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Comparative Analysis of Data Aggregation Algorithms Under Various Architectural Models in Wireless Sensor Networks

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Abstract - Wireless sensor network has emerged as a promising technique that revolutionary the way of sensing information. Dense deployed sensor nodes in a specific region are likely to transfer redundant data to the base station. This increases the communication overhead and affects network lifetime. Since energy conservation is the key issue in wireless sensor network, data aggregation should be incorporated in order to save energy. The main aim of data aggregation technique is to collect and aggregate data in an energy efficient manner so that network lifetime is enhanced. In this paper, authors present state of the research by summarizing the work on data aggregation algorithms that has already been published and by highlighting the performance characteristics that are being addressed. The performance comparison of clustered based data aggregation, chain based data aggregation, tree based data aggregation and grid based data aggregation algorithms have been analyzed using NS-2 for various parameters.

Index Terms: Wireless Sensor Networks, Data aggregation.

1.0 INTRODUCTION

Wireless Sensor Networks (WSNs) have a large number of sensor nodes with an ability to communicate among themselves and also to an external sink or base-station [1, 2]. The sensors could be scattered randomly in harsh environments such as a battlefield or deterministically placed at specified locations as shown in figure 1.Wireless sensors are equipped with limited range of sensing, computational, storage and communication resources. Extensive utilization of communication resources can potentially reduce the battery life of a wireless sensor. Hence energy conservation must be considered as a most basic constraint while designing a WSN as it governs the network lifetime. A lifetime of WSN depends on the lifetime of sensor nodes. After the deployment of sensor devices, it is impossible to charge or replace battery present in the network.WSN's can be used for a wide variety of monitoring and research application, inventory maintenance, health care, military, object recognition and tracking and environmental phenomena. During monitoring sensor nodes collect sensory information which is highly redundant and correlated. Since sensor nodes are energy constrained, it is inefficient for all the sensors transmit the data directly to the base station.

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To conserve energy this redundant information is aggregated and it is transmitted to the base station as illustrated in figure 2. Data aggregation is defined as the process of aggregating the data from multiple sensors to eliminate the redundant transmission and provide consolidated information to the base station [4], [8]. Eventually, the lifetime of the sensor nodes can be increased.

In this paper, the authors made an attempt to present various architectural models that exist under hierarchical networks which are used for data aggregation in WSN and also the

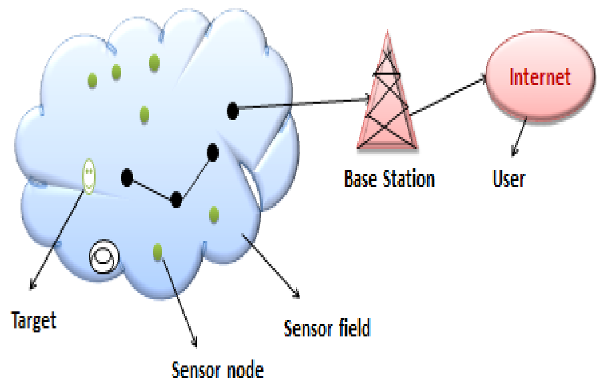

Figure 1: A typical Wireless Sensor Network

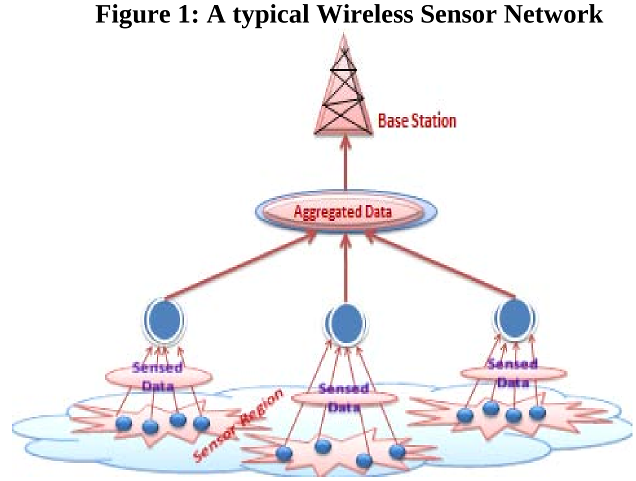

Figure 2: Data Aggregation

performance analysis of various algorithms of each architecture is considered. Some of the network parameter has taken to compare the performance of each algorithm under clustered based data aggregation, chain based data aggregation, tree based data aggregation and grid based data aggregation algorithms.

The remainder of the paper is organized as follows: Section 2 briefly reviews a survey on previous approaches focusing on their disadvantages. Section 3 presents different architectural models of data aggregation. Section 4 describes the performance analysis of data aggregation techniques. The simulation results of various data aggregation algorithms are compared and analyze in section 5. Finally, Section 6 concludes the paper.

2.0 RELATED WORK

During the past few years, many different protocols for data WSN aggregation have been proposed. Literature [1] proposes a detailed survey on various aspects of WSNs and different data aggregation techniques. All of them focus on optimizing performance measures such as network lifetime, data latency, data accuracy and energy consumption.

In a WSN application for tracking multiple mobile targets [2], large amounts of sensing data can be generated by a number of sensors. Generated data must be controlled with an efficient data aggregation technique so that number of data transmissions can be reduced by using one such clustering based data aggregation algorithm which shows effectiveness in restricted type of sensing scenarios, while posing great problems when trying to adapt to various environmental changes.

Power Efficient Gathering Sensor Information System (PEGASIS) [4, 5] is a chain based power efficient routing protocol. This protocol is applicable to homogeneous sensors. PEGASIS assumes that all the sensor nodes have the same level of energy and they are likely to die at the same time. Since all nodes are immobile and have global knowledge of the network, the chain can be constructed easily by using a greedy algorithm. In this approach, each sensor node will have the information about hop neighbors. Sensed information will be passed across to the next hop neighbor and hop neighbour transmit the packet to the next hop neighbour until it reaches the base station.

Sensor Protocol for Information via Negotiation (SPIN) [3, 5, and 6] is an adaptive protocol that uses data activity and resource adjustable algorithms. SPIN follows Proactive type flat architectural approach. In SPIN algorithm all the nodes are close to the base station. The nodes which are closer will sense and gather identical information. In SPIN algorithm all sensor nodes act as a base station. SPIN solves these shortcomings of conventional approaches using data negotiation and resource-adaptive algorithms. The user can query to any node to gather sensed information. Data transmitted within the sensor nodes are called as metadata. Before transmission, meta-data will be passed across all the sensor nodes. After sensor node receives a meta-data it advertises the neighboring node whether interested in receiving the meta-data.

A Tiny Aggregation Approach (TAG) [7] is a data centric protocol. It is a tree based data aggregation approach and designed especially for monitoring applications. This means that all nodes should produce relevant information periodically. Therefore, it is possible to classify TAG as a periodic per hop adjusted aggregation approach.

A Tree based Data Aggregation Mechanism in WSN (TDAM) [8] in which this mechanism describes hop count and energy as new parameters in order to construct aggregation tree. The main aim of this design is to reduce the power consumption of the nodes in the network. Also reduces the number of nodes to relay, thereby reducing the amount of transmitted packets and no too complex operation.

Adaptive clustering based data aggregation technique [10] is a method that implements both static and dynamic clustering methods. This method assumes that the static clustering based data aggregation technique has advantages when there are multiple targets, and when the velocity of those targets is high. On the other hand, the dynamic clustering based technique has great advantages when there are only a few targets with low velocity. Therefore this method will select the static cluster based aggregation when data traffic is high, and adaptively switch to dynamic cluster based aggregation when the network realizes that the data traffic is low. The threshold for deciding when to switch between the data aggregation methods will be configured and decided at the sink node. The initial clustering method of the network will also be configured at the sink.

Threshold sensitive Energy Efficient sensor Network (TEEN) [3, 9] is a Cluster based Hierarchical approach h which follows LEACH protocol. This is an important routing approach used in the Time Critical application. TEEN is a Cluster-based reactive protocol. TEEN uses the LEACH protocol to design a network topology. It follows the same approach of LEACH to identify the Cluster Head and sensor nodes.

In Directed Spanning Tree (DST) [11] routing protocol, a node considers one of its neighbor nodes, which is nearest to the sink as a parent node in the tree. It chronically transmits packets to the parent node. As the case may be, every node (except for the sink) can choose a neighbor node which is nearest to the sink as its parent node. So a tree shape communication path will be constructed, which sets the sink node as its root. By the Directed Spanning Tree, any node can find a shorter and a time-saving path to transmit data packets to the sink.

Low energy adaptive clustering hierarchy (LEACH) [3] is randomized; self-organizing cluster based routing protocol used in wireless sensor network. In this protocol the base station will be a fixed and located far away from the sensor region. In a cluster of sensors a node acts as cluster head or a group leader, which performs aggregation and routing of packets to the sink. In this protocol sensing and gathering of information are equally done with all sensor nodes and aggregated at the cluster head node. Rumor Routing (RR) [3, 12, and 13] is an adaptive algorithm which directs diffusion method. It follows Hybrid type flat protocol. The RR method combines query flooding and event flooding. Rumor Routing is applicable on a network which is composed of densely distributed nodes. RR uses query flooding and event flooding protocols in a randomized manner to fetch the interested information.

The clustered Aggregation algorithm is to compute approximate answers to queries by using spatial and temporal properties of the data [15]. CAG forms clusters of nodes sensing similar values. It ignores redundant data using the spatial and temporal correlations provide significant energy savings. In [16], EECDA combines energy efficient cluster based routing and data aggregation for improving the performance in terms of lifetime and stability [4]. It is for the heterogeneous WSN. EECDA balances the energy consumption and prolongs the network lifetime by a factor of 51%, when compared with LEACH. Chain Oriented Sensor Network for Efficient Data Collection (COSEN) [17]; it is a two-tier hierarchical chain-based routing scheme. COSEN compared to PEGASIS, it can alleviate the transmission delay and energy consumption. In [18] simulation results show that EECHDA has significant gain in network lifetime over direct transmission under the assumption that nodes are randomly and densely deployed.

3.0 ARCHITECTURAL MODELS IN HIERARCHICAL NETWORKS

Hierarchical networks are the special type of networks that comes under WSN. A characteristic of the hierarchical wireless sensor network is creation of cluster head where cluster heads perform several special functions such as maintaining the clusters and aggregation. Data aggregation is performed by cluster heads or a leader node. Overhead is involved in a cluster or chain formation throughout the network. As such the concept of hierarchical network is also utilized to perform energy-efficient task in WSNs. In a hierarchical network, creation of clusters and assigning of special tasks to cluster-heads can greatly contribute to overall system scalability, lifetime and energy efficiency. Several architectural models that exist in hierarchical networks and some of the data gathering techniques have been proposed under each model. The four hierarchical networks under study are clustered based data aggregation, chain based data aggregation, tree based data aggregation and grid based data aggregation.

3.1 Chain based Architecture

In which each sensor sends data to the closest neighbor. All sensors are structured into a linear chain for data aggregation. The nodes can form a chain by employing a greedy algorithm or the sink can determine the chain in a centralized manner. Figure 3 explains chain based architecture. Greedy chain formation assumes that all nodes have global knowledge of the network. The farthest node from the sink initiates the chain formation and at each step, the closest neighbor of a node is selected as its successor in the chain. In each data gathering round, a node receives data from one of its neighbors, fuses the data with its own and transmits the fused data to its other neighbor along the chain.

3.2 Tree Based Architecture

In tree based architecture, data aggregation is performed by constructing aggregation tree which could be a minimum spanning tree where sensor nodes act as the leaf nodes and the sink node or master node act as root node [7, 15]. Figure 4 shows the principle of tree based architecture.

The flow of the data takes place from the leaf node to the parent node. Tree based architecture is suitable for designing optimal aggregation techniques. The aggregation is done at the base station also acts as the parent node.

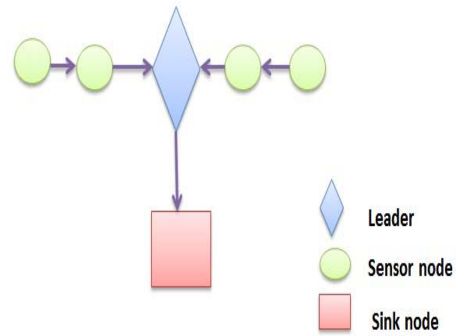

Figure 3: Chain based architecture

3.3 *Cluster Based Architecture*

Cluster based data aggregation approach is widely used in WSN. In cluster based approach the whole network is divided into several clusters. The sensor nodes themselves form a cluster and elect a node as cluster head. The data sensed by the sensor nodes are passed to the cluster head and in the cluster head data aggregation is performed. Cluster head performs data aggregation and forward the data to the sink. Fig. 5 shows the Cluster based approach, data aggregation is performed by cluster heads. Communication cost is reduced since only aggregated results reach the base station.

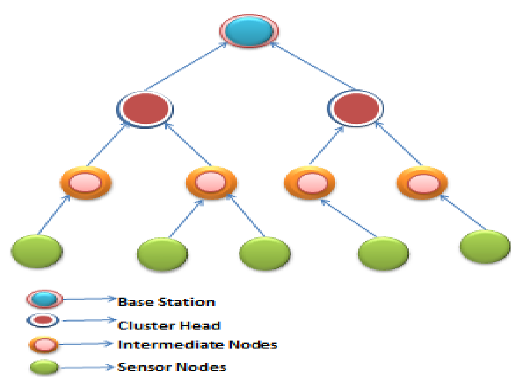

Figure 4: Tree based architecture

In cluster based networks, user can put some more powerful nodes, in terms of energy, in the network, which can act as a cluster-head and other simple node work as a cluster-member only. There is several clusters based network organization and data aggregation protocols have been proposed.

3.4 Grid Based Architecture

In grid based architecture set of sensors is assigned as data aggregators in fixed regions of the sensor network as shown in fig. 6. The sensors in a grid send the data packet directly to the aggregator of that grid. Hence, the sensors within a grid do not communicate with each other. Each sensor within a grid communicates with its neighboring node. Any node within a grid can assume the role of the aggregator node in terms of rounds until the last node dies.

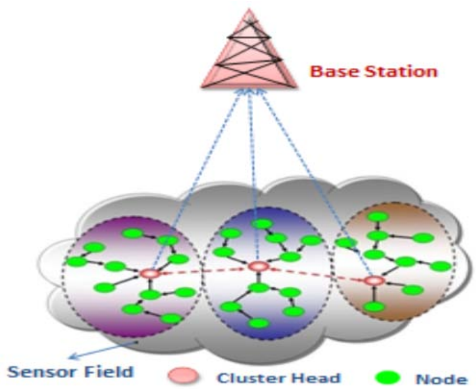

Figure 5: Cluster Based architecture

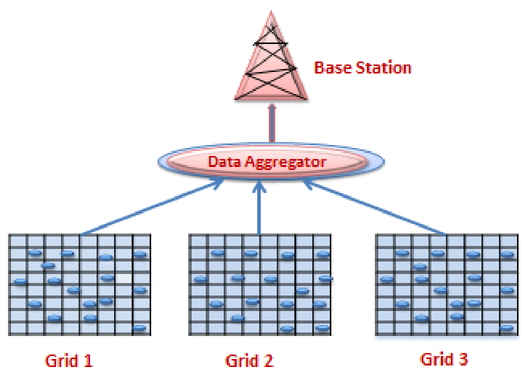

Figure 6: **Grid Based architecture**

4.0 COMPARATIVE ANALYSIS

Algorithms that are considered in each model are compared against the following performance metrics : (i) data accuracy (ii) overhead (iii) latency (iv) energy efficiency. According to the survey analysis the observed details are reported on Clustered based data aggregation algorithm, Chain based data aggregation algorithm, Tree based data aggregation algorithm and Grid based data aggregation algorithms in distinct scenarios and are depicted in table1, table 2, table 3 and table 4.

4.1 Clustered based Data Aggregation

Table 1 shows the performance characteristics of cluster based aggregation algorithms and algorithms under study are Clustered Aggregation Technique (CAG), Energy Efficient Clustering and Data Aggregation Technique (EECDA) and Low-Energy Adaptive Clustering Hierarchy (LEACH). As shown in table1 the first observation we made is that the CAG is much more efficient than EECDA and LEACH in terms of the total number of messages (control and data forwarding) incurred by the algorithms. As reported, CAG is highly accurate than EECDA and LEACH. CAG provides energy efficient and approximate aggregation results with small and often negligible and bounded error. The advantage of CAG is the high precision of the approximate results. The main difference between LEACH and CAG is that LEACH does not provide a mechanism to compute aggregate using cluster head values, while CAG does. LEACH has worse energy consumption, distribution.

Algorithm	Data accuracy	Overhead	Latency	Energy efficiency
CAG	Highly accurate	Low overhead involved	Reasonable delay	Saves energy consumption in terms of number of transmissions
EECDA	Moderate	No overhead involved	Decreases latency by using fewer hops to base station	Balances energy consumption by a factor of 51%
LEACH	Less accurate	Large overhead involved(highest transmission power)	Lower average delay	Energy expensive works.

Table 1: Comparison of Cluster based data aggregation algorithms

4.2 Chain based Data Aggregation

Table 2 studies the Chain based data aggregation algorithms like Power Efficient Gathering in Sensor Information System (PEGASIS), Chain Oriented Sensor Network for Efficient Data Collection (COSEN), Enhanced PEGASIS (E-PEGASIS), Chain-Based Hierarchical Routing Protocol (CHIRON).COSEN is efficient in the ways that it ensures maximal utilization of network energy, it makes the lifetime of the network longer, as well as it takes much lower time to complete a round. Simulation results show that COSEN demonstrate around 20% better performance than that of PEGASIS in respect of the number of rounds before the first sensor dies. It also saves about 260% time on average in comparison to PEGASIS. Performance analysis and simulation show that COSEN noticeably give a good compromise between energy efficiency and latency. COSEN require much lower time and energy as compared to other algorithms of WSN for data collection. However, this achievement is faded by the excessive delay introduced by the single chain for the distant node in CHIRON AND E-PEGASIS. The ultimate
Improvement of COSEN from PEGASIS is that, the delay is much lower in COSEN.

4.3 Tree Based Data Aggregation

Table 3 show tree based algorithms under study are Tree-based Efficient Protocol for Sensor Information (TREEPSI), Power Efficient Routing with Limited Latency (PERLA), Tree-Clustered Data Gathering Protocol (TCDGP). A tree-based data gathering protocol TREEPSI improves upon the PERLA and TCDGP. This protocol further reduces power consumption. We can shorten the transmission distance between nodes and prevent the root nodes from dying quickly.

Algorithm	Data accuracy	Overhead	Latency	Energy efficiency
PEGASIS	Less accurate	No overhead involved	Excessive delay introduced by the single chain for the distance node	Balanced energy consumption
COSEN	Highly accurate	No cluster set up overhead	Reasonable delay	Balances energy consumption
CHIRON	Moderate	Large overhead involved(highe st transmission power)	Excessive delay	Balances energy consumption
E-PEGASIS	Moderate	Large overhead involved	Longer transmission delay	Consume more energy

Table 2: Comparison of Chain based data aggregation algorithms

Algorithm	Data accuracy	Overhead	Latency	Energy efficiency
TREEPSI	Highly accurate	Power consumption is less in data transmission	Low average delay	balances energy consumption
PERLA	Moderate	low overhead involved	Low latency	Needs more energy for error detection
TCDGP	Less accurate	Decreases transmission distance	Reasonable delay	Reduces energy consumption

Table 3: Comparison of Tree based data aggregation algorithms

4.4 Grid based Data Aggregation

As described in table 4 algorithms under study are Grid-clustering Routing Protocol for Wireless Sensor Networks (GROUP), Aggregation Tree Construction Based on Grid (ATCBG). GROUP is an energy-efficient and scalable routing protocol for large-scale wireless sensor networks. In GROUP, cluster heads can perform data aggregation expediently in order to reduce the number of data packets and save energy. GROUP has lower maximum energy consumption than ATCBG. Our simulations have confirmed that GROUP is an effective, scalable and energy-efficient routing protocol for large-scale wireless sensor networks. It can also be observed that the average energy consumption of GROUP is evidently lower than ATCBG, and the lifetime of the network is much longer than ATCBG before the emergence of node death.

5.0 SIMULATION RESULTS

In this section we evaluate the performance of Clustered based data aggregation algorithm, Chain based data aggregation algorithm, Tree based data aggregation algorithm and Grid based data aggregation algorithms through simulations. The Network life time of WSN is determined by the time duration before the first node fails in the network. Therefore, it is very important to manage the sensor nodes in an energy efficient way to extend the lifetime of the sensor network.

Algorithm	Data accuracy	Overhead	Latency	Energy efficiency
GROUP	Highly accurate	Low overhead involved	Lower average delay	Better energy
ATCBG	Moderate	No overhead involved	Decreases latency by using fewer hops to base station	Balances energy consumption

Table 4: Comparison of Grid based data aggregation algorithms

To increase the network lifetime the number of packet transmission between the sensor node and the sink must be decreased. We set up a simulation environment using NS-2. The simulation was performed using this environment in a 100mx100m sensor field and 50 sensors were randomly deployed in this field which is constant with various parameters with respect the architectural models.The graphs in fig.7 depict the comparison of network lifetime with CAG, EECDA and LEACH in relation to the network lifetime and the data transfer rate. The graphs show an increase in network lifetime of the simulated network with CAG. It can be observed that CAG has less energy consumption of nodes in the process of cluster head selection than EECDA and LEACH algorithms. As compared to EECDA and LEACH, CAG gives better performance and extends the lifetime of the network. Based upon the simulation results, CAG can control the residual node energy and effectively extend the network lifetime without performance degradation. The reason is that extra transmissions have been eliminated and total energy consumption has been decreased.As depicted in figure 8 blue lines shows the performance of COSEN which has a better network lifetime, stability and energy efficiency when compared with CHIRON, PEGASIS and E-PEGASIS.It is shown that after several hundreds of rounds the amount of energy consumed is approximately same. But the good point for COSEN is that it spends energy in a totally distributed way such that the network can operate a higher number of rounds before the first sensor dies. COSEN, CHIRON, PEGASIS, E-PEGASIS lifetime pattern is shown in figure 8.Figure 9 shows network lifetime has been uploading for tree based algorithms TREEPSI, PERLA and TCDGP. By observing graphs plotted in figure 9 one can notice that TREEPSI is slightly better than

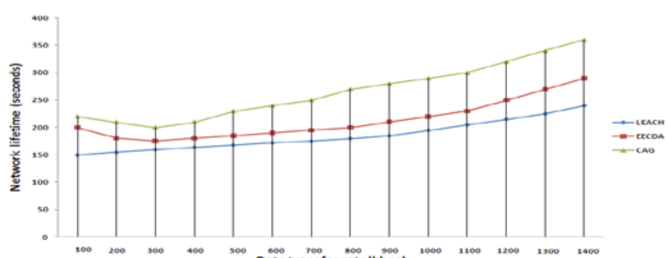

Figure 7: Network Lifetime of Cluster Based Algorithms

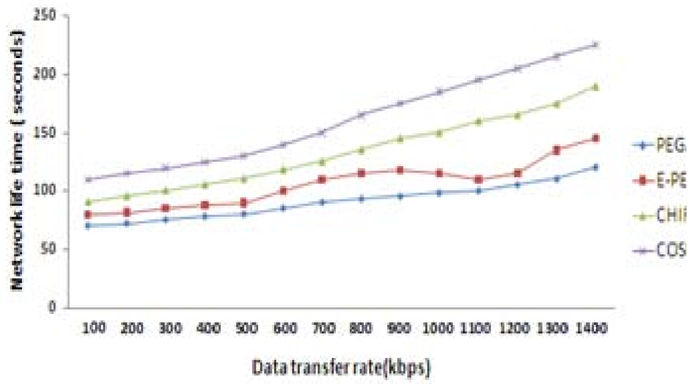

Figure 8: **Network Lifetime of Chain Based Algorithms**

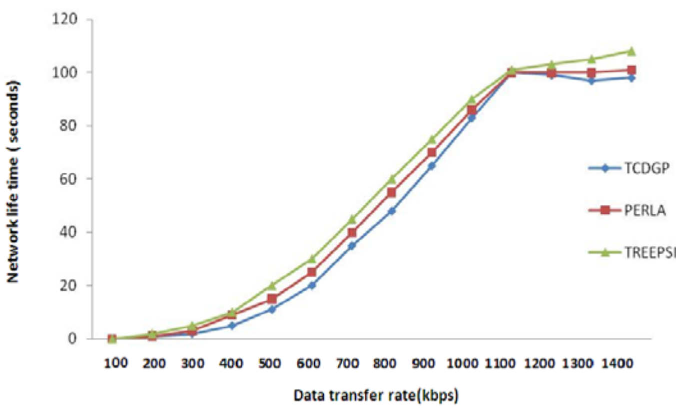

Figure 9: Network lifetime vs. data transfer rate

TCDGP and PERLA. This behavior is because the delay in TREEPSI is lesser compared to other two algorithms PERLA and TCDGP. The graphs in figure 9 depict TREEPSI shows good performance even in highly dynamic situations. Because PERLA needs more energy for error detection and recovery procedures in case of root failure to sink. But in TREEPSI, the path has made a detour in the topology.

Table 4 describes Grid Based data aggregation techniques and the algorithms under study are Grid Clustering Routing Protocol (GROUP) and Aggregation Tree Construction Based on Grid (ATCBG). As per the survey analysis, the following details have been given.

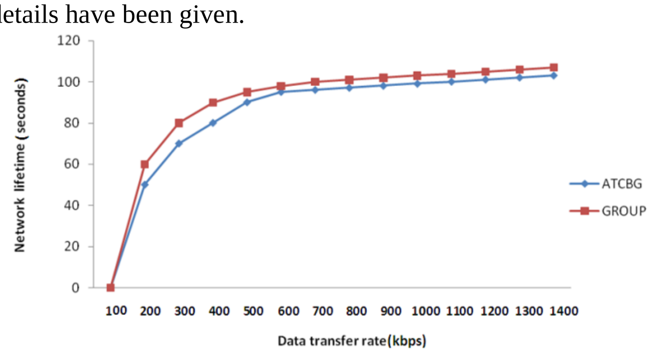

Figure 10: **Network Lifetime vs. Data transfer rate**

Table 4 shows the comparison of the GROUP and ATCBG Grid based algorithms. GROUP has a better data transmission rate than ATCBG especially in the scenarios with more nodes. GROUP has lower maximum energy consumption than ATCBG. GROUP has smaller gaps between maximum and average energy consumption. GROUP has a lower average delay with fewer nodes. GROUP is more scalable grid based algorithm and shows significantly better performance than ATCBG. Lifetime pattern of grid based algorithms is shown in figure 10.

6.0 CONCLUSION

In this paper, the authors studied various data aggregation algorithms based on various architecture such as Cluster based data aggregation, Chain based data aggregation, Tree based data aggregation and Grid based data aggregation in WSN. Through simulation, the performance of different data aggregation algorithms is evaluated and analyzed . Their advantages and disadvantages are discussed and compared. Results demonstrate data accuracy, overhead, latency, and energy efficiency of these algorithms.

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