

Performance Comparison of Structured Based Data Aggregation Schemes in Wireless Sensor Networks

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ABSTRACT

Data aggregation is one of the fundamental property of a Wireless Sensor Networks (WSNs), which is used to collect and combine useful information in a particular region of interest. However, it has been learnt from the literature review that the underlying network structure/topology significantly affects the efficiency of data aggregation solutions. From the system architectural point of view, data aggregation is an important aspect of the design and deployment of large-scale WSNs. In this paper, we investigated and analysed the existing solutions of data aggregation in WSNs and evaluated these solutions both quantitatively and qualitatively to judge their performance and suitability for large scale WSNs. For qualitative analyses, we critically analysed various schemes and compared them and presented the comparison in a tabular form. Further, we highlighted their strengths and limitations for resource-constrained WSNs. Secondly, we performed the simulation based quantitative performance comparison using the MATLAB simulation tool. Using simulation, we compared the TAG, PEGASIS and LEACH protocol, using various network parameters, including energy efficiency, network lifetime and delay. From the qualitative and quantitative analysis, it is concluded that hierarchical based clustering data aggregation protocols are best suited for resource-constrained WSN. Furthermore, the network topology has a significant impact on the data aggregation of WSNs.

Keywords: Data Aggregation, TAG, PEGASIS, LEACH, Wireless Sensor Networks,

Author's Contribution

^{1,2,4}Manuscript writing, Data Collection
Data analysis, interpretation, Conception,
synthesis, ³planning of research, and
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INTRODUCTION

Due to the recent technological advancements, Wireless Sensor Networks (WSNs) has emerged as one of the most widely researched and popular fields. It has many applications both in Civil and Military domains, and further due to the emergence of the Internet of Things (IoT) in the recent years, the number of potential applications and impact of WSNs is increasing day by day. They are widely used in health-care, industrial automation and production, environmental monitoring, control networks, security surveillance and critical

infrastructure monitoring, and many more [1, 2]. From the architectural standpoint, WSN is composed of a large number of low cost and small sensor nodes, having sensing, processing and communication capabilities. Usually, these sensors are randomly deployed in a monitoring area, commonly known as sensing field, and sensor-nodes communicate remotely with a Sink or Base Station, as shown in Figure 1.1 [3]. The structure of a normal WSN network is made up of four basic components, which are: sensor-nodes, gateway node,

sink node and a sensing area. In the sensing area, Sensors are interconnected with each other and communicate, as shown in Figure 1.1 below.

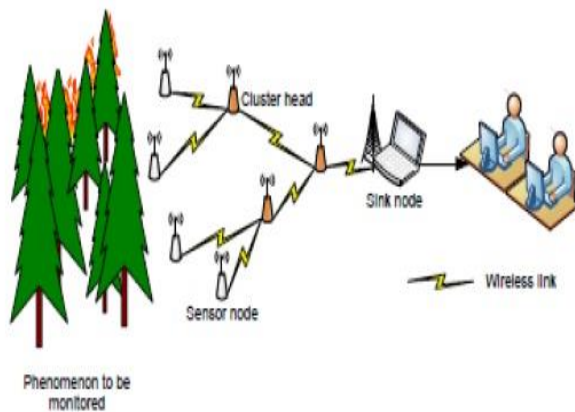


Figure 1. Wireless-Sensor-Network Layout

Each sensor-node of WSN is composed of the following different parts, which are Sensing hub, Processing part, Memory module, Transceiver, Area discoverer, Mobilizer, and Power component [4] as shown in Figure 1.2.

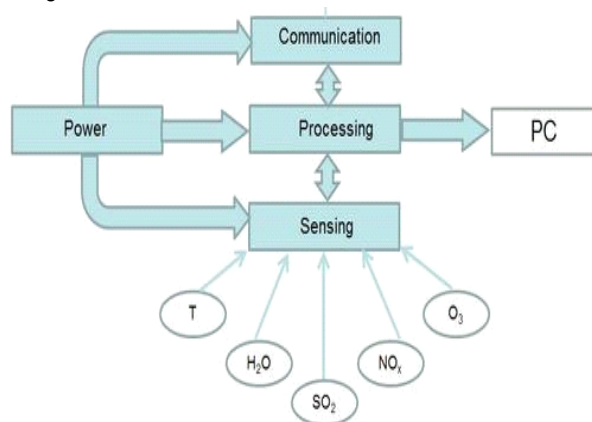


Figure 2. Structure of a Typical Sensor Node

Different types of mechanical, heat, natural, biochemical, light, attractive, seismic, and temperature sensors are connected to the sensing hub to detect the physical wonders of the surroundings.

Application of WSNs – WSNs have numerous applications, including environment monitoring, industrial control and monitoring, military and medical surveillance, smart and intelligent management and human-computer interaction, commercial applications, medical applications, agriculture applications, and military applications [5-8] as shown illustrated in Figure 1.3. Due to its wide range of

applications, WSNs have attracted great attention both from academia and industrial researchers.

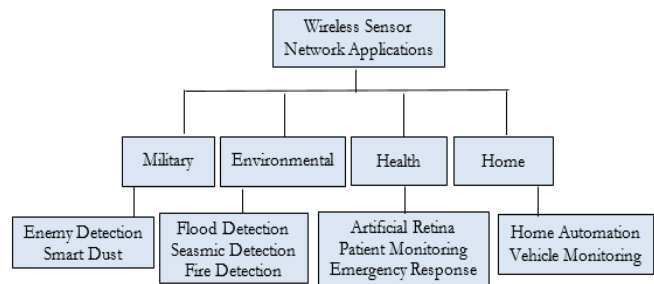


Figure 3. Applications of WSN

Technically, WSNs are highly resource-constrained i.e. limited battery power, short range communication, low processing, etc., and are usually deployed in harsh and hostile environments. Due to these limitations, WSNs have their own unique characteristics and features that distinguish them from the conventional wireless networks. Some of the most important unique characteristics of WSNs are: Application Oriented, Inexpensive Network, Energy efficiency, Communication Capabilities, Security and Authenticity Dynamic Network Architecture and Self-Configuring [9-11]. The architecture, design, and execution of a WSN's applications are influenced by different factors. These factors which poses various issues and challenges including Network Topology, Transmission Media, Limited Energy, Fault Tolerance, and Data aggregation [10, 12, 13].

In WSNs, sensor-nodes are usually sparsely deployed over a large geographical area in a random fashion. Therefore, the position of the nodes plays a valuable role in the operations and data aggregation of WSNs. Each sensor-node in a network senses the phenomenon/objects and transmits data to the sink or base station. Logical topology (physical deployment or arrangements of nodes) organizes sensor-nodes and give a structure to the network, so that data aggregation and communication take place in an efficient manner [14]. Therefore, data aggregation is an important aspect to the design and deployment of large-scale WSNs. Data aggregation in WSNs is affected by many factors [13] including network topology, scalability, fault-tolerance, delay and inefficient use of available limited resources. To address the issue of data aggregation, we studied the

hierarchical layout data aggregation schemes/solutions. In WSNs, data aggregation is performed by using either a Chain structure [15, 16], Tree structure [17-19], or Cluster structured [2, 20, 21] paradigm [22].

Given the motivation, it is significant to investigate and analyse the existing solutions for data aggregation in WSNs. In addition, to evaluate these solutions both quantitatively and qualitatively to judge their performance and suitability for WSNs. For instance, it will be more interesting to investigate the performance of (TAG, PEGASIS and LEACH) protocols, the most popular and widely used. To study the real strengths and weakness of these protocols. Furthermore, the detail comparison and evaluation will benefit other researchers to implement, evaluate and select efficient and reliable data aggregation schemes/protocols according to the network requirements and conditions. Furthermore, the protocol's analysis and simulation-based results will help researchers in the future to know how topology change influences the performance of the network.

In section 2 we present the detailed literature review of the related work, discussion various types of WSNs and network types. In section 3, we present the implementation and simulation framework. In section 4, result analysis and discussion is given, while in section 5 and 6, the conclusion and future work are discussed respectively.

LITERATURE REVIEW

In this section, we present a detail literature review of the state-of-the-art data aggregation for Wireless Sensor Networks (WSNs). Moreover, a detailed analysis of the existing solutions is presented in the Performance Analysis Chapter 4. It should be noted that in this chapter, a focus is on the hierarchical network paradigm-based solutions for WSN. In relevant literature, data aggregation paradigm is mainly divides into two types, i.e. hierarchical and Flat networks as shows in Figure 2.1. This classification of networks is based on the physical configuration of the network i.e. Unstructured layout, which is flat network or Structured layout which is hierarchal network [23]. In this paper, hierarchical data aggregation schemes are mainly targeted.

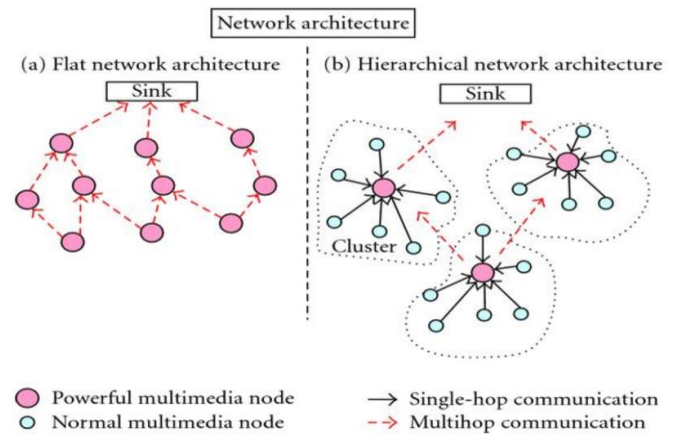


Figure 1. Flat network vs. Hierarchical Network Layout

2.1. Flat Network

In flat network layout/topology, there is no organized structure of the network, and usually every sensor node has the same responsibility in a network. Normally each sensor senses data and transmits it towards the Sink, as shown in Figure 2.1. The main drawbacks of this network are data redundancy, higher bandwidth, and delay, etc. Earlier, different protocols have been developed for flat network paradigm including centralized approach, directed diffusion [24], and spin protocol [25]. In centralized approach, every sensor-node can sense data and communicate the sense data to a central point called central processing node that has the shortest possible route. This central processor node is also called a header node and has a responsibility of aggregation and after aggregation, data is communicated to the sink node. The disadvantages of this approach are that the central processor node is usually overloaded, and exhaust its energy more quickly and dies soon, which may decrease the overall network lifetime.

Directed-Diffusion [24] is a well-known flat network architecture based data aggregation protocol for WSNs. In Directed-Diffusion method, a sink node broadcasts a message in the network, then a Sink node propagates interest to initialize gradients setup and communicate along the reinforcement path. Sink propagate interest throughout the network, if the attributes of the data sent by sink matches the interest, then gradient is setup and communicated along to a reinforcement path. However, Directed-Diffusion suffers from high limited memory storage for data caching inside the sensor-node.

Furthermore, the run time costs of matching consume high energy.

To overcome the limitations of Directed-Diffusion, Sensor Protocol for Information via Negotiation, (SPIN) [26] has been proposed. In SPIN, sensor-nodes communicates efficiently to conserve energy. It works on three basic steps: in first step the sensors broadcast ADV (advertisement) message composed of Meta-data; in second step if any sensor node is interested in the data, it will send REQ message that is a request message for that data; and in third step DATA will be sent to the requested node. Finally, every interested sensor node in a sensor network will get a data on a basis of this data centric routing. The SPIN family of protocols have many protocols that communicate information with low latency and are energy-efficient. Simulation results also shows that, sensor-nodes with a higher degree tend to consume more energy than nodes with a lower degree, creating potential energy-holes in a battery-operated network [25, 26].

2.2. Hierarchical Network

Hierarchical data aggregation is one of the most prominent technique, which allows a network to construct a structure ahead of communication and transmit data in a well-organized manner as shown in Figure 2.2. It also overcomes the drawbacks of flat network data aggregation schemes, which has no organized structure. In this section, we have concentrated on the structure-based data aggregation schemes to highlight the requirements of sensor systems and give an organized paradigm for routing in a WSNs.

The detailed literature review reveals that generally, hierarchical networks is based on either Tree, Chain or Clustered paradigm or architecture [15, 17, 20, 27-29]. In the next few sections, we discuss each of these paradigms in detail.

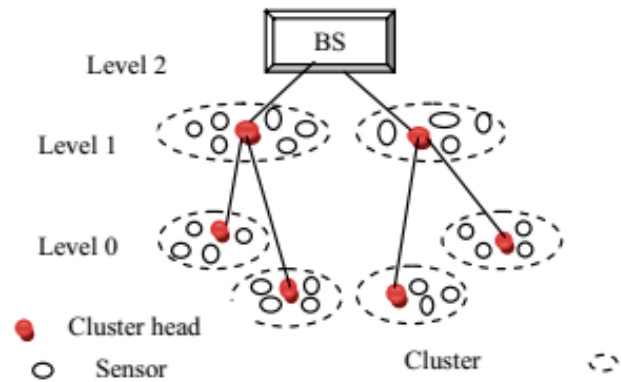


Figure 2. Hierarchical Data Aggregation Architecture for WSNs [30]

2.2.1. Tree Based

Tree-based approach is an aggregation technique that constructs a tree structure network. Aggregation tree is defined as minimum spanning tree that sink node is considered as a root and source nodes considered as a leaf nodes [18]. Each leaf node sends the sensed data to their corresponding parent node, which is responsible for aggregation. The aggregated data is then sent towards the root node, as illustrated in Figure 2.3. This scheme is suitable for designing optimal aggregation techniques. Demerits of this approach is that if data packet losses or fault occurs at any level, then the further sub levels suffer from the loss and faults too. In a nutshell, it has a single point of failure of the whole network. Figure 2.3 shows tree-based approach of aggregation.

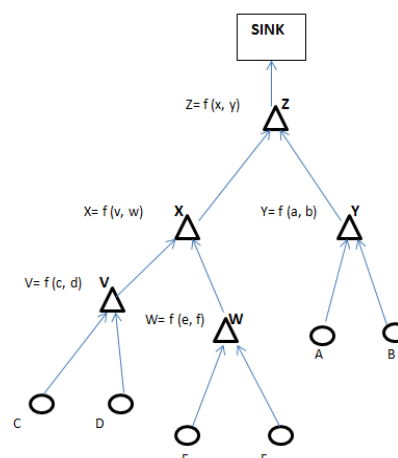


Figure Tree Based Data Aggregation

J. Franklin and J. M. Hellerstein proposed TAG [18] (Tiny Aggregation) protocol that performs data aggregation in simple and hierarchical paradigm. TAG

efficiently distributes and performs data collection and aggregation in WSNs in an energy efficient way. The limitation of the TAG includes overall networks dependency on a single parent's node as every child node in a network depends on its own parent node. If a parent node dies within a network, the performance of whole networks affected due to the reconstructing of new parent.

To address this issue, M Ding et.al. proposed an improved protocol for data aggregation, EADAT (Energy-Aware Distributed Aggregation Tree) [19], which is a heuristic approach. In this scheme/protocol data aggregation perform whenever it become possible. Furthermore, it reduces the power consumption and number of packets. In EADAT, the network lifetime is enhanced by sleeping the nodes to turn off its radios signals. However, both protocols having the same drawbacks, i.e. when the parent's nodes die, it affects overall performance of the networks and regeneration of the tree structure is initiated.

2.2.2. Chain Based

In this network paradigm, every sensor-node can send its data to the adjacent neighbour node. PEGASIS, as proposed by Lindsey [15], is a well-known chain based protocol. In PEGASIS, structure of a sensor network has been created in the form of a linear sequential chain, in which each sensor node sends its data to its adjacent node. Every node has its responsibility to aggregate data and forward it to the leader node, as illustrated in Figure 2.4 below. Base station is selected in a centralized manner of the chain by applying greedy algorithm. In each round, every sensor node transmits and receives data from its neighbour node. All the aggregated data can fuse into a leader node, which further forward data to the base station.

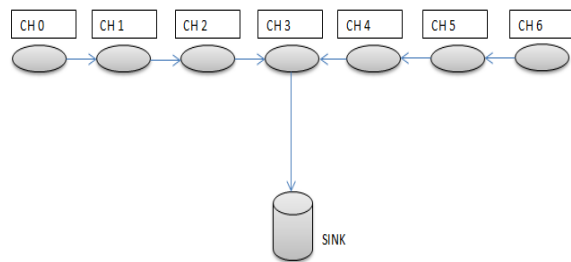


Figure 4. Chain Based Data Aggregation

To address the drawbacks of a tree-based approaches. Hierarchical chain structure protocols are developed. PEGASIS [15], chain based data aggregation protocol, which performs data aggregation to construct a chain by using a greedy algorithm, all nodes, header-node is selected at the mid of a chain among all, if a header-node dies, then reconstruction of a chain is initiated, by selecting a new header-node. However, limitation of PEGASIS is its higher delay due to the multi-hop transmission link (chain) from source-node to the Sink. Likewise, In [31] Parul and Poonam et.al. PEGASIS is better. Due to the limitation of LEACH, i.e. periodical changing cluster head role, [21]. However, they neglected to analyse the limitations of PEGASIS, and did not analyse the Traffic-load parameter, which is usually very high in chain-base schemes/protocols due to the single communication link.

2.2.3. Cluster Based

Cluster based approach is energy efficient paradigm, which is usually used for large size sensor networks, which splits the network into several network clusters. Each cluster consists of cluster-head, which is a powerful node (highest residual energy) among other cluster nodes. Cluster-head has a responsibility of aggregation, which aggregates the sensed data received from the cluster nodes and further transmits to the Sink node. Figure 2.5 shows a cluster-based sensor network. (Low Energy Adaptive Clustering Hierarchy (LEACH) [2, 21] is a well-known cluster-based aggregation protocol. It works on cluster routing, while in each round cluster head is selected among the cluster members on the base of Time Division Multiple Access (TDMA) approach. It then aggregates the data and transmits it to the sink node.

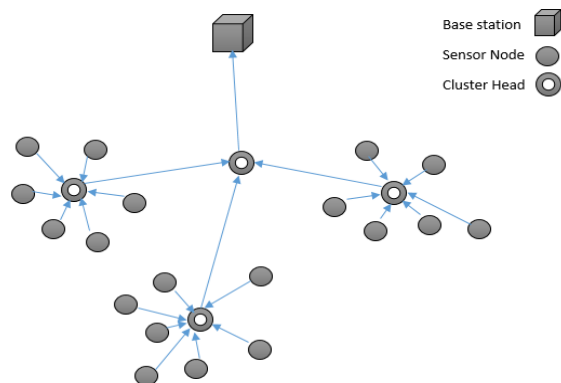


Figure 5. Cluster Based Data Aggregation

To address the issues of high traffic load and delay of chain-based approaches, clustered based data aggregation schemes were developed, where sensor-nodes are scattered in a set of multiples Clusters. HEED (Hybrid Energy Efficient Distributed Clustering) [20], and LEACH (Low Energy Adaptive Clustering Hierarchy) are two well-known cluster-based data aggregation protocols. In LEACH protocol, cluster-heads are selected from all clusters on the bases of highest residual energy, periodically change cluster head role when its energy becomes low and select another header node among members. Clustering enhance the network performance and control the delay issue, to reduced energy-consumption and bandwidth size by clustering a network. However, the limitation of LEACH includes worse performance of stability period as compared with chain-based protocol PEGASIS.

In doing so, S. P. Ardakani et.al. proposed CBA protocol, (cluster client/server data aggregation) [27], to overcome the issue of LEACH and PEGASIS, with the aim to extend the lifetime of a network. Furthermore, it concludes that the hierarchical data aggregation protocols are more energy-efficient, and reliable as compared to Flat network protocols/schemes, and they overcome the limitation of Flat network layout data aggregation approaches. In the preceding section, we briefly reviewed the most well-known hierarchical structure-based data aggregation schemes/protocols, i.e. data aggregation was performed by using Chain [15, 16], Tree [17-19], and Cluster [2, 20, 21] structure architecture. However, the in-depth performance comparison and evaluation of data aggregation schemes/protocols proposed for WSN is required because topological changes affect the performance of resource limited WSNs and also affect various factors of a network, e.g. energy-consumption, transmission load, delay, accuracy and reliability, etc. [22]. In addition, it is also required to examine that what other related factors affect the performance and efficiency of data aggregation in WSNs.

Therefore, it will be motivating to analyse the performance of selected data aggregation protocols (TAG, LEACH, PEGASIS) to identify the real merits and demerits in performance comparison using the qualitative analysis. Furthermore, simulation based quantitative analysis is also required of the mentioned schemes using

the most significant parameters, i.e. Energy-consumption, delay, accuracy, stability period and network lifetime to evaluate its effectiveness and suitability for WSNs. This detail comparison of data aggregation protocols/schemes will help other researchers to develop and implement an efficient and reliable data aggregation protocol for WSNs, by keeping in mind network specification and requirements of recourse constrained WSNs.

IMPLEMENTATION AND SIMULATION FRAMEWORK

WSN is a set of interconnected sensor devices which can communicate their sensed data through wireless medium, i.e. Zigbee, Bluetooth, or Infrared, etc. The performance evaluation and comparison of hierarchical data aggregation protocols is based on a system that consists of a set of 100 homogeneous sensor Nodes, and a sink node that is located at (0,0) of (x, y) coordinates, of 100*100 network area as shown in Figure. WSN can be featured by a graph $G = (N, L)$, where N represent sensor nodes, and L represents communication links. A link is generated, if two sensor nodes can communicate directly together.

Furthermore, sensor-nodes can transmit/exchange their information with each other by assuming that all the sensor-nodes are within communication range/radius after network organization. For example, sensor-node SN_i can directly communicate with node SN_j if the distance between them is less than the communication range $R(COMM)$ as shown in equation 3.a.

$$\text{if } (Dist(i, j) < RCOMM) \text{ then } (SN_i \leftrightarrow SN_j) \dots \dots (3.a)$$

Topology creation setup for TAG, PEGASIS and LEACH using MATLAB script (code can be provided on request). A snapshot of the simulated network deployment of TAG, PEGASIS, and LEACH are shown in Figure 3.2, 3.3 and 3.4 respectively.

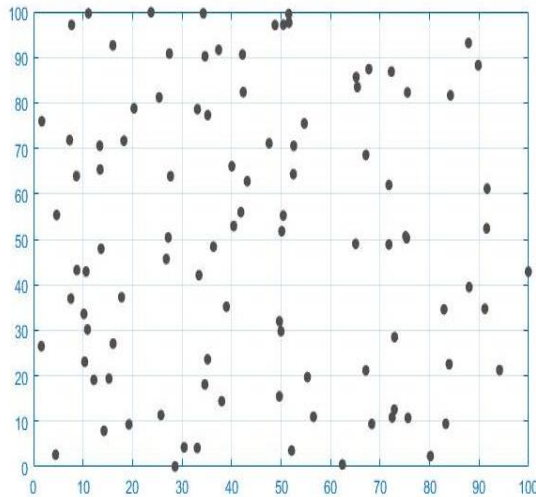


Figure 1. Network Deployment

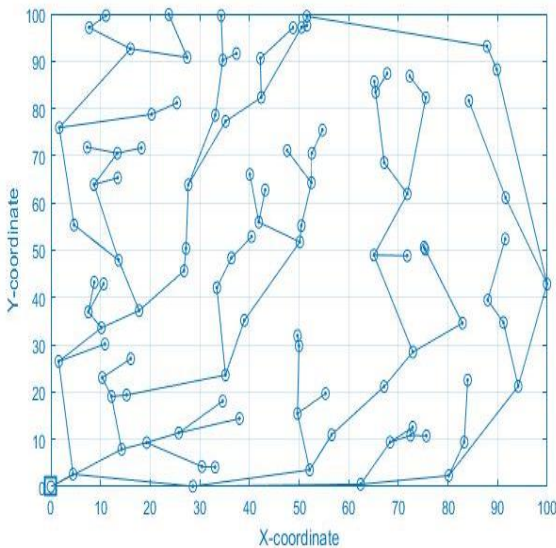


Figure 2. Topology Creation of TAG Protocol

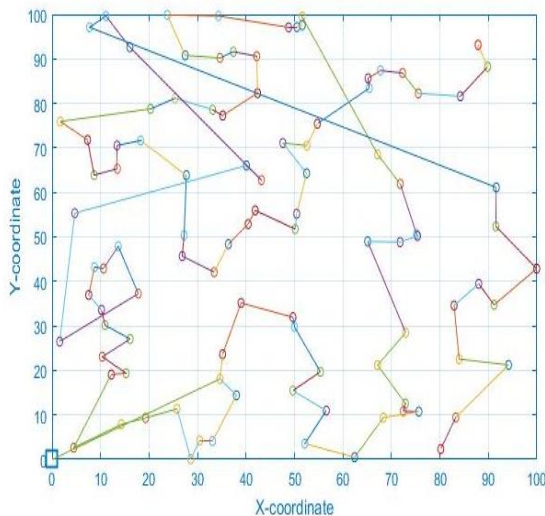


Figure 3. Topology Creation of PEGSIS Protocol

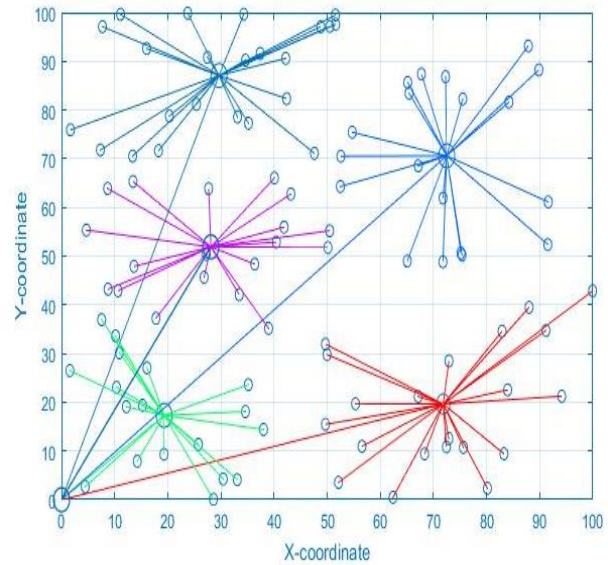


Figure 4: Topology Creation of LEACH Protocol

In WSN each sensor node is operated on battery while a lot of this limited energy is consumed in communication by transceiver unit, other than sensing and processing. The transmission and receiving of sensed data is the basic responsibility of transceiver unit, which is updated every time. From the literature various radio energy model are available for analysis of energy consumption in WSNs [32]. However, to check the efficiency of different techniques in WSNs, first order radio energy model is most widely used as shown in Figure 3.5 below.

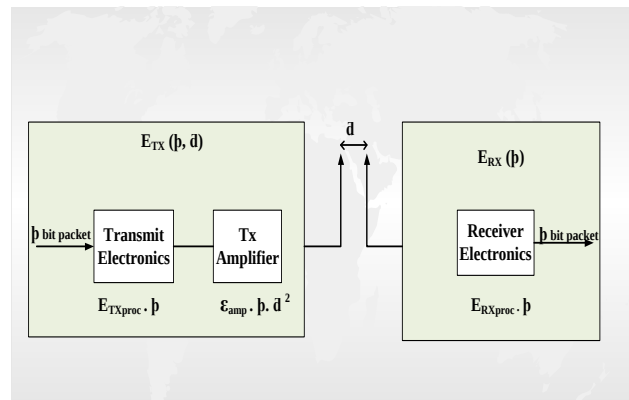


Figure 5. Radio Energy Model

The equations of this radio energy model are given.

$$E_{TX}(p, d) = E_{TXproc}(p) + \epsilon_{amp}(p, d) \dots (3.b)$$

$$E_{TX}(p, d) = E_{TXproc} \cdot p + \epsilon_{amp} \cdot p \cdot d^2 \dots (3.c)$$

$$E_{RX}(p) = E_{RXproc}(p) = E_{RXproc} \cdot p \dots (3.d)$$

Where, E_{TX} is the energy consumption during in transmission, while E_{RX} is the energy consumption during receiving process. E_{TXproc} and E_{RXproc} are the energies needed by a transceiver unit to transmitting and receiving of sensed data respectively. The energy required by amplifier circuit is represented by ϵ_{amp} , as shown in Table 3.1. Furthermore, packet size is represented by p , and distance is represented by d , while d^2 represent loss of energy during transmitting and receiving.

Table 1. Radio Characteristics	
Operations	Energy Consumed
Transmitter-Electronics (E_{TXproc})	50 nJ/bit
Receiver-Electronics (E_{RXproc})	
Transmit-Amplifier (ϵ_{amp})	100 nJ/bit

To implement and evaluate the performance of existing hierarchal protocols (TAG, PEGASIS, LEACH), we used Network Simulator MATLAB. In this work, 100 sensor-nodes are randomly deployed on 100*100 (X, Y) coordinates network area with one Sink-node located at (0, 0). Furthermore, initial energy of 0.5 joule is assigned to every sensor-node in the network. The parameters listed in Table 3.2. Sensor nodes are deployed randomly in a sensor area. After deployment first organize it into a network structure according to the applied algorithm, either Cluster, Chain or Tree.

Table 2: Simulation Parameters	
Parameter	Level
Area	100m × 100m
Number of Sensor nodes	100
Initial node energy	0.5 joule
Network Topology	Tree, Chain and Cluster
Sink-Node	At Origin Position (0, 0)
Transmit Amplifier-Energy (ϵ_{amp})	100 nJ/bit/m ²
Transmission-Energy (ETx)	50 nJ/bit
Reception-Energy (ERx)	50 nJ/bit
Node Distribution	Random

Performance Analysis

After the detailed critical analysis of the hierarchical data aggregation solutions for WNS, it is concluded that energy-efficiency, delay, accuracy, stability and network lifetime are the main performance parameters that the designers must consider while developing new solutions for data aggregation for resource constrained WSNs.

PERFORMANCE METRICS AND SIMULATION RESULTS

Set of experiments by using the following performance metrics. These metrics present the key factors that affect the behavior and performance of a WSNs. Selected performance matrices used in this quantitative research-based analysis are:

- A. Energy consumption
- B. Delay
- C. Stability period and Network lifetime

These mentioned matrices are discussed in detail further during experimentations and evaluation. Furthermore, in our experiments, we have used the following radio parameters as shown in Table 4.1. The transmit and receive power requirements are calculated using the equations (4.a) and (4.b). To check and evaluate the performance of existing schemes in WSN, we carried out several

$$E_{tx}(k, d) = E_{tx} - elec(k) + E_{tx} - amp(k, d)$$

$$E_{Rx}(k) = k(E_{Rx} - elec)$$

Table 1. Radio Characteristics	
Parameter	Level
Node initial energy (Ei)	0.5 Joules
Transmit Electronics (ETx-elec)	50 nj/bit
Receiver Electronics (ERx-elec)	50 nj/bit
Transmit Amplifier (ETx-amp)	100nJ/bit/m ²
Number of bits for data transmission (k) (Payload)	2 Bytes (16 bits)
Nodes Distribution	Random

A. Energy Consumption

Experiment - Each sensor-node in WSNs operates with a limited resources i.e. limited battery power, memory, bandwidth and processing capabilities. Moreover, a lot of this limited energy is expended in communication instead of sensing and processing. Therefore, it is needed to design and develop energy-efficient solutions which can enhance the overall lifetime of sensor node. Furthermore, data aggregation is one such core operation that constantly requires and consumes sensor-nodes energy, hence, it has direct impact on the overall network lifetime.

Due to limited energy resources of sensor network, to enhance the network lifetime by saving energy of a node is required. Re-charging sensor nodes power sources (batteries) is usually difficult/impossible as they may be scattered in out of reach or harsh environment. Therefore, it would be crucial to reduce power consumption during the data aggregation process in a WSN.

We will use this important metric to compare the energy consumption of TAG, PEGASIS and LEACH protocol, and will analyze that which protocol is more suitable for a resource-constrained WSNs. We have used the same network parameters and deployment setup as described in earlier in detail, with the First Order Radio Model as presented and with the radio model parameters mentioned above in Table 4.1.

The experiment with 100 deployed nodes and run for 2500 data aggregation round at maximum. Since, in the assumed network setup, all the deployed sensor-nodes consumes their energy entirely, and the network becomes dysfunctional, and there is no more energy in sensor nodes. From the graph plotted below in Figure 4.1, it has been learnt that TAG protocol runs for the lowest number of data gathering rounds, i.e. 1800 data gathering rounds, as consumes all its energy. However, LEACH exhibits better performance as compare to both TAG and PEGASIS, and it last for 2500 data gathering rounds. The extended lifetime of LEACH is due to the hierarchical clustered network structure. Data is gathered in local cluster heads, and then an aggregated packet is sent to the sink, hence it avoids excessive data packets communication. Furthermore, there is no long-haul communication in LEACH as compare to PEGASIS, which further saves valuable residual energy of the nodes.

This experimentation proves that LEACH is a more practical and suitable data gathering protocol for resource-constrained WSNs. However, a notable drawback of the LEACH protocol is that the role of the cluster-heads changes very frequently, and for applications, which run for a long time, the network lifetime can be affected [33].

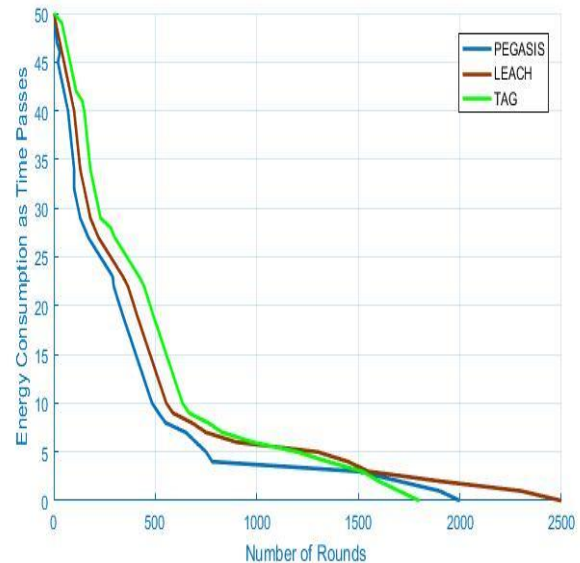


Figure 1. Energy Consumption as Time Passes

B. Delay

Delay is the time taken by a packet to transmit from source to destination. It depends on a distance between sensor-node and Sink-node. Another way, Delay is measured the time taken during sending packets from sender to the sink node at each round. Clustering approach performs very well and overcome the delay issue in aggregation process. Average End-To-End delay (ETE) is measured during data aggregation procedure. It is measured as average time since network start to collect data until they return to the sink and deliver the results. ETE depends on communication and computation delays at the sensor nodes such as medium access, message reception and transmission, itinerary planning and aggregation delays [34, 35].

Experiment – In this experiment, we evaluated the delay in the network in terms of the transmission time taken to send a data from the source node to the sink. The simulation is performed using the same parameters as mentioned in Table 4.4 above, with the network setup

as discussed above in section 4.

The simulation was run for 3000 data gathering rounds for TAG, PEGASIS and LEACH protocols and the results were traced. In the graph below in Figure 4.2, shows the average time taken to travel from source node to sink node, PEGASIS has the highest delay, while LEACH and TAG comparatively incurs the same competitive delay. The highest delay of PEGASIS is due to the multi-hop communication on a single link, where each node waits for a data packet from its adjacent neighbours. While, LEACH have the lowest delay during the data aggregation, because using the clustering paradigm, data is fused into each designated cluster-head, and is further sent to the Sink. Likewise, TAG incurs lesser delay as compare to PEGASIS, because sensor-nodes sends their data to their immediate parent node, and parent node further forward it to the sink without any further ado.

From this experiment, it is evident that the delay in the network is closely associated with the network topology, and clustered-based data aggregation protocols have proved to be the most suitable data aggregation paradigm for resource-constrained WSNs.

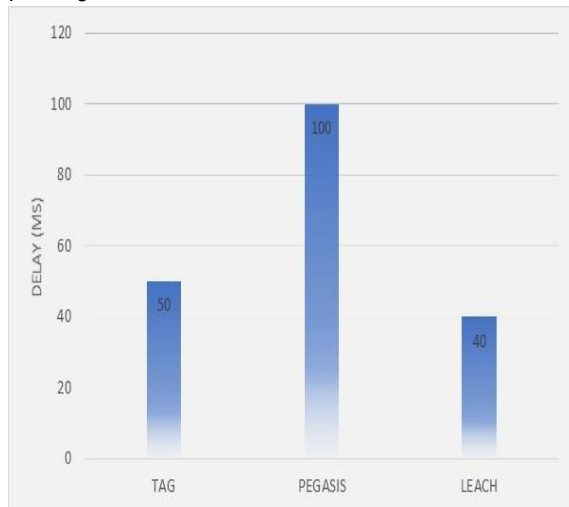


Figure 2. Delay Comparison

C. Stability Period and Network Lifetime

Stability period is the total time of network operations until the death of first node. If the first node within a network dies, the remaining operation time is considered to be unstable. When the last node within a network dies then the lifetime of a network is terminated. Network lifetime in a sensor network depends on the battery life of

sensor nodes and the node death ratio [36, 37]. All sensor nodes work on small batteries. Due to sensing, processing and communication among nodes, energy is depleted until node death occurs. Whereas, Stability of a network is measured by the first node death occurs. Due to the loss of first node, network becomes unstable and affect network communication.

Experiment - The performance parameters like the lifetime of nodes and average-time taken to transmit a packet from source node to destination are considered in the performance comparison of routing protocols. We compared the TAG, PEGASIS and LEACH, protocols and tests the stability period/network lifetime of these protocols in comparison. The Stability period is calculated by finding the number of rounds for which the first node dies in the network. In addition, the Network lifetime is calculated by finding the last node death in the network during simulation. The TAG takes 420 rounds for first node failure. Similarly, for LEACH, PEGASIS, it takes 205, 410, respectively for its first node to fail. And the death of the last node of TAG, PEGASIS and LEACH becomes at 1800, 2000 and 2500 round. The node lifetime of the evaluated protocols is graphically plotted as shown in Figure 4.3.

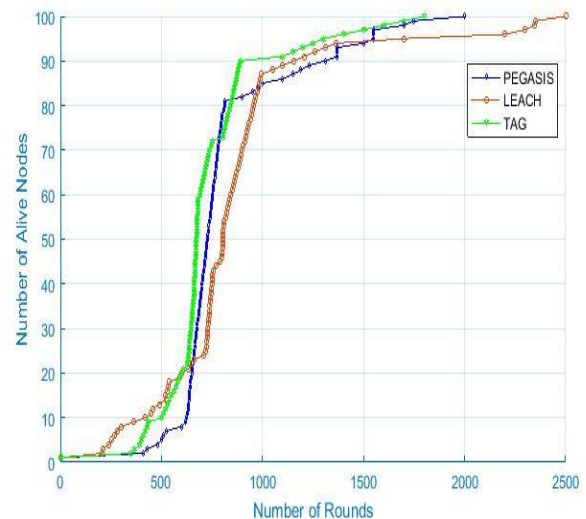


Figure 3. Stability and Network Lifetime Comparison

From the simulation results, it argues that PEGASIS has a better stability period as compared to TAG and LEACH. While LEACH has the extended network lifetime, because LEACH is simple in operation, and it does not

have location information and does not incur an extra overhead in this exchange information. Furthermore, LEACH avoids data redundancy at the Sink node. However, it also learnt that the communication overhead in PEGASIS increase without an increase as the number of nodes. The overhead thus increases and ultimately affects the energy consumption and stability of the network.

CONCLUSION

The resource limitations of sensor-nodes and their deployment in harsh and inaccessible environment, poses various issues and challenges, e.g. energy-efficient operations, scalability, fault-tolerance and dynamic structure, etc. Added to this, Data Aggregation is one such important issue that requires important attention from the research community. The aggregation process permits and arranges data collected from various sensor-nodes in an energy-efficient way. It also reduces packet size and removes the duplicated packets in an energy-efficient way to extend the lifetime of individual sensors and the overall network. From the system architectural point of view, data aggregation is an important aspect of the design and deployment of large-scale WSNs. Data aggregation in WSNs is affected by many factors [13] including, network topology, scalability, fault-tolerance, delay, and inefficient use of available limited resources. To address the issue of data aggregation, we studied the hierarchical design-based data aggregation schemes/solutions.

In WSNs, data aggregation is performed by using either a chain structure [15, 16], Tree structure [17-19], and Cluster structure [2, 20-22] paradigm. We investigated and analysed the existing solutions for data aggregation in WSNs and evaluated these solutions both qualitatively and qualitatively to judge their performance and suitability for WSNs. For qualitative analyses, we critically analysed various schemes and compared them and presented the comparison in a tabular form. Further, we highlighted their strengths and limitations for resource-constrained WSNs. Secondly, we performed the simulation based quantitative performance comparison using the MATLAB simulation tool, and compared the TAG, PEGASIS and LEACH protocol, using various

network parameters, including energy-efficiency, network lifetime and delay. From the qualitative and quantitative analysis, it is concluded that hierarchical based clustering data aggregation protocols are best suited for resource-constrained WSNs. Furthermore, the network topology or physical infrastructure has a significant impact on the data aggregation of WSNs.

Future Work

We are committed to continue our research work in WSNs and provide more novel contributions in the future. The presented work can be extended as follows in future. Our work asserts that the topological change plays a very important role for data aggregation in resource constraint WSN. From our analysis and results, we showed that which parameters are more important for data aggregation in WSNs. Based on this, in the future, we will develop a new structure base data aggregation protocol which would help overcome the drawbacks of existence schemes by keeping in view their limitations.

While designing new solutions, we will focus on the energy hole and load balancing aspects. Since, due to the limited energy during the data aggregation, some nodes exert their limited energy and die earlier than other nodes, and consequently, create energy holes. Finally, from the overall network management perspective, data aggregation protocols need to be more fault-tolerant. Therefore, we will propose a new solution to enhance fault tolerance during the data aggregation operation.

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