Unleashing the Power of Connectivity: Exploring Data Aggregation in Wireless Sensor Networks

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Abstract: *In recent years, the exponential growth of data has brought significant challenges to cloud computing. Addressing the issues associated with edge computing has emerged as a promising solution to enable efficient and timely data processing.* Wireless Sensor *Networks (WSNs) are widely used in various applications such as environment monitoring, healthcare, and military surveillance. In WSNs, data aggregation is a critical process to reduce network traffic, prolong the network lifetime, and improve energy efficiency. This research paper evaluates the performance of data aggregation algorithms in WSNs using NS2, NSG, and NAM. The proposed work investigates the impact of different data aggregation algorithms on network throughput, delay, and energy consumption. Simulation results show that the data aggregation algorithms significantly improve network performance by reducing the amount of data transmitted and decreasing network congestion.*

Keywords: *Edge devices, Wireless Sensor Networks, Data Aggregation, NS2, NSG, NAM.*

I. Introduction:

A distributed computing prototype called "edge computing" moves data storage and processing closer to the point of need. Prior to sending data to the cloud or data center, it analyzes data from Internet of Things devices [1]. There are a wide variety of edge device types. These gadgets carry out tasks directly at the edge or send data to the cloud via IoT or industrial IoT. Data is also transmitted over the internet by edge devices. Edge devices come in two varieties: traditional edge and intelligent edge. Conventional edge devices have little to no processing power and send data over a secure network. When it comes to industrial automation, intelligent edge devices are smart devices that can carry out edge computing tasks close to the data source.

Traditional Edge Devices

<u>Traditional edge devices include:</u>

I. *Edge routers:* Networks for multiple packet transmissions are connected by edge routers. They control data flow to an IP address, enabling the use of a single internet connection by numerous devices. Within a particular geographic area, a router manages multiple devices connected to a Local Area Network (LAN).

II. *WAN devices:* Wide Area Networking (WAN) devices cover a lot of ground and are sometimes even worldwide. No matter where they are located, organizations can collaborate easily throughout the enterprise thanks to WAN devices.

III. *Firewalls*: Firewalls keep an eye on every network communication for security. They can be set up to prevent data transmission that the rule set deems detrimental and have rules-based functionality [2].

Intelligent edge devices include:

I. *Sensors*: Sensors track an event or condition, initiate a response, and direct data to its next location. There is an almost infinite variety of sensor types, such as temperature, humidity, vibration, motion, GPS, and optical.
II. *Actuators*: Actuators serve as the physical link that connects electronic components, such as sensors, to the movement that machines need to perform. Actuators use electric, air, or hydraulic power to trigger actions based on sensor signals and instructions from intelligent edge devices.
III. *IoT Gateways:* For analytics, computation, processing, and storage, IoT gateways link a variety of sensors and other devices to cloud computing platforms. [3].

Wireless sensor network (WSN) is an edge device made up of one or more base stations (BS) or sinks, along with a number of sensor nodes. Sensor nodes take in information from their physical surroundings and transmit it to the base station as signals. These nodes have a transceiver and a sensing element. They also have low-power batteries and restricted processing capabilities. It also has a transceiver and a sensing component. We can cut down on the number of packets and energy usage by aggregating the data from sensor nodes before sending it to the base station. Additionally, this will lengthen the nodes' or a cluster's lifespan [4]. WSN has numerous uses in a variety of industries, including the military, healthcare, and atmospheric data [5].

Power efficiency is one of the key constraints for wireless sensor networks (WSNs), as these networks are initially dependent on small sensor nodes that have irreplaceable power sources. In order to effectively fuse the data gathered by a large number of sensor nodes [6] data aggregation techniques that minimize the quantity of data packets transmitted through the network are crucial [6].

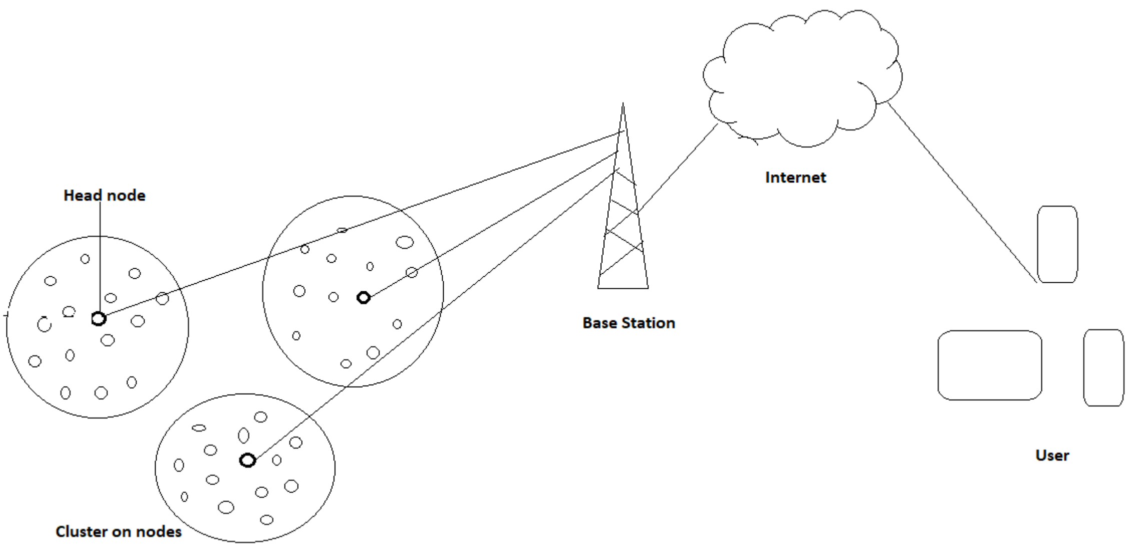

Figure 1: WSN Architecture.

In this research, we use NS2, NSG, and NAM to assess the effectiveness of data aggregation algorithms in WSNs. We study the effects of various data aggregation algorithms on energy consumption, latency, and throughput of the network. The three distinct data aggregation algorithms—Maximum, Minimum, and Average aggregation—are compared for performance. Our simulation results show that by lowering network congestion and transmitting less data, the data aggregation algorithms greatly enhance network performance [7].

This research paper's remaining sections are arranged as follows. A review of prior studies on data aggregation in WSNs is given in Section II. The methodology for our simulation, which includes the NS2, NSG, and NAM tools, is described in Section III. The outcomes and analysis of our simulation are shown in Section IV. The implications of our findings are covered in Section V, along with suggestions for further study topics. The research paper is finally concluded in Section VI.

II. Literature Review

Previous research has investigated different data aggregation algorithms and their impact on network performance in WSNs. Many studies have focused on the design and analysis of data aggregation algorithms that can reduce network traffic and minimize energy consumption. Several algorithms have been proposed, including Maximum, Minimum, and Average aggregation. Rajagopalan and Varshney [8] conducted a creative review of the literature on data aggregation in wireless sensor networks. The state of the art for distributed data aggregation algorithms is reviewed by Jesus et al. [9], who also describe the various aggregation function types. The body of research on data aggregation is still expanding steadily. A thorough review of the literature is required in order to assess and incorporate the current research that has been presented in this area.

The following describes the data aggregation taxonomy that was used in this survey, including network lifetime, energy efficiency, data accuracy, latency, and data aggregation rate:
(a) Energy Efficiency: In an ideal world, each sensor would use the same amount of energy during each round of data collection; however, in reality, sensor nodes use different amounts of energy to transmit data. If a data aggregation technique in WSNs maximizes functionality while consuming the least amount of energy, it is considered energy-efficient. The ratio of successfully transferred data in a sensor network to the total energy used for data transfer is known as energy efficiency. Energy efficiency is calculated by using equation.

$$Energy\ Efficiency_i = \sum_{i=1}^{n} \left(\frac{Amount\ of\ data\ successfully\ transferred\ in\ a\ sensor\ network}{Total\ energy\ consumed\ to\ transfer\ those\ data} \right)$$

----Eq. (1)

Where, n is a sensor network's total number of sensor nodes.

(b) Duration of Network The number of completed data aggregation rounds until the first sensor node runs out of energy is the definition of the network lifetime. To put it another way, it's defined as the amount of time (measured in rounds) that passes until the first sensor node or set of sensor nodes in the network runs out of energy (battery power) or until the network disconnects as a result of one or more sensors failing, as equation 2.

$$NL_n^n = \min_{v \in V} NL_v$$ **---------------Eq. (2)**

when the lifetime of the network With NLv representing node v's lifetime and V denoting the node set excluding the sink node, NLnn comes to an end as soon as the first node fails.[10]

Architectural based data aggregation:

The simplest type of wireless sensor network architecture is centralized architecture. This the data fusion process can be applied to. signifying that every sensor node detects data and sends it to a single central node known as the central processor fusion node.Every sensor node's report was combined by this central processor. The network's central node is in charge of the enterprise in this architecture. Its ability to quickly identify inaccurate information reports that are gathered by the entire wireless sensor network is the fundamental benefit of this style. The drawback is that the workload is just one point of concern and is not adaptable to changes in sensors [11]. In a decentralized wireless sensor network, multiple sensor nodes collaborate to make decisions rather than a single centralized node acting as the group's spokesperson.

Data fusion, in which all sensor nodes are connected to one another based on observations, happens locally at each node based on local observations and the information received from neighbouring nodes. This architecture's advantages include scalability and resistance to changes in the network's [11,13] dynamic properties as well as the addition or removal of sensing nodes. We can lower the quantity of data packets sent to the sink by using special nodes in hierarchical networks, where data aggregation must be carried out at specific nodes. Thus, this network raises the network's [11,13,14] overall energy efficiency.

Networks Based on Chains for Data Aggregation wherein every sensor transmits data to its nearest neighbour. The power-efficient data-gathering protocol for sensor information systems, known as Pegasis, is one type of chain-based data aggregation. All the sensors in PEGASIS [12] are arranged into a linear chain for data aggregation. A greedy algorithm can be used by the nodes to create a chain, or the sink 170 Mousam Dagar & Shilpa Mahajan can decide the chain centrally. The Greedy chain formation makes the assumption that every sensor has comprehensive network knowledge. Chain formation is started by the node that is farthest from the sink, and at each stage, a node's closest neighbour is chosen to be its successor in the chain. During every round of data collection, a node receives a packet of data from one of its neighbours, combines it with its own, and then forwards the combined packet to the next neighbour along the chain. The combined data is eventually sent to the base station by the leader node in the area that resembles the cluster head [13].

Two data aggregation schemes, as proposed by Vaidhyanathan et al. [14], are predicated on segmenting the area that a sensor network monitors into multiple grids. In-network data aggregation and grid-based data aggregation are these. In fixed regions of the sensor network, a group of sensors is designated as data aggregators in grid-based data aggregation. Data is directly transmitted from the sensors within a given grid to the data aggregator within that grid. As a result, there is no communication between the sensors in a grid [15,16].

III. Proposed System

Here, in this research considered multiple scenarios and compared their output. First there is network with 18 nodes, then 50 nodes then 5 nodes and cluster-based algorithm with tcp and udp network agents. Finally recorded the following network traits and came to a conclusion.

IV. Results and Analysis

A. Network Throughput:

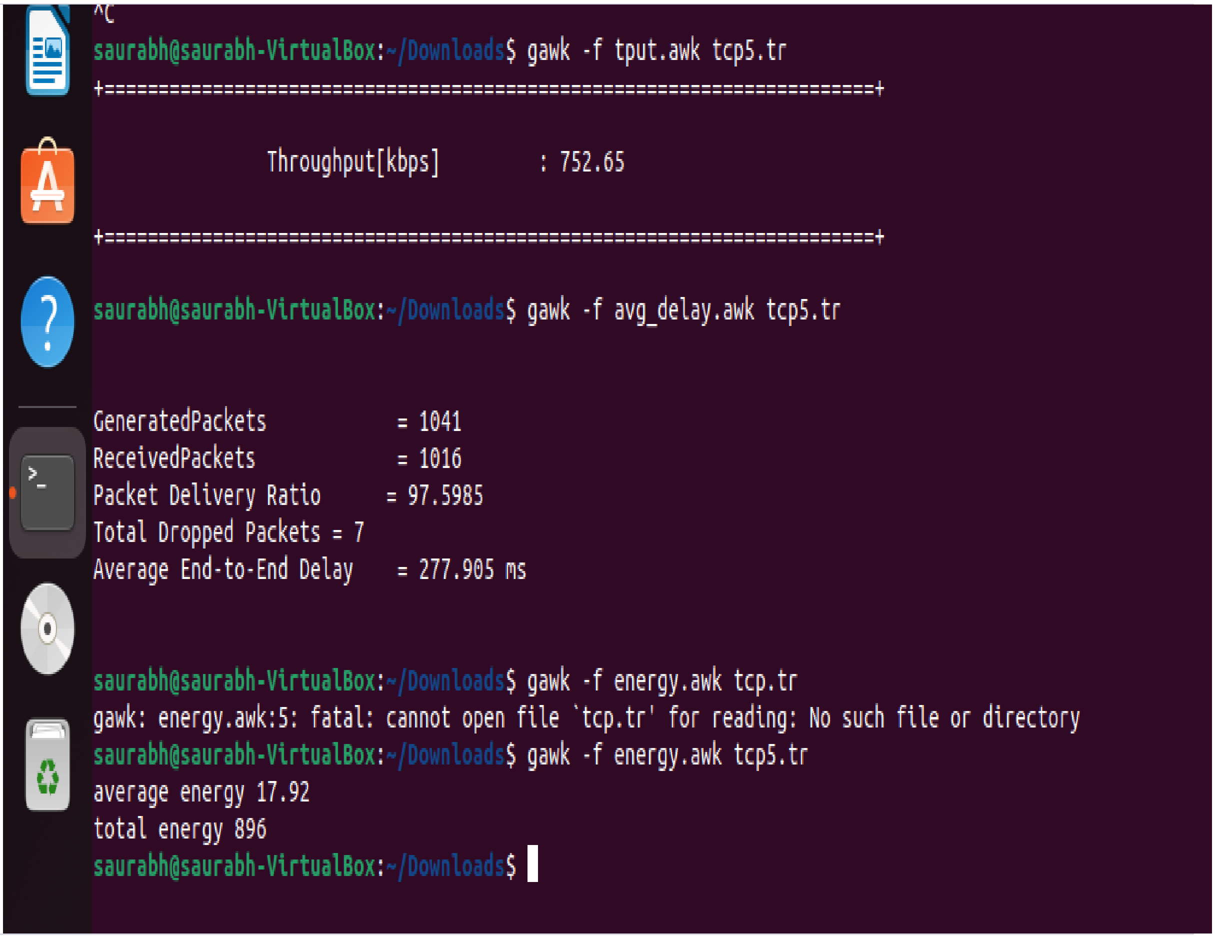

Figure 2: Shows result of a network architecture with 5 nodes and tcp agent.

B. Network Delay:

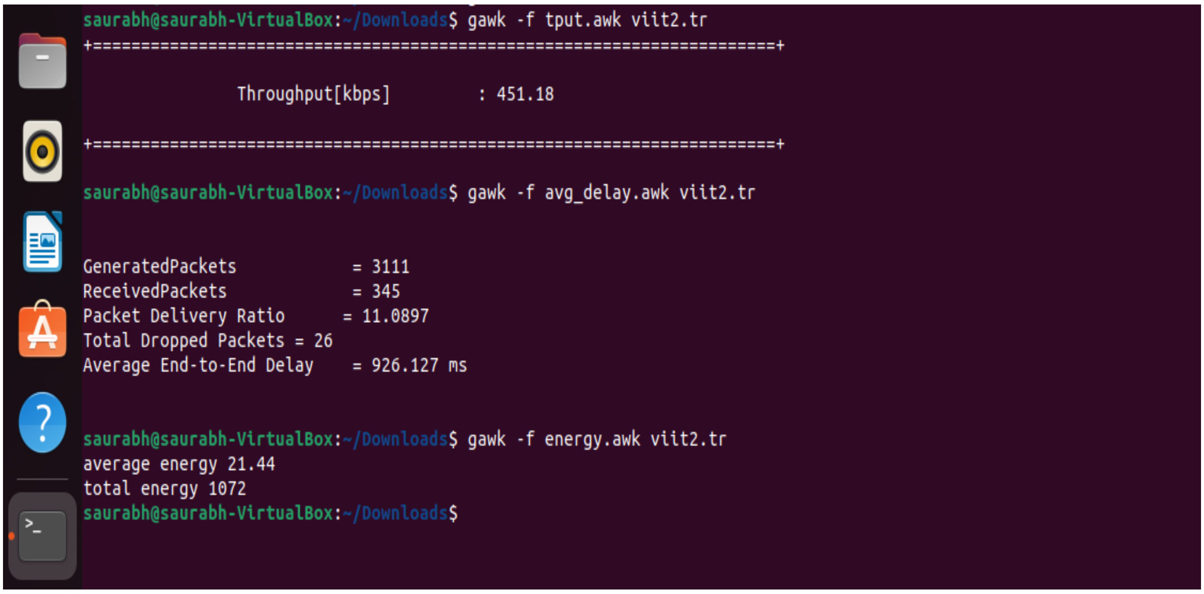

Figure 3: Shows result of a network architecture with udp and tcp agents

C. Energy Consumption:

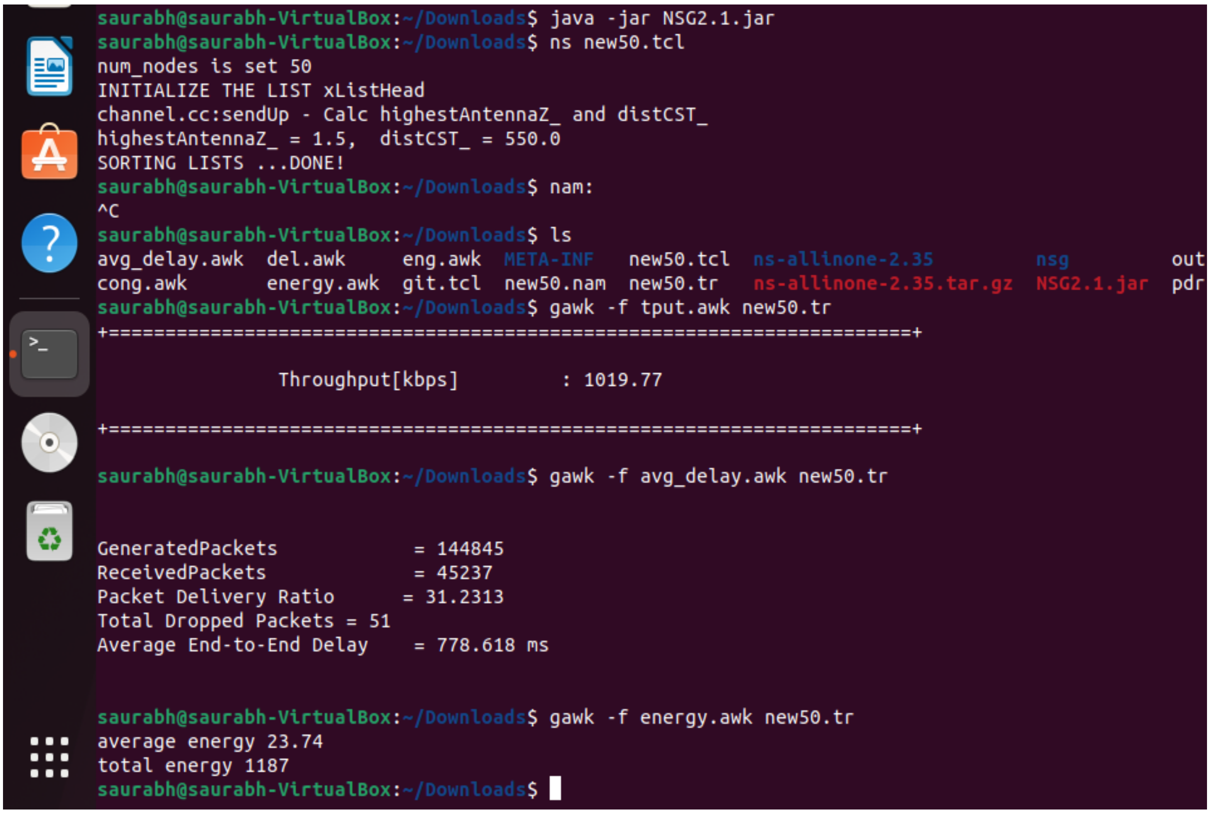

Figure 4: Shows result of a network architecture with 50 nodes and tcp agent

V. Discussion

Our simulation results demonstrate that data aggregation algorithms significantly improve network performance in WSNs. The selection of a particular network scenario depends upon the need and environment. Although, in large networks, cluster-based algorithm will consume more energy and more delay as compared to tcp with 5 nodes. Throughput is almost similar in both cases. More accuracy is guaranteed with a greater number of nodes. Another observation was that tcp agent is more effective in congestion control than udp and consumes less energy and throws less delay.

Table 1: Shows the results obtained with various network architecture

Sr. No.	Network Architecture with	TPut(kbps)	Delay	PDR	Energy
1	5 nodes and tcp agent	752	278	97	896
2	udp and tcp agents	451	926	11	1072
3	50 nodes and tcp agent	1019	778	31	1187

VI. Conclusion:

The data aggregation is a critical process in WSNs that can improve network performance by reducing network traffic, prolonging network lifetime, and enhancing energy efficiency. In this research paper, we evaluated the performance of data aggregation algorithms using NS2, NSG, and NAM. The research reveals that different data aggregation algorithms have varying effects on network delay. The Maximum aggregation algorithm exhibits the lowest delay, followed by the Average and Minimum aggregation algorithms. This suggests that selecting the appropriate aggregation algorithm can help minimize packet transmission delays and improve real-time data delivery. Because sensor nodes have a limited battery life, energy consumption is a major concern in wireless sensor networks. The research indicates that data aggregation algorithms are essential for cutting energy use. By sending fewer packets and minimizing pointless data transmission, the Maximum and Average aggregation algorithms use less energy than the Minimum aggregation algorithm.

VII. Future Scope

In future advanced algorithms can be developed for data aggregation ,developing and evaluating more sophisticated aggregation algorithms that consider additional factors such as data quality, node reliability, or context-awareness to further improve network performance.

Investigate dynamic data aggregation schemes that adaptively adjust the aggregation strategy based on network conditions and application requirements. This could involve dynamically selecting the most suitable aggregation algorithm or adjusting aggregation parameters in real-time to optimize network performance.

Further, more energy efficient, secure and fault tolerant aggregation can be developed. We can also introduce AI in aggregation to enhance performance and adaptability. These are just a few potential areas for future research based on the findings of the current study. In addition to enhancing the effectiveness and performance of WSN applications, more research in these areas can advance the field of data aggregation in wireless sensor networks.

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