighbor nodes. Re-election of CH has not been considered, thus, saving energy. In the second phase, CH is responsible for aggregation of the data packets of a fixed size. In the third phase, the aggregated packets from CH are forwarded to the mobile sink with inter-cluster aggregation at multi-hop level. This reduces the communication cost.

To perform aggregation, the CH takes the spatial and temporal relations into account in terms of PGR of source nodes and random data within cluster limits. This phase runs recursively for all the clusters within the network for intra-cluster aggregation. In the third phase, each CH is considered as one node for performing inter-cluster aggregation and communicates the aggregated packets/data to the sink by forming graph of CH as G = {C_1, C_2, C_3, …, C_n}. The aggregation function applied on packets at intra and inter cluster aggregation reduces the packet count hence PDR and throughput. The algorithm considers the effect of packet and data aggregation of MHCDA with and without the mobility of sink.

4.1 Details of Algorithm

This section deals with the actual working phases of MHCDA. MHCDA works in three phases as cluster formation, intra-cluster and inter-cluster aggregation.

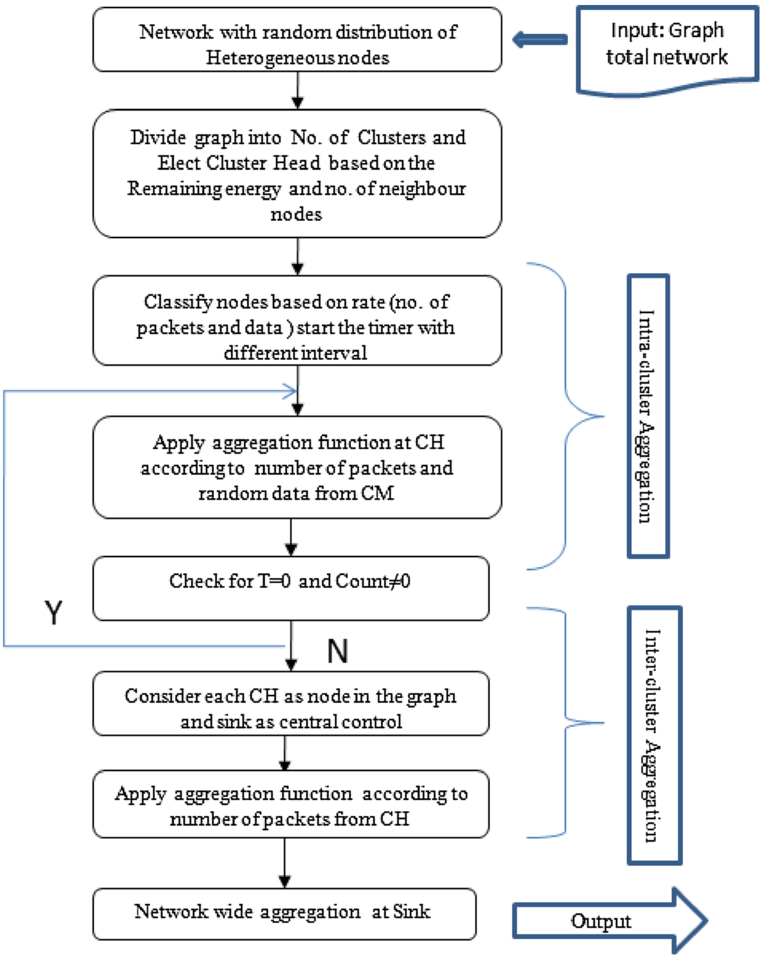

Fig. 3 Flow chart for the steps to be followed

4.1.1 Intra-cluster Aggregation

It is assumed that nodes are heterogeneous and part of the network graph G with 'N' number of nodes into each cluster. Let P denote the set of all packets received by the CH from the nodes within the region R. CH performs the aggregation on the packets arrived at $t = 0$ and calculates effective count $C_p > 0$. Let $f_p(t)$ denote the number of packets aggregated at time $t > 0$. The state of CH at time t is denoted by its vector $f(t) = \{f_p(t)\}$. Note that each node u, h ε R will transmit a packet to CH with a set of active links (u, h, CH). Let 'P_s' denote the set of all possible packets received, and $P(u, h)$ denote the set of packets transmitted when node 'u, h' are active. Therefore, an intra-cluster aggregation function based on the current number of packets from nodes at time t calculated according to Eqs. 1 and 2 is.

$$f(P_s, CH) = \sum_{p \in P} C_p\{p(u,h) \in R, f_p(t)\} \tag{5}$$

Algorithm 1 gives details of CH formation and intra-cluster aggregation.

```
Algorithm1: for Intra-cluster Aggregation
Input: Graph G (V, E) with 'n' clusters distributed in Clusters
Output: CH with aggregated information
1. Sink node generate parent announcement message
   (Par_ann_msg)
2. Set  Par_ann_msg -> parent_ch = Sink_id
   Par_ann_msg -> hop_count =1
   Par_ann_msg ->Previous_hop=Sink_id
3. Initialize the timer for periodically broadcast Par_ann_msg
4. If Par_ann_msg is received by CM
   If (Routing_table (seq_no) < Par_ann_msg ->seq_no)
   { Update the Routing Table
     (Next_hop) = Par_ann_msg – >Previous_hop:
         Hop_ count ++, Previous_ hop->current node id
     Par_ann_msg ->hop count++;
     Par_ann_msg ->Previous_hop=current_node_id
     Forward to CH }
     Else
   { If (Routing_table (seq_no) == Par_ann_msg ->seq_no)
   { If (Routing_table (hop_count) < Par_ann_msg – >hop_count)
{
     Routing_table (Next_hop) = Par_ann_msg – >Previous_hop
     Increment hop count
     Par_ann_msg ->hop count++;
     Par_ann_msg ->Previous_hop=current_node_id
         Forward to CH    }  }  }
     Else   {
     Drop the Packet  }
5. If  Par_ann_msg is received by CH
   If (Routing_table (seq_no) < Par_ann_msg ->seq_no)
  { parent_ch = Par_ann_msg -> parent_ch;
     (Next_hop) = Par_ann_msg –> Previous _hop:
     change parent cluster id to its node id
     Par_ann_msg -> parent_ch=current_node_id;
     Forward to other CH   }
     Else
   { If (Routing_table (seq_no) == Par_ann_msg ->seq_no) {
     If (Routing_table (hop_count) < Par_ann_msg – > hop_count)
{
     Sets parent_ch = Par_ann_msg -> parent_ch ,
     Routing_table (Next_hop) = Par_ann_msg –>Previous_hop
    Par_ann_msg -> parent_ch=current_node_id;
                 }        }  }
    Else
   {
    Drop the Packet  }
    End if
```

4.1.2 Inter-cluster Aggregation

In the third phase, graph G includes the sink and all participating CH as G = {CH_1, CH_2, … CH_n} with all V {CH, sink} and E_c are the connecting edges between all the cluster heads and the sink. The algorithm 2 used for the intra-cluster aggregation operates recursively for the inter-cluster aggregation with the same assumptions.

Algorithm2: for Inter-cluster Aggregation

Input: Graph *G (V, E)* with *'n'* clusters $G = \{C_1, C_2, C_3, \text{- -} C_n\}$
Output: CH with aggregated information and sink with network wide aggregation.

1. All the CH acts as nodes with aggregated packets
   { If (intra-cluster aggregation) then
   If (event of interest) then
   Generate packets and data at a variable rate
   Forward to CH
   Apply the aggregation function at CH according to equation 1 and 2
   else
   Store it and aggregate with other readings
   End if
   Else
   Generate the data and packets using a variable rate and a random function
   End if
   Forward to CH (Aggregator) }
2. Collection Phase:
   { If (packet reaches to the aggregator)
   Store into routing table
   If (Previous packet/ data= next Packet/ data) then
   Drop the packet/data (no aggregation)
   Else
   Wait for T sec/count
   If (count =0) then
   Apply perfectly compressible aggregation function
   End if
   End if
   End if
   }
3. provide mobility to sink
4. Sink with all the aggregated packets.

4.1.3 Energy Model

According to the first order communication model of [15], the energy consumption by the nodes to transmit 'K' bit of data packet to CH is proportional to d^2 and is

$$ET_c = K \times E_e + \begin{cases} K \times E_S d^2 & d \leq d_0 \\ K \times E_l d^4 & d \geq d_0 \end{cases} \tag{6}$$

where 'E_S' and 'E_l' represents the energy consumed by nodes in the transmission of data packets to CH or sink i.e. the distance of nodes to its CH (d^2) and sink (d^4), E_e is the energy dissipated per K bits by the transmitter and receiver circuit. The threshold distance 'd_0' is a function of amplifier energy. Moreover, the energy consumed to receive K bit message includes the cost of aggregation.

$$ER_c = K \times (E_e + E_{DA}) \tag{7}$$

where 'E_{DA}' is the energy consumed in aggregation of data packets at CH. Under the random distribution of nodes, each cluster contains the 'N/n' nodes, then energy consumed by the CH (E_{ch}) is

$$E_{ch} = \mathrm{K} \times (\mathrm{E}_e + E_s d^2) + (((N/n) - 1) \times \mathrm{K} \times (\mathrm{E}_e + \mathrm{E}_{DA})) \tag{8}$$

First part of the equation indicates the energy consumed by CH in the transmission of broadcast messages within the cluster region. The second part indicates the energy consumed in the reception of packets from {(N/n)-1} nodes in the cluster. Therefore, Eq. (8) can be rewritten as:

$$E_{ch} = \mathrm{K} \times \mathrm{E}_e(N/n) + \mathrm{K} \times E_s d^2 + (((N/n) - 1) \times \mathrm{K} \times \mathrm{E}_{DA}) \tag{9}$$

5 Simulation Results and Analysis

The performance of the MHCDA algorithm is evaluated with heterogeneous WSN, with and without mobile sink. Each node has variable packet and data generation capability. The results are obtained using a network simulator NS-2 for different performance measures and are compared with the Energy Efficient Clustering and Data Aggregation Algorithm (EECDA) [19]. Table 1 summarizes the simulation parameters used. The parameters are considered according to TRF 1000 sensor node.

5.1 Results by Node Heterogeneity with Sink Mobility

In this section, the performance of MHCDA is analyzed by considering the heterogeneous nodes in terms of energy and movement of sink throughout the network to collect the packets aggregated by all the CH. Sink is moved at the constant rate by predefined path.

Table 1 Simulation parameters

Parameter	Value
Network size	100 × 100 m
Number of nodes	100
Initial energy of sink	100 J
Energy of heterogeneous nodes [NN, AN, SN]	20 J, 30 J, 40 J
Propagation model	Two ray ground
Packet size	64 bytes
Transmission power	0.8 mW
Receiving power	0.6 mW
Simulation time	500 s
Packet generation rate	0.02–0.2 Kb
Sink mobility	10 m/s

5.1.1 Throughput

Figure 4 shows throughput results under equal and different PGRs for the CH to mobile sink. MHCDA achieves around 68.79 and 72.87 % lower throughput as compared with EECDA. Lower throughputs are due to the elimination of repetitive readings in the packet and data aggregation at the intra and inter-cluster aggregation stage. Also; it shows lower throughputs of 19.08 and 25.17 % in equal and different rate of data aggregations of MHCDA and packet aggregation of EECDA. If only MHCDA is considered, then data aggregation has higher throughput of 61.43 and 63.75 % over packet aggregation. Throughput is measured with the number of bits received at the sink. Lower throughputs as compared with EECDA indicate that MHCDA consumes less bandwidth as discussed in Sect. 4.

5.1.2 Average Energy Consumption

Figure 5 demonstrates the comparison of average energy consumption. With the application of additive and divisible aggregation functions at the CH, MHCDA consumes 3.47 and 3.95 % less energy with equal and different PGRs as compared with EECDA. With the data aggregations, the energy consumption increases by 0.43 %. This is because each node generates the different number of data packets in each round of aggregation and packets that reach the sink are more. EECDA has a higher number of packets and consumes more energy as compared with MHCDA. The energy savings of MHCDA prolongs the lifetime of the network and shows the effectiveness of MHCDA.

5.1.3 Packet Delivery Ratio

Figure 6 shows that MHCDA achieves 68.42 and 74.51 % PDR as compared with EECDA with equal and different rates of PGR. When compared with data aggregation, MHCDA has 19.97 and 29.26 % low PDR (i.e. number of packets with redundant/repetitive data travelling in the network). It is due to the application of additive and divisible aggregation functions at intra and inter-cluster aggregation stage. It shows effective utilization of bandwidth and an

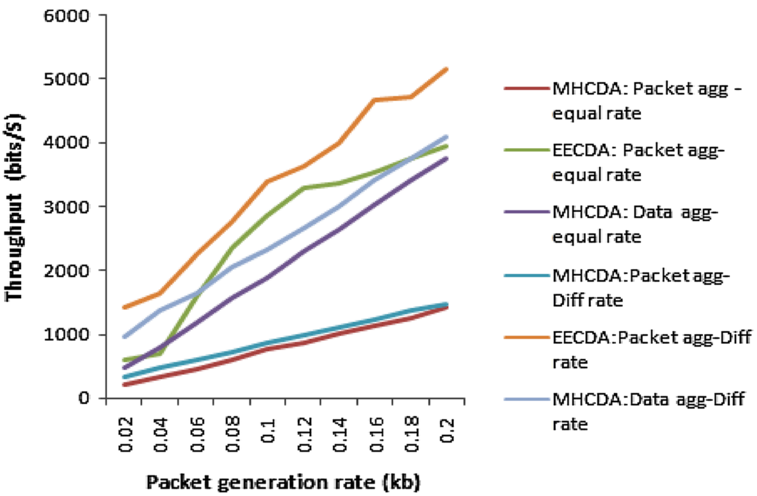

Fig. 4 Comparison of throughput

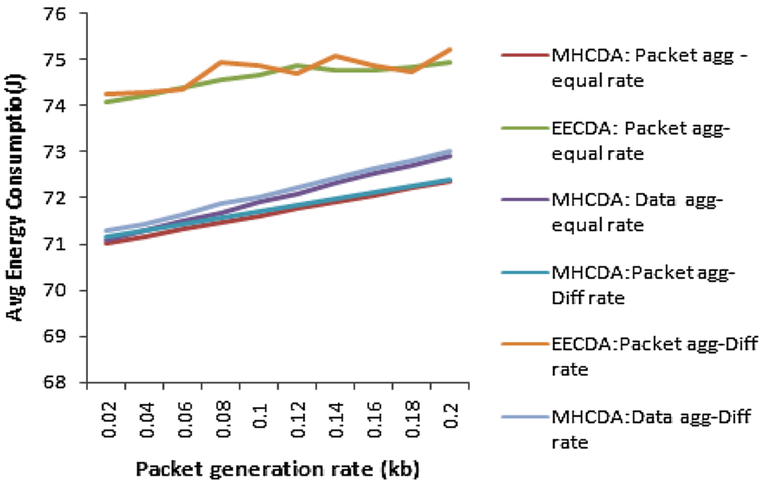

Fig. 5 Comparison of average energy consumption

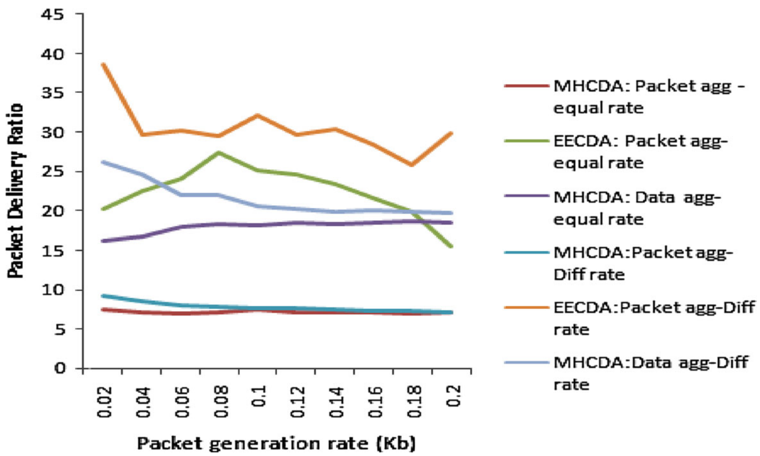

Fig. 6 Comparison of packet delivery ratio

increase in network lifetime. PDR is defined as the ratio of the total number of packets received by the sink to the total number of packets generated by all the nodes.

5.1.4 Residual Energy

Figure 7 shows that, the residual energy of MHCDA is higher by 8.23 and 9.78 % as compared with EECDA with equal and different PGRs. As compared with data aggregation, it is less by 7.02 and 8.33 %. The residual energy of MHCDA slightly (1.02 %) differs with packet and data aggregation. Residual energy directly varies with the number of packets that reach to the sink, and it also depends on the aggregation time. Higher residual energy indicates an improvement in the network lifetime.

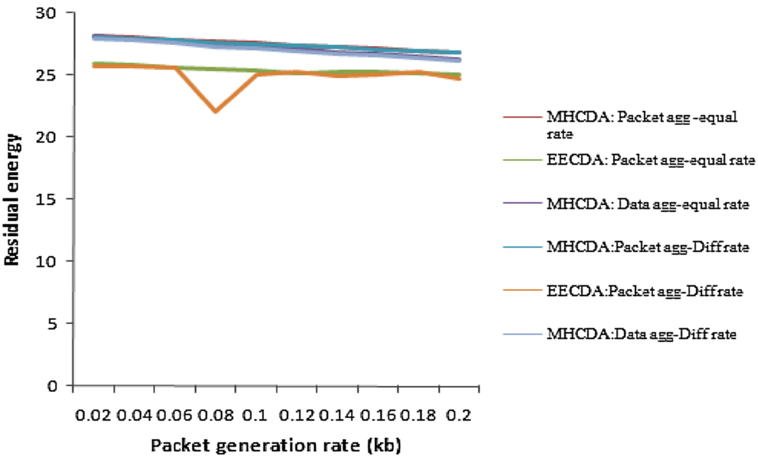

Fig. 7 Comparison of residual energy

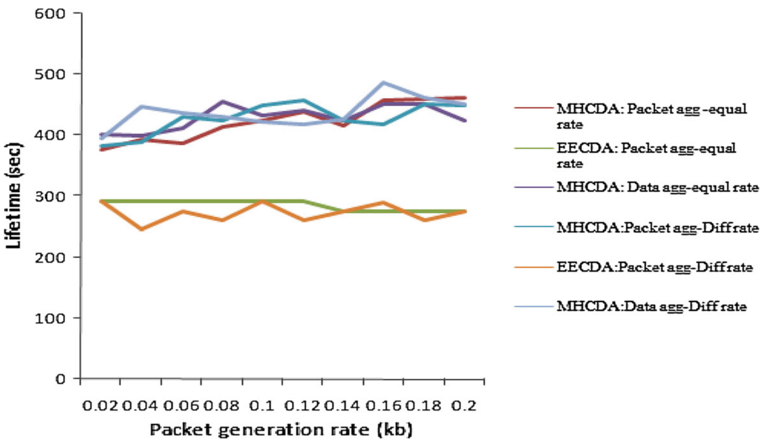

Fig. 8 Comparison of network lifetime

5.1.5 Network Lifetime

Figure 8 indicates the network lifetime. It is the time at which sink receives the last packet after the first node die. Lifetime of MHCDA is higher by 32.72 and 36.17 % as compared with EECDA with an equal and different PGR. With data aggregation network lifetime reduces by approximately 1.3 %. This indicates that MHCDA with packet aggregation has an improvement in the lifetime of the network as compared with data aggregation and EECDA.

5.1.6 Round Energy

According to Fig. 9, energy consumption in the number of rounds is lower in the MHCDA as compared with EECDA. In EECDA, the network sustain only up to 28 rounds as compared with 48 rounds of MHCDA. In comparison with EECDA network can sustain up to 28 rounds only.

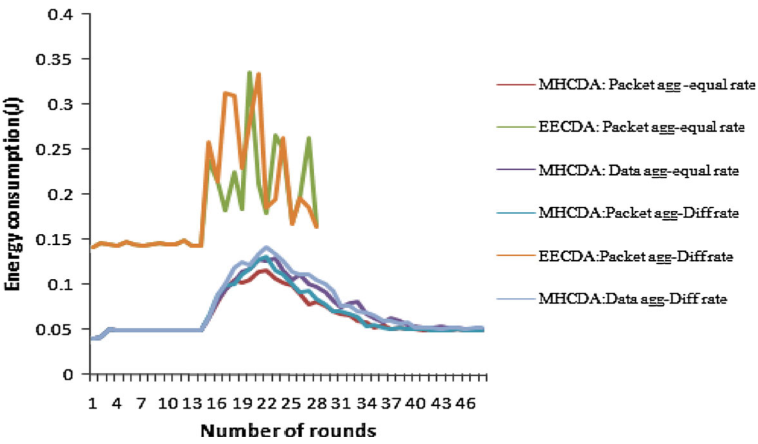

Fig. 9 Comparison of round energy consumption

5.2 Results by Node Heterogeneity and Without Sink Mobility

This section considers the network model shown in Fig. 2 that uses the same assumptions for the nodes and network except stable sink. The algorithm considers the perfectly compressible aggregation function on the random data and packets generated by the nodes. These are routed to the sink with multi-hop clustering and the aggregation algorithm. The algorithm 2 is used for intra and inter-cluster aggregations without sink mobility.

5.2.1 Throughput (Without Sink Mobility)

Figure 10 shows the throughput of MHCDA under equal and different PGRs. It is lower by 46.20 and 60.47 % in packet aggregation as compared with data aggregation. This is caused due to the elimination of repetitive readings in the packet aggregation at intra and inter-cluster aggregation stage. Throughput of the MHCDA is less in packet aggregation as compared with EECDA and data aggregations.

5.2.2 Average Energy Consumption

From Fig. 11, the average energy consumption for packet aggregation is low i.e. 0.41 and 0.45 % as compared with data aggregation. MHCDA saves 8.44 % energy with an equal rate of packet generation as compared with a different rate. The average energy consumption of MHCDA is also lower than EECDA. Since EECDA consider only different rate of packet generation. Average energy consumption is the measure of the ratio between the sums of the energy consumption of all nodes to the total number of nodes.

5.2.3 Packet Delivery Ratio

In Fig. 12, it is seen that MHCDA with packet aggregation under an equal and a different rate of packet generation has lower PDR of 64.73 and 68.51 % as compared with data aggregation and 52.73 and 69.65 % with EECDA. These are due to the application of the

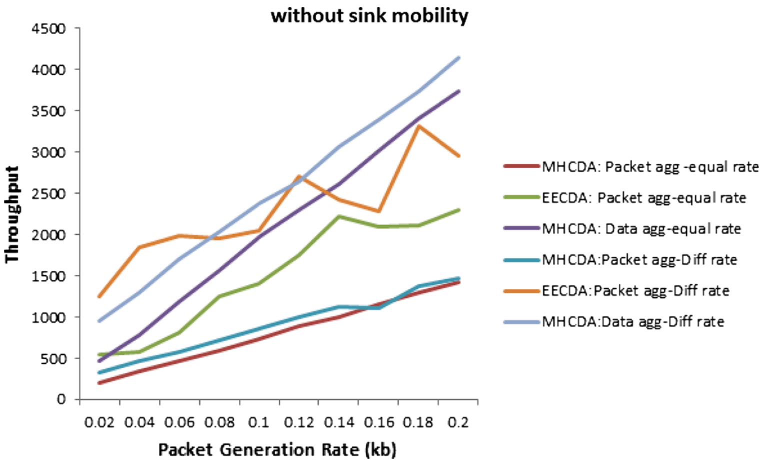

Fig. 10 Comparison of throughput

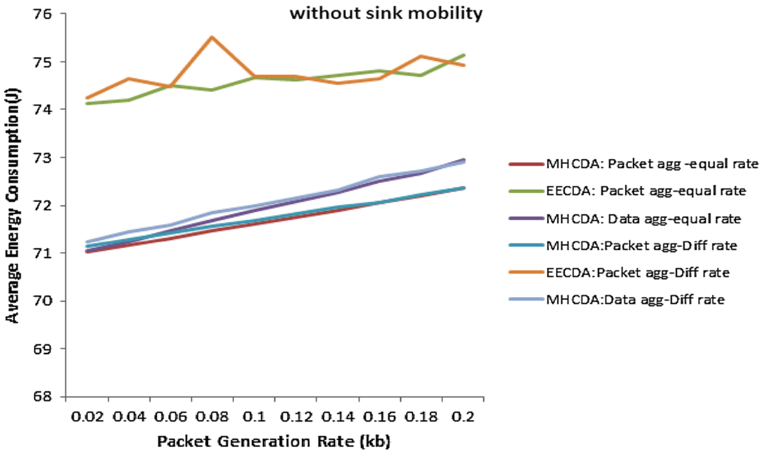

Fig. 11 Comparison of average energy consumption

additive and divisible aggregation function at CH and sink which eliminates the same packets.

5.2.4 Residual Energy

Figure 13 shows that MHCDA with packet aggregation has high residual energy (1.04 and 1.17 %) as compared with data aggregation and more by 9.32 and 90.56 % as compared with EECDA in equal and different rates of PGR. The number of packets received by the sink with packet aggregation is less as compared with data aggregation. It is the measure of the ratio between the sums of the remaining energy of all nodes to the total number of nodes.

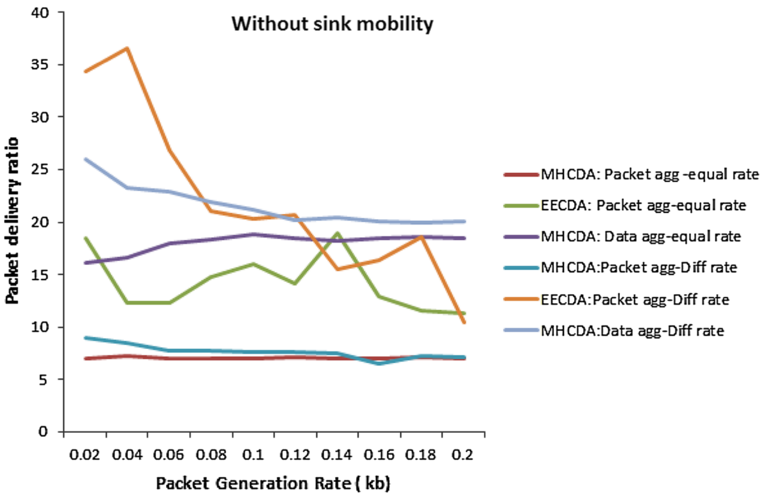

Fig. 12 Comparison of packet delivery ratio

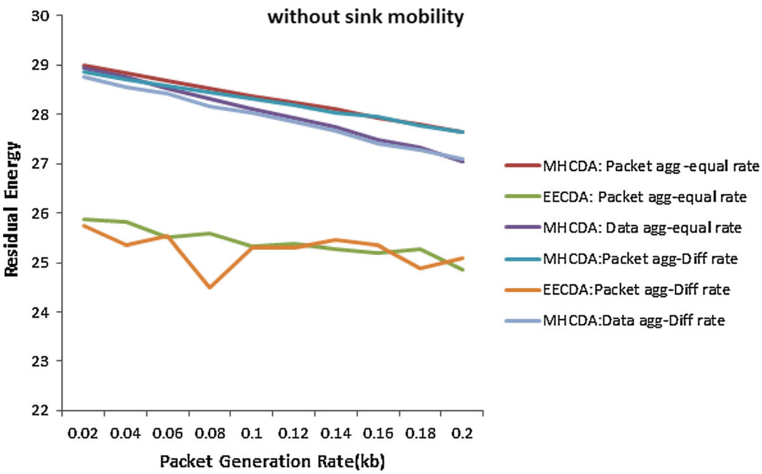

Fig. 13 Comparison of residual energy

6 Conclusions and Future Work

In this paper, proposed cluster-based data aggregation algorithm MHCDA is applicable to IoT applications using mobility as one of the parameter. The proposed algorithm applies the additive and divisible aggregation functions on the packets and data generated at variable rate by considering the spatial and temporal correlation of packet and random data. From the results, it is observed that the packet count reached at the sink reduces with an improvement in communication cost as compared to EECDA. Also, with mobile sink PDR, and throughput is reduced which is better for the effective utilization of bandwidth.

BHCDA shows increase in network lifetime, and reduced energy consumption as compared with EECDA and without sink mobility.

The algorithm will be further extended taking into consideration other parameters such as mobility and heterogeneity of both the nodes and sink with improvement in connectivity with IoT.

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