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Bayes Clustered Data Aggregation in Wireless Sensor Network

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ABSTRACT

Data aggregation collects sensed data from multiple sensors on sensed element in an energy efficient manner so that the network lifetime is increased. In this paper, a novel data aggregation scheme based on Bayesian Cluster in WSNs (abbreviated as BC-DA) to improve data aggregation efficiency and reduce aggregation delay is presented. The scheme adopts a Bayesian Network by forming clusters based on the similar packets to reduce energy consumption. The Bayesian Network is then combined with aggregation tree (Markov Blanket) to form cluster around the nominated cluster heads to check and minimize the aggregation delay. Finally, data aggregation is performed using transmission slot based on reduced TDMA so that greater number of packets can be aggregated in a given interval of time and therefore improving the data aggregation efficiency. Simulation results and performance analysis show that our BC-DA scheme significantly improves the data aggregation efficiency and reduces aggregation delay to prolong network lifetime with other existing WSN data aggregation schemes.

***Keywords**:* Wireless Sensor Network, Data aggregation, Bayesian Network, Markov Blanket, Cluster head selection, Cluster formation, Health monitoring

1. INTRODUCTION

Due to the resource constrained and battery limited sensor nodes in wireless sensor networks, data must be aggregated to avoid huge amounts of traffic in the network. There has been significant work on data aggregation schemes in wireless sensor networks. Cluster-based Eigen-system Realization Algorithm (C-ERA) [1] for high quality structural health monitoring in WSN using Minimum Connected Dominated Set (MCDS) and along the Shortest Path Tree (SPT).

Recoverable Concealed Data Aggregation (RCDA) [2] reduced the transmission overhead on both homogeneous and heterogeneous wireless sensor networks. Another method for structural health monitoring was designed in [3] using online signal reconstruction algorithm to recover from wrong diagnosis.

Conventional multi-hop wireless routing protocols measure the shortest path between sources and destinations in a network to improve data aggregation rate. In [4], a network optimization process called, data stashing was investigated to significantly improve the routing performance. In [5], secure data aggregation technique was designed using iterative filtering algorithms to ascertain the trustworthiness of data and reputation of sensor nodes in WSN. A polynomial time distribution algorithm [6] was designed to improve the network lifetime in a distributed manner.

Wireless sensor networks are applied to numerous applications, for example, healthcare monitoring, wild habitat monitoring, forest fire detection and so on. With the technological advancement, sensor node's size is getting smaller, so the energy consumption is increased. Hence, there arises a need to design data aggregation algorithm that reduces the energy and subsequently increases the network lifetime.

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In [7], Virtual Force-based Algorithm (VFA) was designed to achieve significant energy saving and increase the network lifetime. A data aggregation model based on balanced privacy preserving was designed in [8] to reduce the communication overhead and increase the network lifetime. Location-based data aggregation was performed in [9] to reduce spatial redundancy and energy consumption. An adaptive spanning tree to improve the aggregation ratio was designed in [10].

The central theme of this paper is to effectively perform data aggregation in wireless sensor network by forming clusters and identification of cluster head node based on the highest energy possessed by it by applying Bayesian Network and Markov Blanket model. The objective would be to increase data aggregation efficiency by reducing the data aggregation delay and therefore improve the network lifetime time by utilizing reduced TDMA. The energy consumption of this scheme is also minimized in order to prolong the WMSN lifetime. The proposed method will be analyzed and compared to other existing schemes.

This paper is organized as follows. Section 2 reviews related Work. Section 3 provides problem definition and the proposed scheme Bayes Clustered Data Aggregation in WSN. Performance evaluation is outlined in Section 4 and discussions included in Section 5. Section 6 concludes this paper.

2. RELATED WORKS

Data aggregation gets rid of redundant data transmission and strengthens the network lifetime in wireless sensor network. Different from other WSN applications, a large amount of classical data aggregation methods, such as energy-efficient slice-mix-aggregate based on data slicing and mixing [11], using accurate distance estimation [12], using security model [13], computationally intensive and with energy efficient collaboration of multiple sensors.

In several environmental monitoring applications, as the packets sensed by wireless sensor networks are of high temporal redundancy, data aggregation based on prediction is an important method to reduce redundant data communications. In [14], novel prediction-based data collection protocol was presented using a double-queue that synchronized the prediction data series of the sensor node and the sink node, therefore minimizing the continuous predictions. However, network lifetime was not resolved. To address network lifetime, in [15], energy efficient routing algorithm using A-star and fuzzy logic was designed. Another method using tree structure [16] was designed to not only improve the network lifetime but also reduce data aggregation delay.

As WSN are deployed in remote and hostile environments, the sensor nodes in WSN are highly susceptible to physical attacks and therefore the sensor networks poses many practical challenges. Data integrity, confidentiality, source authentication are all certain major security concerns to be addressed.

In [17], preserving data integrity was addressed by proposing an Efficient Integrity-Preserving Data Aggregation Protocol (EIPDAP) to increase the data aggregation integrity through aggregation in WSN. Identity-based aggregate signature scheme [18] was designed to improve data aggregation ratio using constant length signature. Homomorphic primitives were investigated in [19] using symmetric key to improve data aggregation rate and therefore improve network lifetime. In [20] layer-based data aggregation was designed and practical performance was analyzed in WSN.

To cope with the above said problem, this paper proposes to perform efficient data aggregation in WSN using Bayesian Network and Markov Blanket model received from different sensor nodes at the sink node. The aggregated sensed packet is then sent to the sink node. The proposed scheme utilizes a Bayes clustered scheme to perform data aggregation and therefore reduce aggregation delay using reduced TDMA.

3. BAYES CLUSTERED DATA AGGREGATION IN WIRELESS SENSOR NETWORK

In this section, we give the detailed description of our proposed scheme for improving data aggregation in healthcare monitoring. The basic idea is that we first construct a Bayesian Network by dividing the cluster head and non cluster head nodes based on the highest energy. Then a Markov Blanket model is designed in such a way that during each round the cluster formation is different from other rounds with one time slot for each frame using transmission slot based on reduced TDMA.

3.1. Problem definition

One of the efficient schemes for data aggregation is clustering, where each sensor node sends packets to the aggregator node or the Cluster Head Node (CHN). The CHN in turn performs data aggregation on the received packets and then send it to the sink node. In this work, an algorithm is proposed to perform data aggregation within a cluster by selecting the cluster head with the highest energy in the field of healthcare. After selecting the CHN, clusters are formed with the neighbour nodes (i.e. patients) based on Markov Blanket. When, the cluster heads energy gests reduced, associate cluster head is selected (i.e. the next highest energy possessing node) and finally aggregate the packets to sink node.

3.2. Bayesian Markov Blanket Dynamic cluster algorithm

In this section, a scheme is proposed to reduce the energy consumption of each sensor node (i.e. patient) in WSN and as a result to improve the data aggregation efficiency. Let us consider the total energy consumption for all sensor nodes in WSN be given as below.

$$E(Tot) = \Sigma_{i=1}^{n} E_i\,(Tot) \tag{1}$$

From (1) '*E* (*Tot*)', represent the total energy consumption of all sensor nodes in the network '*N*'. Also the entire sensor network is designed in the form of a graph '*G* = (*V*, *E*)', where '*V*' represents the vertices denoting the set of sensor nodes and '*E*' represents the edges connecting the pair of sensor nodes.

The set of sensor nodes are denoted as '$V = \{sn_1, sn_2, ..., sn_n\}$' over a two dimensional area '$l*m$' of radius '*r*' with the sink node denoted as '*S*'. The objective of our work is to minimize the '*E* (*Tot*)' by using a dynamic clustering algorithm and dynamic cluster head selection, thus reduce their energy consumption.

In the proposed scheme BC-DA, the overall process starts with identification of the cluster head node, responsible for data gathering within the specified cluster and performs data aggregation sensed from multiple sensor nodes. The CHN task is to receive the packet from the cluster members, perform data aggregation over the received packet based on similar packets (i.e. data regarding heart rate, glucose level monitoring and so on in corresponding cluster) and then sent to the sink node.

The Bayesian Network in the proposed scheme assigns a probability to every sensor node in the network that denotes the likelihood that the node represents a cluster head whereas the other nodes are called as the non-cluster head nodes. The probabilities of the sensor nodes' are based on the on the sensors' current conditions (i.e. energy possessed by each sensor node) and each sensor node calculate its own probability (i.e. according to the energy used) based on its current condition.

The Bayesian Network in the BC-DA scheme is constructed in each sensor node rather than the entire network to reduce the energy consumption of the entire network. Figure 1 shows the design of Bayes Clustered Data Aggregation in Wireless Sensor Network. As shown in the figure, initially, all the sensor nodes considered are deployed in the region (as shown in figure 1. a). The proposed scheme is designed in such a way that all sensor nodes in WSN are in a formed cluster, and all of them are covered. This is performed using a distance formula as given below.

$$Dis = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2} \tag{2}$$

Using the above distance measure '*Dis*' the sensor nodes are grouped as clusters (as shown in figure 1.b). In our example scenario two cluster's 'C_1' (i.e. heart rate) and 'C_2' (i.e. glucose level monitoring) are formed. Figure 1.c shows the sensor node sending their energy to the sink node.

$$S = \Sigma_{i=1}^{n} E(sn_i) \quad (3)$$

Once all the energy of the sensor nodes are collected by the sink node, the sensor node possessing highest energy is selected as the cluster head and is as given below.

$$CHN = MAX\ \Sigma_{i=1}^{n} E(sn_i) \quad (4)$$

As soon as the cluster head node '*CHN*' is selected the task of cluster head node is to aggregate the packets from all the sensor nodes and sent it to the sink node. During this process, if the cluster head nodes' energy gets reduced, the process of selection of cluster head node is performed with the other sensor nodes present in the corresponding cluster. The next highest energy possessing node is then selected as the associate cluster head node and data aggregation continuous with the associate cluster head node.

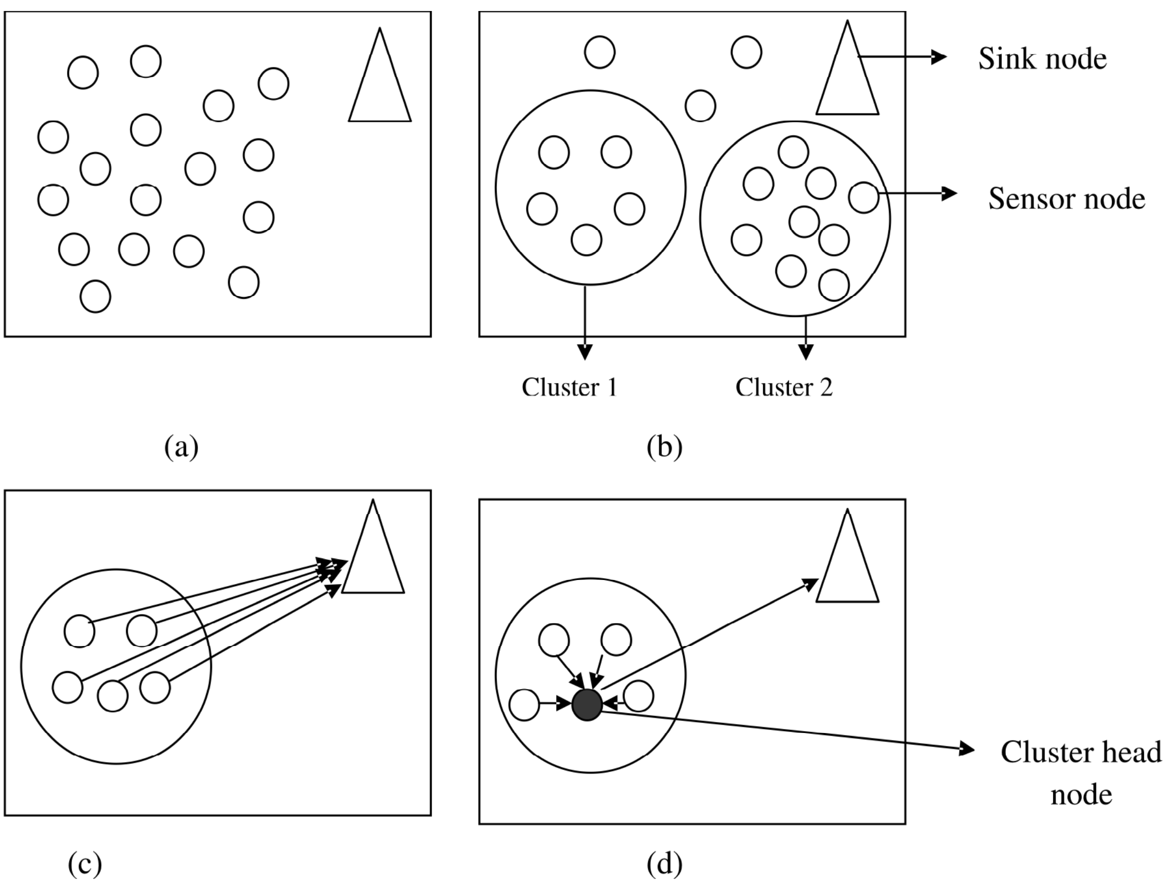

Figure 1: (a) Sensor node deployment (b) Cluster formation (c) sensor nodes send the energy to sink node (d) Cluster head node selected and sensor nodes sent packets to cluster head node that sends the aggregated packets to the sink node

Once the cluster head nodes are selected '*CHN*', the proposed work uses define clusters in a dynamic manner using Markov Blanket of CH node where the clusters are formed with the neighbouring sensor nodes based on the Markov Blanket, ensuring network lifetime. Figure 2 shows the Markov Blanket model for node 'sn_p'.

As shown in the figure. Let us consider a set of nodes '$\{sn_1, sn_2, \dots, sn_n\}$'. Then, the Markov Blanket for a node 'sn_p' (as shown in the figure 2) in Bayesian Network is the set of nodes '∂sn_p' compose of 'sn_p' parent node, its children node and its children's other parent nodes and is defined as given below.

$$Ch\left(sn_p\right) = \left\{sn_q : \left(sn_p, sn_q\right) \in N\right\} \quad (5)$$

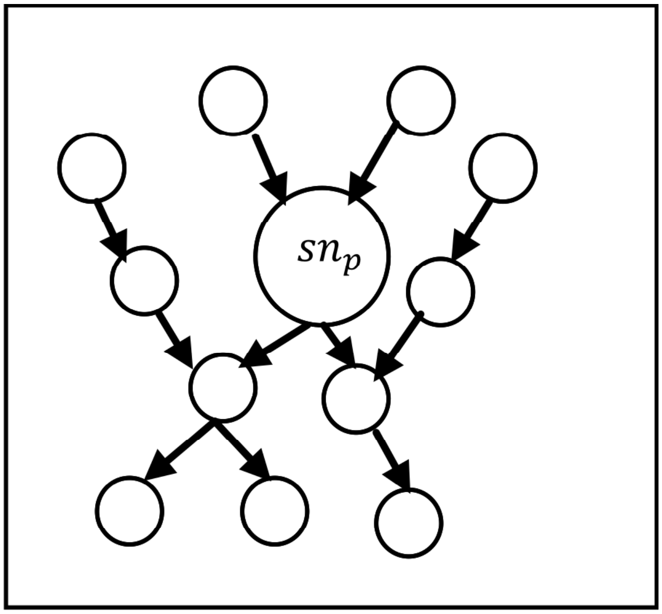

Figure 2: Markov Blanket model for node 'sn_p'

However, the sensor nodes from the children set of the node 'sn_p' are not only influenced by the node 'sn_p' but also by its parents and therefore BC-DA scheme consider edges that came out from node 'sn_p'. Therefore, the Markov Blanket of a node 'sn_p' is given as below.

$$MB(sn_p) = Par\ (sn_p)\ \cup Ch\ (sn_p) \tag{6}$$

From (6), the Markov blanket of a sensor node contains all the other variables that shield the node from the rest of the network. Therefore, using the Markov blanket of a sensor node, the proposed work predicts the behaviour of the sensor node, ensuring network lifetime. Figure 3 shows the Bayesian Markov Blanket Dynamic cluster algorithm.

Input: Sensor Nodes '$sn_1, sn_2, \dots, sn_n$', Radius 'r', Sink Node 'S', Packets '$P = p_1, p_2, \dots, p_n$'
Output: Optimal energy consumption and improved network lifetime
1: Begin 2: For 'n' sensor nodes deployed in a region with radius 'r' 3: Identify the distance between the sensor nodes to form cluster using (2) 4: Measure the energy for each sensor node using (3) 5: Measure the highest energy using (4) and assign it as the cluster head node 'CHN' 6: Define clusters dynamically using (5) 7: End for 8: End

Figure 3: Bayesian Markov Blanket Dynamic cluster algorithm

As shown in the figure, the Bayesian Markov Blanket Dynamic cluster algorithm presented a protocol to form the clusters in a dynamic manner based on the current conditions of the network. Initially, cluster heads are selected based on the highest energy possessing node, clusters are formed based on the Markov Blanket to optimize the energy consumption and improve the network lifetime. Followed by this the process of data aggregation is performed with low data aggregation delay using optimal energy consumption that is discussed in the following sections.

3.3. Data Aggregation based on Reduced TDMA

In this section, data aggregation based on reduced TDMA is used to minimize redundancy during data aggregation and as a result the traffic gets less congested. The data aggregation based on reduced TDMA is performed by combining the packets arising from multiple sensor nodes (i.e. from multiple patients with similar data) to eliminate redundant aggregation and therefore reduce data aggregation delay.

In the proposed work, a transmission slot based on reduced TDMA is allocated to each non-cluster head nodes (i.e. patient) once per frame because greater number of packets (i.e. patients data) can be aggregated in a given interval of time. Figure 4 shows the structure of reduced TDMA. Here, each sensor node is divided in to frames.

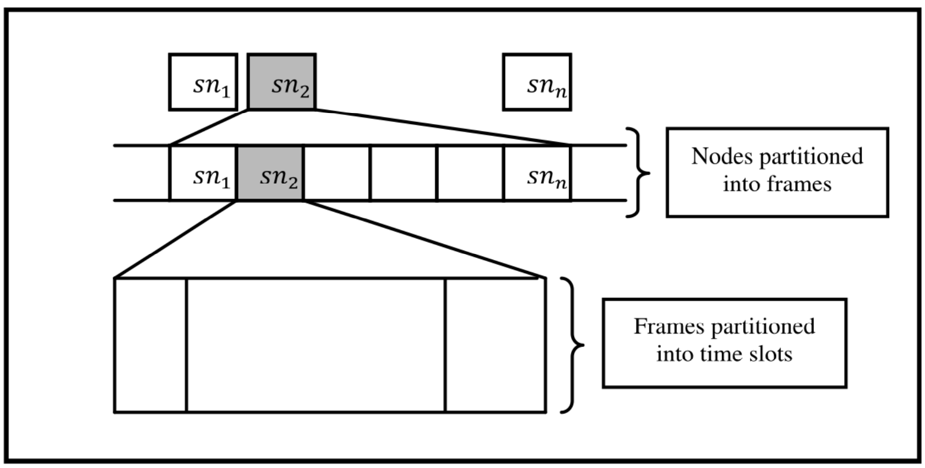

Figure 4: Structure of reduced TDMA showing sensor nodes partitioned into frames and each frames partitioned into reduced timeslots

As shown in the figure, each sensor nodes is partitioned into frames. Each frame's are partitioned and allocated with one slot. The frames are divided into slots with no constraint of minimum frame length and each sensor node is allocated one slot. As a result, the sensor nodes in the network aggregate the packet without collisions, minimizing the congestion arising in the network.

The sensor nodes in the network are further time synchronized, where the synchronization pulses are sent by the sink node to each sensor nodes. In addition, to improve the network lifetime, each non-cluster head node is turned off until its allocated transmission time. At the allocated time, the CHN collects all the packets from the sensor nodes in the corresponding cluster. Upon successful reception of all the packets from the non-cluster head nodes, the cluster head node performs data aggregation.

Once all the cluster heads complete the data aggregation of the local cluster, the resultant packet is transmitted along the tree. The tree is designed in such a way that the sensor node with the highest energy is selected as the root node. All other sensor nodes are connected to this selected highest energy root via the shortest-path. Each cluster head will send its packet after performing data aggregation from sender node. The sink node finally receives the final resultant packets from the root of the tree. Figure 5 shows the Data aggregation reduced TDMA algorithm.

Input: Sensor Node '$sn_1, sn_2, \dots, sn_n$', Cluster Head Node 'CHN', Sink Node 'S', Packets '$P = p_1, p_2, \dots, p_n$', Time Division '$td_1, td_2, \dots, td_n$', Non Cluster Head Node '$NCHN$'
Output: Reduced aggregation delay
1: Begin 2: For each sensor node 'sn_i' 3: If the sensor node 'sn_i'is cluster-head node 'CHN' 4: Create reduced time division 'td_i' and send to the non-cluster head nodes '' $NCHN$ 5: Aggregate cluster-head node information (packets) to the sink node 6: Create minimum spanning tree between cluster-head nodes 7: Reception of packets by the sink node from root of minimum spanning tree 8: Else 9: Wait for cluster head selection 10: Go to step 3 11: End if 12: End for 13: End

Figure 5: Data aggregation-based reduced TDMA algorithm

As shown in the figure, the data aggregation is performed in an efficient manner by eliminating the redundant packet transmission and therefore improving the network lifetime using reduced TDMA algorithm. Once the data aggregation is performed by the cluster-head nodes, the aggregated data from the corresponding cluster is sent to the sink node. As this aggregation involves high energy due to the fact that the sink node is far away from the cluster-head node, the proposed scheme used tree structure that in turn reduces the aggregation delay.

4. SIMULATION SETUP

The scheme Bayes Clustered Data Aggregation (BC-DA) in Wireless Sensor Network uses the NS-2 simulator with the network range of 1200*1200 m size. The number of sensor nodes selected for experimental purpose is 70 nodes for BC-DA scheme. Destination Sequence Based Distance Vector DSDV is used as routing protocol to conduct experiments for BC-DA scheme. The BC-DA scheme's moving speed of the sensor nodes in WSN is about 25 m/s for each sensor node with a simulation rate of 50 milliseconds to perform data aggregation between sensor nodes to the sink node through cluster head node. The parametric values for performing experiments are shown in table 1.

Experiment is conducted on the factors such as energy consumption, network lifetime, aggregation delay, for data aggregation with respect to sensor node and packet density in WSN. The results of the metrics of BC-DA scheme is compared against the existing schemes such as Cluster-based Eigen-system Realization Algorithm (C-ERA) [1] Recoverable Concealed Data Aggregation (RCDA) [2] respectively.

Table 1
Simulation setup

Parameter	*Value*
Protocols	DSDV
Network range	1200 m * 1200 m
Simulation time	50 ms
Number of mobile nodes	10, 20, 30, 40, 50, 60, 70
Packets	9, 18, 27, 36, 45, 54, 63
Network simulator	NS 2.34
Mobility speed	25 m/s
Pause time	15 s

5. DISCUSSION

To validate the efficiency and theoretical advantages of the Bayes Clustered Data Aggregation (BC-DA) scheme with Cluster-based Eigen-system Realization Algorithm (C-ERA) [1] Recoverable Concealed Data Aggregation (RCDA) [2], simulation results under NS2 are presented. The parameters of the BC-DA scheme are chosen as provided in the experiment section.

5.1. Scenario 1: Energy consumption

Energy consumption for data aggregation at the sink node is measured using the energy consumed by a single sensor node with respect to the total sensor nodes in WSN. The mathematical formulation for energy consumption is as given below.

$$EC = \Sigma_{i=1}^{n} Energy(sn_i) * Total(sn_i) \quad (7)$$

From (7), the energy consumption '*EC*' for data aggregation is obtained by the product of the energy for single node '*Energy* (sn_i)' and total sensor nodes '*Total* (sn_i)' in the network. The consumption of energy is measured in terms of Joules. Lower the energy consumption, more efficient the scheme is said to be. To better understand the effectiveness of the proposed BC-DA scheme, extensive experimental results are shown in figure 6.

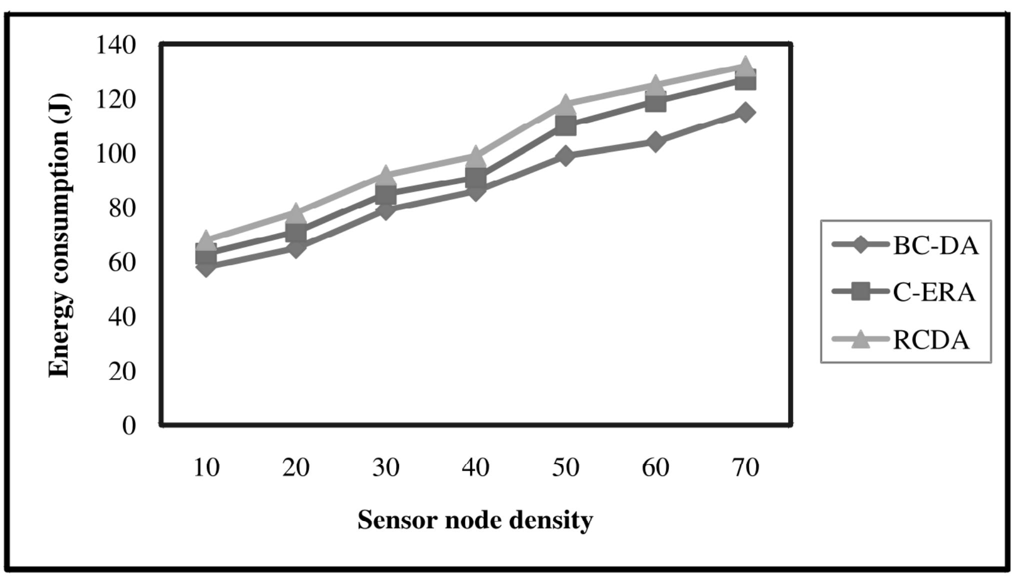

Figure 6: Measure of energy consumption with respect to sensor node density

NS2 simulator is used to experiment energy consumption by analyzing the result using graph values. Results are presented for different number of sensor node density and the results reported here confirm that with the increase in the node density, the energy consumption also gets increased in a linear manner. The proposed BC-DA scheme performs relatively well when compared to two other schemes C-ERA [1] and RCDA [2]. The energy consumption is reduced in the BC-DA scheme by applying Bayesian Network and Markov Blanket model for cluster head selection and cluster formation. By applying the Bayesian Network and Markov Blanket model, efficient and best cluster head is identified using dynamic cluster head selection in wireless sensor networks. Moreover Bayesian Network and Markov Blanket model performs local cluster and sends packet to the sink node or another cluster head whichever lies closer to the sensor node in a significant manner. This helps in reducing the energy consumption by 9.60% compared to C-ERA [1]. In addition, data aggregation is performed over the received similar packets, resulting in different clusters and therefore minimizing the energy consumption of each sensor node by 17.56% compared to RCDA [2].

5.2. Scenario: Network lifetime

The lifetime of the network is determined by the number of sensor nodes in the network after repeated data aggregation in WSN. The network lifetime is mathematically formulated as given below.

$$NL = \left(\frac{sn_{addressed}}{Total_{sn}}\right) * 100 \tag{8}$$

From (8), the network lifetime '*NL*' is measured using the total number of sensor nodes '$Total_{sn}$' in the network and the sensor node addressed '$sn_{addressed}$' during data aggregation in WSN. Higher the network lifetime, more efficient the scheme is said to be and is measured in terms of percentage (%). Figure 7 given below shows the network lifetime with respect to sensor node density in the range of 10 to 70.

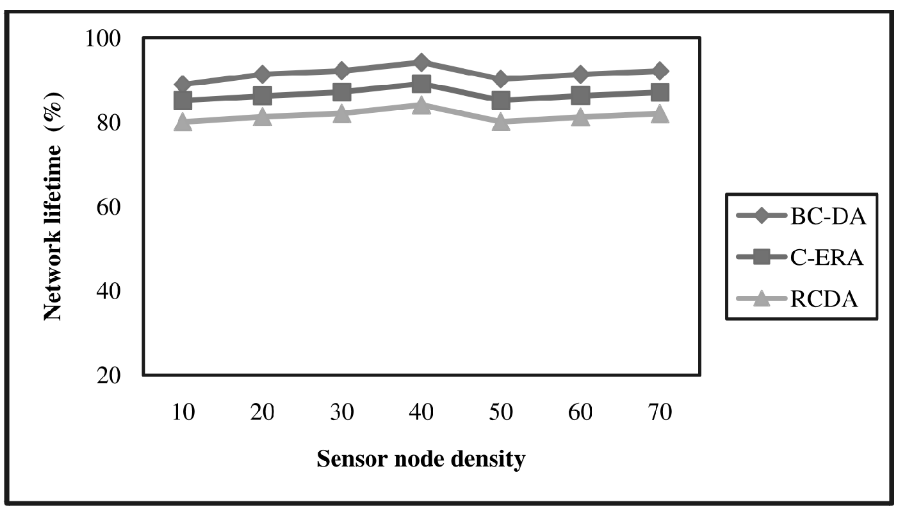

Figure 7: Measure of network lifetime

From figure 7, it is evident that the network lifetime is improved using the proposed BC-DA scheme. The Bayesian Markov Blanket Dynamic cluster algorithm with optimal strategy results in the improved network lifetime in BC-DA scheme. With the application of Bayesian Markov Blanket Dynamic cluster algorithm, clusters are formed in a dynamic manner at different time intervals resulting in the improvement of network lifetime. At the same time, in BC-DA scheme, the probabilities of the sensor nodes' to be in a specific cluster are based on the on the sensors' current conditions and each sensor node calculate its own probability based on its current condition in an efficient manner. With this probability evaluation, the cluster head node performs data aggregation and sends the results of aggregated packets to the sink node in WSN. This in turn increases the network lifetime using BC-DA scheme by 5.33% compared to C-ERA [1] and 10.79% compared to RCDA [2] respectively.

5.3. Scenario 3: Aggregation delay

Aggregation delay is also evaluated by measuring time spent on processing time on aggregating the packets and the number of packets to be aggregated in the proposed scheme. Aggregation delay is measured as given below.

$$AD = \sum_{i=1}^{n} (p_i) * Time\ (Data\ Agg\ [p_i]\ ) \tag{9}$$

From (9) aggregation delay '*AD*' is measured on the basis of data packets to be aggregated and the time taken for data aggregation '*Time* (*Data Agg* [p_i]'.

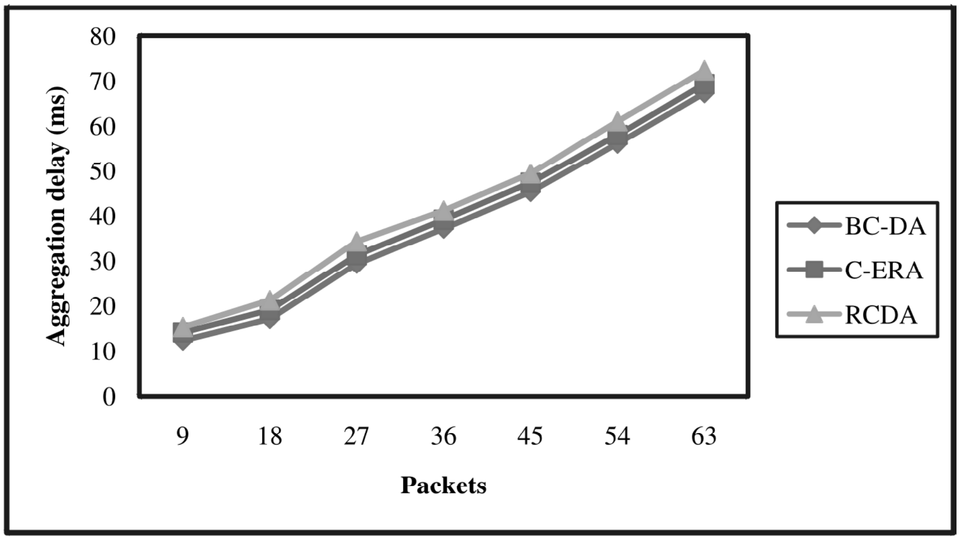

Figure 8: Measure of aggregation delay with respect to packet density

Figure 8 presents the variation of aggregation delay with respect to packets in wireless sensor network. All the results provided in figure 8 confirm that the proposed BC-DA scheme significantly outperforms the other two schemes, C-ERA [1] and RCDA [2]. The aggregation delay is minimized in the BC-DA scheme using the reduced TDMA. With the application of cluster-based routing, reduced TDMA is applied to each sensor node. Followed by this, the sensed packets are aggregated and mapped with the similar sensed packets to provide a transmission slot to each sensor node. This in turn reduces the aggregation delay by 6.99% compared to C-ERA. As a result, aggregation delay is reduced in the BC-DA scheme using the reduced TDMA algorithm. Moreover, multiple event aggregation at different time intervals are also made in a significant manner by creating the minimum spanning tree between cluster-head nodes which in turn reduces the aggregation delay by 14.43% compared to RCDA.

6. CONCLUSION

In this paper, we have proposed Bayes Clustered Data Aggregation scheme to perform data aggregation in WSN. We propose an efficient scheme for data aggregation using Bayesian Network and Markov Blanket model to reduce the energy consumption of each sensor node, thus increase the entire network lifetime. The Bayes Clustered Data Aggregation scheme designed for wireless sensor networks increase the efficiency of the network by using Bayesian Markov Blanket Dynamic cluster algorithm. In addition to minimize the aggregation delay, reduced TDMA is allocated once per frame to each non-cluster head nodes. Experiments conducted on varied simulation runs shows improvement over the state-of-the-art schemes. The results show that BC-DA scheme offers better performance with an improvement of network lifetime by 8.06% and reduces the aggregation delay by 10.71% compared to state-of-the-art schemes respectively.

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