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Implementation of Data Transmission Methodology for Multimedia in Wireless Sensor Network (WSN)

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Abstract

Wireless sensor networks (WSNs) confront specific hurdles in multimedia transmission (MMT) due to the low-cost, low-power sensor nodes. These nodes work together to gather and transmit environmental data; therefore, effective communication and resource management are critical. This paper introduces a cross-layer optimization strategy for MMT in WSNs which will select the best cluster heads to ensure multimedia data is delivered in a timely manner. This proposed method of optimizing WSNs applies the Prey-Predator Chasing (PPC) optimizer followed by multi-objective optimization to enhance cluster formation (clustering) and route formation (routing) toward transmitting data without interruptions. The method takes advantage of resource assignment, data routing, and improves performance factors related to optimizing applications. The extension of the PPC optimization method provides efficiency in WSN operation when dealing with error-sensitive multimedia data while minimizing energy and processing delay. The results obtained show and indicate that applying a cross-layer with this optimization enhanced throughput for WSNs and reduced energy consumption for those sensor nodes whilst enhancing WSN reliability and efficiency for multimedia communication.

Categories: Security and Privacy, Computer Networks, Networking Technologies
Keywords: wireless sensor network, cross-layer optimization, prey predator chasing optimization, network clustering, optimal data routing

Introduction

The transmission of multimedia data in a Wireless sensor network (WSN) can be extremely challenging due to the limited energy and computational power of each sensor node. WSNs are frequently used with tenders such as environmental monitoring, medical, surveillance, or wherever multiple sensors collect and send data from their environment. Multimedia files, such as images, audio, or videos, need more careful handling to better manage transmission of data and energy. Given the potentially large amounts of multimedia data transferred, it is vital to utilize effective, efficient compression techniques. Formats like JPEG for images and MPEG for videos will help reduce data while maintaining reasonable quality. Different multimedia applications require different requirements for quality and latency in a timely manner, and therefore, quality of service must be balanced with energy usage. In some cases, quality may even need to be sacrificed in popular instruction to save energy in these scenarios, enhance reliability, or some combination. Using data fusion techniques can increase the efficiency of the program application by aggregating data from multiple sensor nodes prior to transmission and reducing the amount of overall data sent. Instead of sending raw multimedia data from all nodes, aggregated or some processed information could be sent by some of the sensor nodes, resulting in less data congestion which ultimately uses less energy. WSNs operate through multiple communication layers, like the physical, Medium Access Control (MAC), and network layers. Improving these layers together is expected to improve the efficiency of the transmission. Further, scheduling mechanisms that allow nodes to alternate among energetic and snooze methods help save power. Scheduling mechanisms that can keep nodes required to send multimedia data active, when necessary, are critical for improving network efficiency.

Routing protocols based on tradition may not always provide the highest efficiency for multimedia transmission (MMT) in a WSN. To ensure minimal delays and acceptable quality of multimedia, it is necessary to use routing protocols that account for Quality of Service (QoS). Wireless channels tend to be susceptible to interference, causing errors in transmission. Therefore, it is imperative to consider mechanisms for error detection, error correction and retransmission in efforts to facilitate reliable multimedia communications. Processing in the network helps decrease the volume of information that needs to be spread by having sensor nodes perform certain processing steps prior to transmission. Nodes may extract important information from image data or perform preliminary computations and reduce the amount of unprocessed information that needs to be spread. In addition, MMT may be improved through

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the usage of numerous sensor nodes, individually of which carries out specific roles leading to greater efficiency overall. Furthermore, it may be possible to prioritize the broadcast of hypermedia data based on its significance which would further improve performance, ensuring that important information is sent first, thus reducing the risk of losing critical information. A balance must be obtained between acceptable data quality and energy efficiency with a performance metric tied to the network performance to achieve reliable and successful transmission of multimedia data in WSN (Janakamma and Hegde, 2023). The choice of devices and protocols in the MMT technology use case is founded on the application and characteristics of the sensor network. In a situation where data accuracy is important-such as in health imagery, surveillance, or scientific research-lossless MMT is required.

This means that images, audio, and video are transmitted to the destination, intact, without loss of any data. This is important for preserving the honesty of the information that was collected. This research significantly advances WSNs in effectively delivering multimedia traffic. This advancement demonstrates increased energy efficiency and reduced data delay, making for a more reliable WSN, one that can better meet the requirements of multimedia applications. The key contributions of this research include the Cross-Layer Multimedia Data Transfer (CLMDT) strategy, which is a cross-layer optimization of the various layers of WSNs, including Network, MAC and Physical layers. When the parameters are fine-tuned across the films of the system, the system can achieve an energy and quality of data balance while reducing transmission delays, achieving an enhancement in overall QoS. The best node in a cluster is determined to be the CH and the effective path is further assessed using a fitness assessment routing algorithm to deliver data, as well as the Prey-Predator Chasing (PPC) Optimizer, which is used for optimization and is derived from the hunting methods of the search agents within a changing environment. Used with cross-layer optimization strategies, the PPC algorithm effectively finds the best data routing paths and increases the efficiency of MMTs while aiding in stabilizing the network quality. These advancements lead to the creation of more robust and improved WSN that will allow usable multimedia applications or services to be provided with less energy usage.

Literature work

To create non-correlated and node-disjoint routes to transmit media data from the media source to the media destination, Imen Jemili presented a cross-layer multi-path routing scheme. When selecting the best next-hop from the relevant predecessors, the scheme balanced issues of energy reserves and the impact on previously selected routes to increase efficiency [1].

Yazici Adnan et al. proposed a fusion-centric Wireless Multimedia Sensor Network (WMSN) architecture that minimizes transmitted data using intra-node processing. Their architecture highlights the benefits of multimodal data collected via multimedia sensors capable of recording, storing, and transmitting multimedia data. A problem with WMSNs is the delivery of huge quantities of information to a CH due to the WMS nodes having limited energy resources [2].

Ramesh et al. presented a trust-based paradigm to address security concerns with video sensor networks. Their process ensures secure WSN communication using trust values to decrease the risk of eavesdropping. Adversaries container remain known besides prohibited from participating in the network through a trust level assessment [3].

Zhang and Zhu introduced a virtual machine framework for delivering predictive QoS in 5G multimedia big data WiFi networks. The framework uses available energy resources to improve network performance [4].

Kadiravan et al. proposed to improve energy performance in WMSNs through the usage of a Density-Based Clustering (DBC) model, which can reduce hot-spot problems and enhance the network lifetime. It may be possible to improve performance even further by combining DBC with bio-inspired algorithms [5].

Jianbo Du suggested an optimization methodology that accommodates viewport rendering offloading and control of downlink transmit power simultaneously, reducing long-term energy usage in Mobile Edge Computing systems that are wireless access-oriented, while providing highly interactive virtual video services [6].

Rahman et al. examined the evaluation of effectiveness in streaming video using CoAP (Constrained Application Protocol) and its congestion control approaches. While CoAP was designed to serve IoT applications, its default congestion control settings could cause delays in streaming video. Algorithms that facilitate adjusted video quality can be improved by modifying the transmission parameters in CoAP, like throughput and buffer management [7].

Kim et al. looks into the integration of WSNs in big data environments, highlighting the ability of WSNs to efficiently capture, process, and transmit vast data. It highlights challenges like power consumption, data processing, and scalability of the network, proposing solutions for better support in big data environments [8].

Barakabitze et al. provide an overview of managing Quality of Experience (QoE) for multimedia streaming. It discusses methods to ensure high user satisfaction in future networks (e.g., 5G), including models, measurement techniques, optimization strategies, and open research problems in QoE-oriented multimedia delivery [9].

Negra et al. presents MTM-MAC, a novel MAC protocol designed specifically for Wireless Body Area Networks used in healthcare systems. It focuses on medical data transmission based on urgency and reliability requirements with better performance in delay, packet loss, and energy efficiency compared to traditional MAC protocols [10].

Yamagiwa and Ichinomiya propose a compression method using variable bit-length ADPCM encoding for stream data. It pursues visually lossless compression, i.e., the compressed data appears exactly the same to the human eye, while optimizing data reduction efficiency for applications like sensor networks and visual data streaming [11].

Singh and Devgon examined encryption methods and lossless compression formats that ensure secure data transfer. The study highlighted that one of the greatest efficient forms of secure multimedia transfer was JPEG XR encoding with image scrambling using blocks for encryption [12].

Janakamma and Hegde consider methods for implementing reliable multimedia data transmission over WSNs with a focus on methods of handling packet loss, energy constraints, and congestion in the network to ensure the integrity and quality of data [13].

Xue et al. recommend a hybrid cross-layer routing protocol coupled with Harris Hawk Optimization for improving energy efficiency, network lifespan, and data transfer in WSNs over traditional routing methods [14].

Mahajan and Badarla present a cross-layer protocol for Internet of Things (IoT) applications in smart agriculture that employs a nature-inspired optimization algorithm to enhance energy efficiency, communication reliability, and responsiveness in agricultural WSN deployments [15].

Materials And Methods

In WSN, the architecture is structured in several layers, with each layer having its unique protocols and functionalities. Cross-layer communication enhances the operation of WSN by evaluating data and constraints from different layers simultaneously to provide intelligent routing and transmission decisions. The main aspiration of WSNs is to gather and send information efficiently while minimizing energy usage. Though, near is an inevitable tension: high data transfer can demand high energy consumption which can adversely affect the network lifespan considerably. CHs are also essential in WSNs because they are responsible for all intra-cluster communication and for relaying information after the basis nodes to the Base Station (BS).

One important consideration when establishing the WSN is the selection of CHs and data forwarder nodes as both contribute to high-effective communication and routing strategy. On the similar time, energy efficiency is becoming extremely important in WSNs due to the battery-constrained nature of the sensor nodes. To ensure the longevity of the operational network, energy consumption must be optimized throughout the WSN protocol stack. The paper describes a cross-layer approach for CH and forwarder nodes selections that addresses an optimization perspective across varied layers of the WSN to minimize transmission delays and optimize energy use. Overall, effectiveness of a sensor node in the WSN environment involves some form of trade-off amongst these elements, including routing decisions that minimize delay while optimizing energy efficiency for longevity of the network.

Results

The experimental setup of the PPC Optimization-enabled CLMDT technique was undertaken using simulations in full detail. The total application was developed with the Python language, which enabled sufficient flexibility and computational power to the implementation of the optimization algorithms, the storage of data, and the simulation approach representing possible WSN environments. Scientific libraries of Python, as guidelines for example, NumPy and Matplotlib, and other libraries offered sufficient features to enable mathematical computations, graphics, and performance analysis. The simulation models were run on a personal computer using Windows10 operating system using 16 GB RAM. The computer was selected to ensure that simulations with many nodes and with high data transmissions would run without concerns about the memory appearing to run out or no lagging while computations occurred.

The experimental dataset was used to provide multimedia data as input for the transmission simulation, thereby creating a room for video content and visual animations to be created, and assess the performance of the PPC-CLMDT technique in a contextualized assessment scenario. The dataset acted as the source of multimedia content to evaluate how cross-layer transmission techniques performed within the constraints of real-time data acquisition, energy efficiency requirements, and optimal outcomes.

Network thoughtput

It represents the volume of information that has been sent successfully in a measured time. It is assessed based on the data rate for each individual node and the total node count in the WSN. The total transmission time consists of the data transmission time as well as overhead to transmit data.

Figure 1 shows the network thoughtput of Wireless Sensor Optimization (WSO)-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the amount of packet information transmitted through time over rounds for WSO-CLMDT. It has been computed in terms of the number of data packet delivered and packet size, showing a decreasing order over the PPC-CLMDT (i.e., more efficient than WSO-CLMDT).

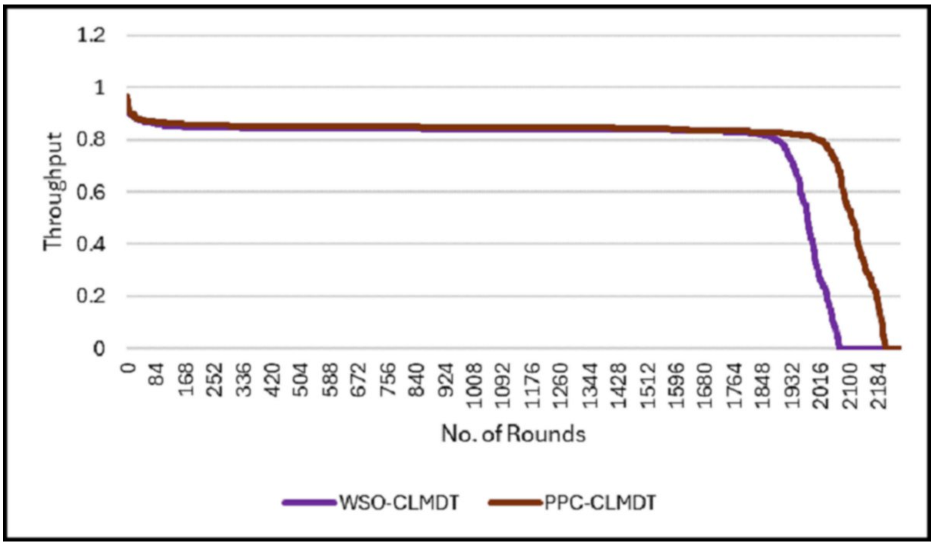

FIGURE 1: Total no. of rounds over throughput of WSO-CLMDT vs PPC-CLMDT

WSO-CLMDT, Wireless Sensor Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 2 shows the network thoughtput of CL-CFMPR vs PPC-CLMDT over 500 nodes. It demonstrates the amount of packet information transmitted through time over rounds for CL-CFMPR. It has been computed in terms of the number of data packet delivered and packet size, showing a decreasing order over the PPC-CLMDT (i.e., more efficient than CL-CFMPR).

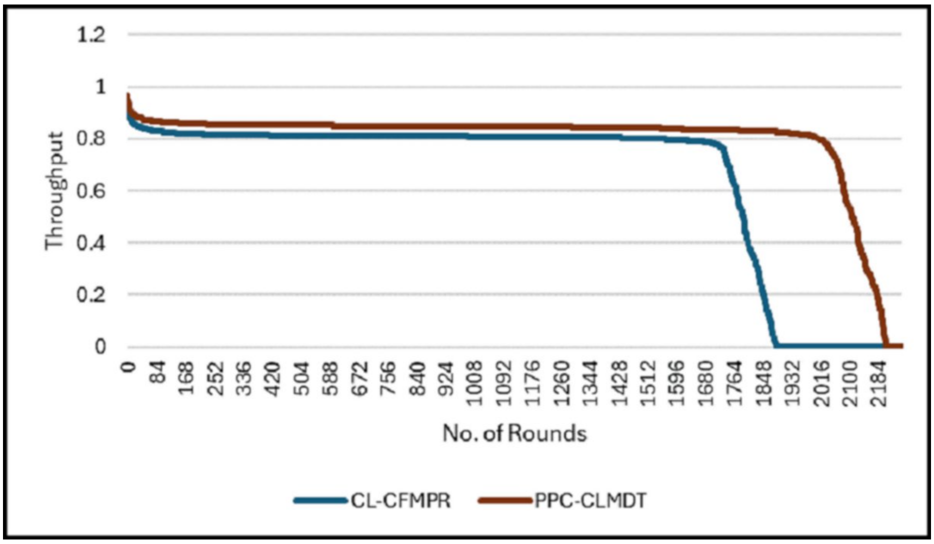

FIGURE 2: Total no. of rounds over throughput of CL-CFMPR vs PPC-CLMDT

CL-CFMPR, Cross-Layer Cluster Formation and Multi-Path Routing; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure *3* shows the network thoughtput of WSN-Nature-Inspired Algorithm-Based Cross-layer Clustering (NICC) vs PPC-CLMDT over 500 nodes. It demonstrates the amount of packet information transmitted through time over rounds for WSN-NICC. It has been computed in terms of the number of data packet delivered and packet size, showing decreasing order over the PPC-CLMDT (i.e., more efficient than WSN-NICC).

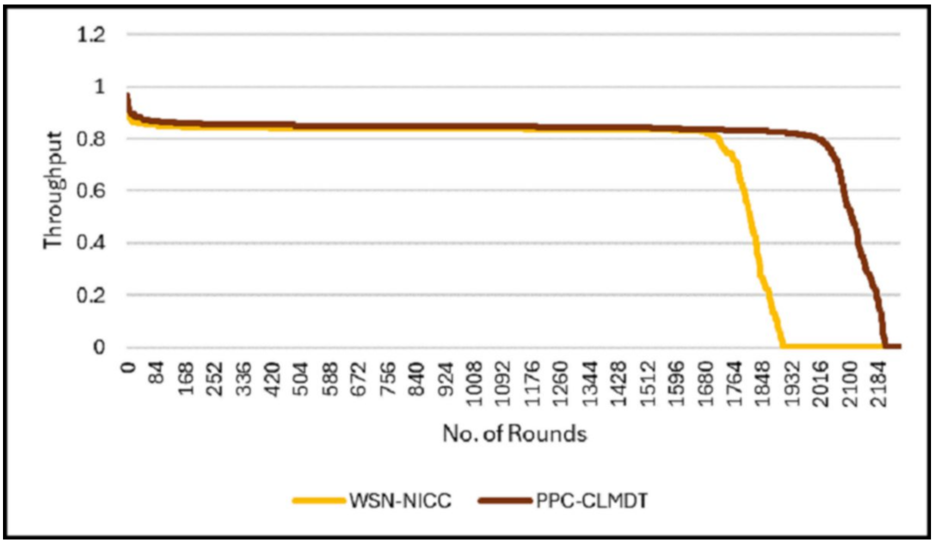

FIGURE 3: Total no. of rounds over throughput of WSN-NICC vs PPC-CLMDT

WSN-NICC, Wireless sensor network-Nature-Inspired Algorithm-Based Cross-layer Clustering; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure *4* shows the network thoughtput of Cat Swarm Optimization (CSO)-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the amount of packet information transmitted through time over rounds for CSO-CLMDT. It has been computed in terms of the number of data packet delivered and packet size, showing decreasing order over the PPC-CLMDT (i.e., more efficient than CSO-CLMDT)

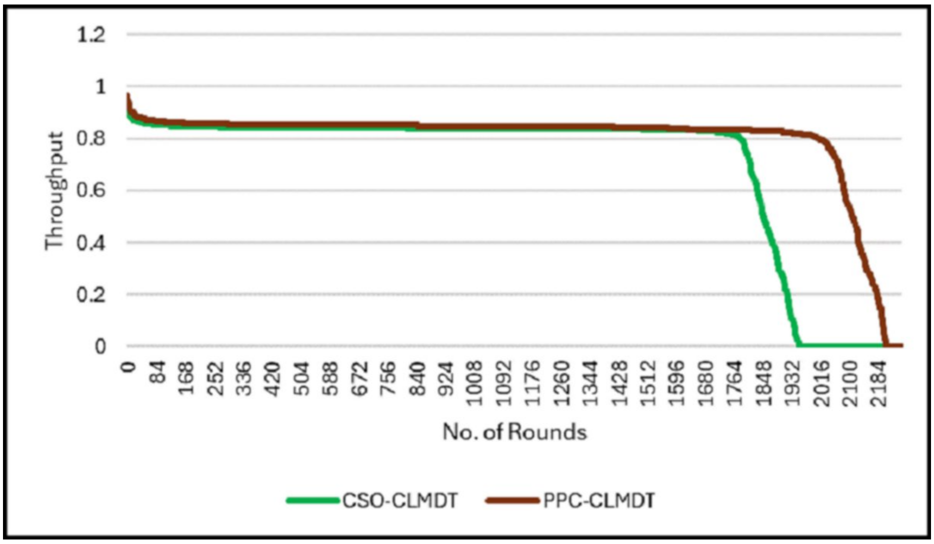

FIGURE 4: Total no. of rounds over throughput of CSO-CLMDT vs PPC-CLMDT

CSO-CLMDT, Cat Swarm Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 5 shows the network thoughtput of Particle Swarm Optimization (PSO)-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the amount of packet information transmitted through time over rounds for PSO-CLMDT. It has been computed in terms of the number of data packet delivered and packet size, showing a decreasing order over the PPC-CLMDT (i.e., more efficient than PSO-CLMDT).

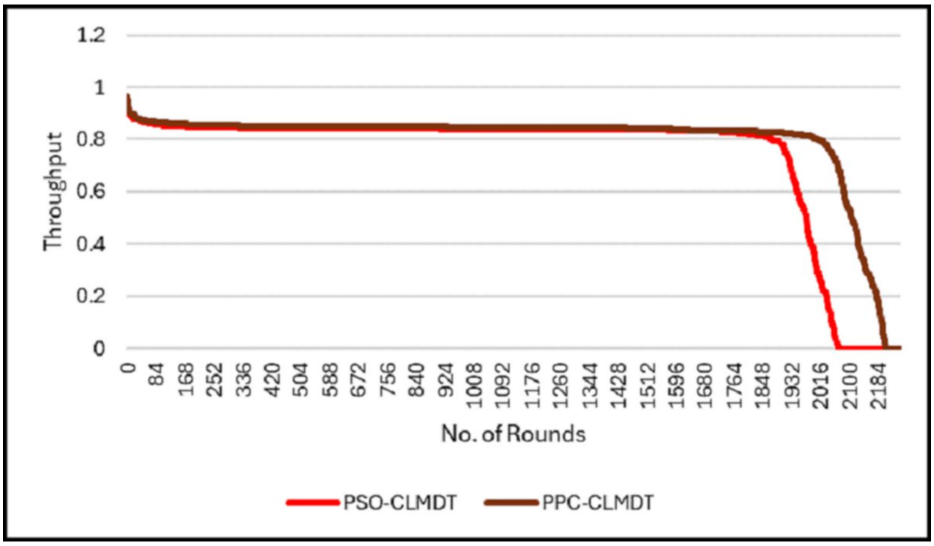

FIGURE 5: Total no. of rounds over throughput of PSO-CLMDT vs PPC-CLMDT

PSO-CLMDT, Particle Swarm Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Alive nodes

The alive nodes metric is the amount of sensor nodes that remain operational after a predetermined number of rounds. As sensor nodes expend energy, a certain number of them are likely to fail due to depletion of their battery, thus changing performance. This metric helps to analyze the network's lifespan and energy utilization.

Figure 6 shows the alive nodes of CL-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the no. of alive nodes to BS through time over the number of rounds. The situation might remain distinguished that the CL-CFMPR shows fewer information packets to BS with PPC-CLMDT through means of the equal quantity of energy.

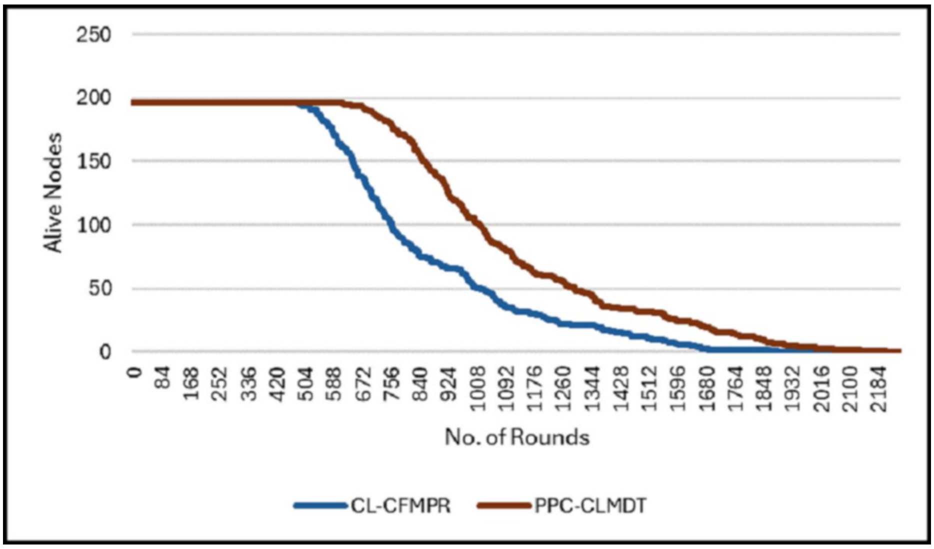

FIGURE 6: Total no. of rounds over alive nodes of CL-CFMPR vs PPC-CLMDT

CL-CFMPR, Cross-Layer Cluster Formation and Multi-Path Routing; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 7 shows the alive nodes of WSN-NICC vs PPC-CLMDT over 500 nodes. It demonstrates the no. of alive nodes to BS through time over the number of rounds. The situation might remain distinguished that the WSN-NICC shows fewer information packets toward the BS with PPC-CLMDT through means of the equal quantity of energy.

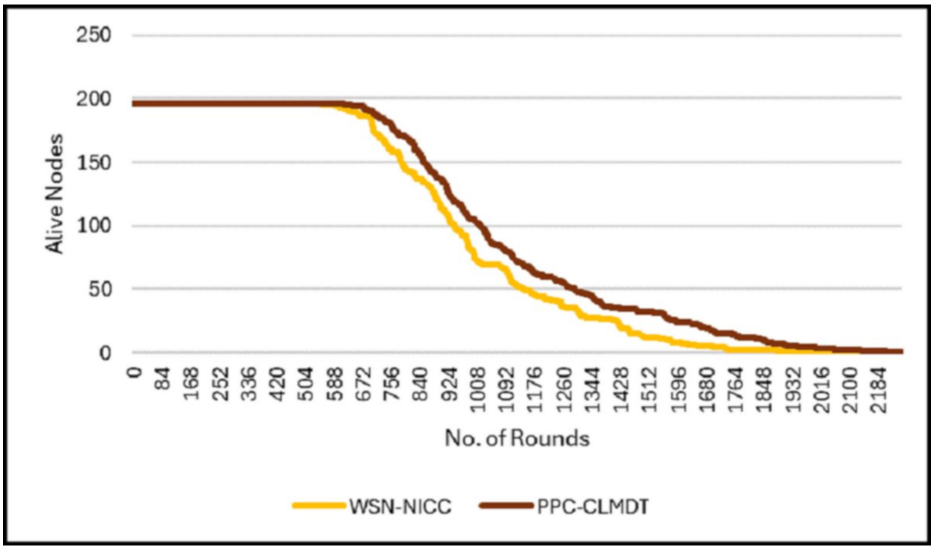

FIGURE 7: Total no. of rounds over alive nodes of WSN-NICC vs PPC-CLMDT

WSN-NICC, Wireless Sensor Network-Nature-Inspired Algorithm-Based Cross-layer Clustering; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 8 shows the alive nodes of CSO-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the no. of alive nodes to BS through time over the number of rounds. The situation might remain distinguished that the CSO-CLMDT shows fewer information packets to the BS with PPC-CLMDT through means of the equal quantity of energy.

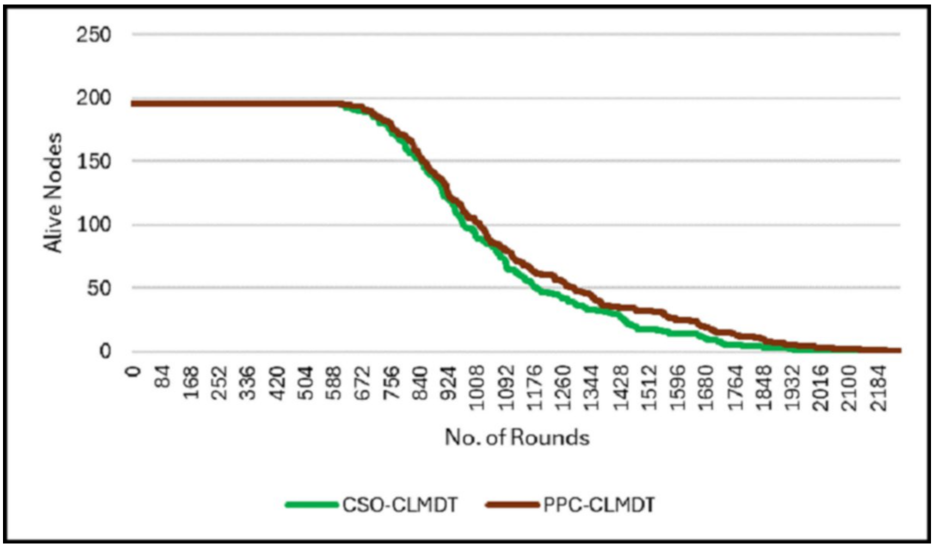

FIGURE 8: Total no. of rounds over alive nodes of CSO-CLMDT vs PPC-CLMDT

CSO-CLMDT, Cat Swarm Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 9 shows the alive nodes of PSO-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the no. of alive nodes to BS through time over the number of rounds. The situation might remain distinguished that the PSO-CLMDT shows fewer information packets to BS with PPC-CLMDT through means of the equal quantity of energy.

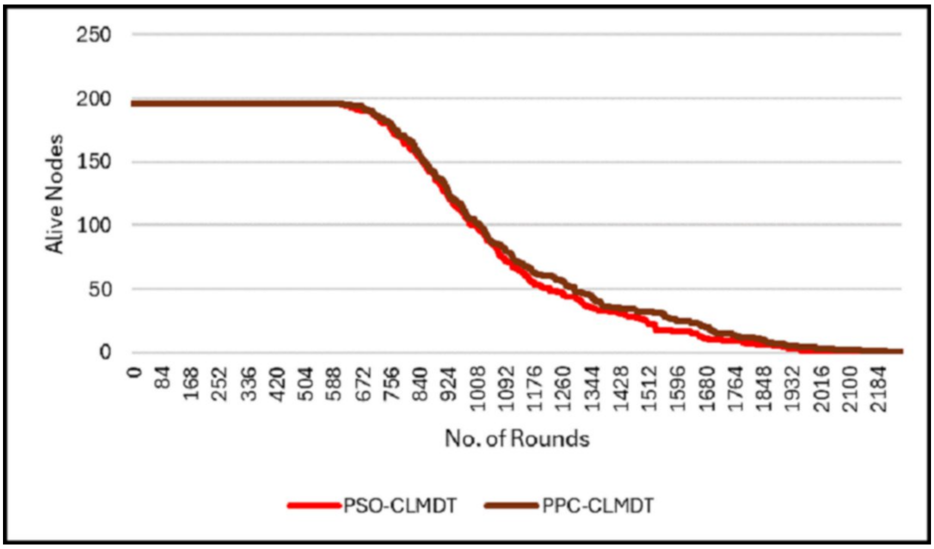

FIGURE 9: Total no. of rounds over alive nodes of PSO-CLMDT vs PPC-CLMDT

PSO-CLMDT, Particle Swarm Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 10 shows the alive nodes of WSO-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the no. of alive nodes to BS through time over the number of rounds. The situation might remain distinguished that the WSO-CLMDT shows fewer information packets to BS with PPC-CLMDT through means of the equal quantity of energy.

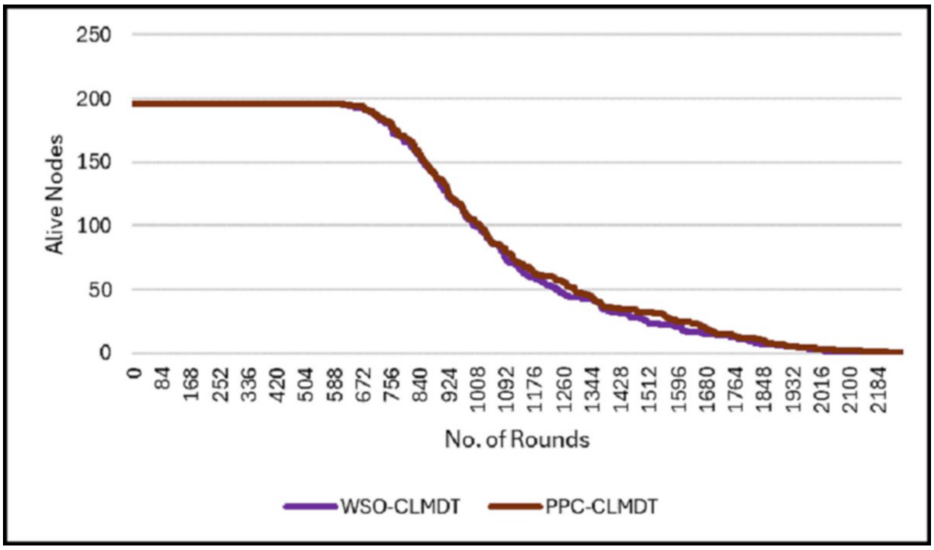

FIGURE 10: Total no. of rounds over alive nodes of WSO-CLMDT vs PPC-CLMDT

WSO-CLMDT, Wireless Sensor Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Average energy left

The average energy remaining metric measures the amount of energy left in the sensor nodes as the number of rounds increases. PPC-CLMDT method aims to PPM-CLMDT for multimedia type data transmission which takes into account the performance of energy savings in improving the overall lifespan of the network.

Figure *11* shows the average energy left of CL-CFMPR vs PPC-CLMDT over 500 nodes. It demonstrates the average energy remaining of the network with respect to the number of rounds for the CL-CFMPR by taking the total initial energy of the network. This energy saving, greater lifetime WIFI enhancements, is related to CL-CFMPR having less lifetime in comparison to the PPC-CLMDT.

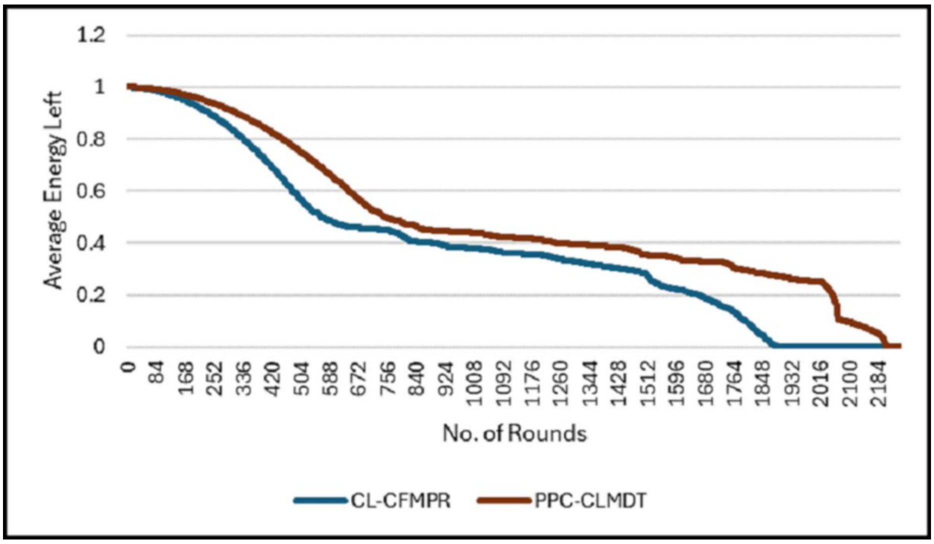

FIGURE 11: Total no. of rounds over average energy left of CL-CFMPR vs PPC-CLMDT

CL-CFMPR, Cross-Layer Cluster Formation and Multi-Path Routing; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 12 shows the average energy left of WSN-NICC vs PPC-CLMDT over 500 nodes. It demonstrates the average energy remaining of the network with respect to the number of rounds for the WSN-NICC by taking the total initial energy of the network. This energy saving, greater lifetime WIFI enhancements, is related to WSN-NICC having less lifetime in comparison to the PPC-CLMDT.

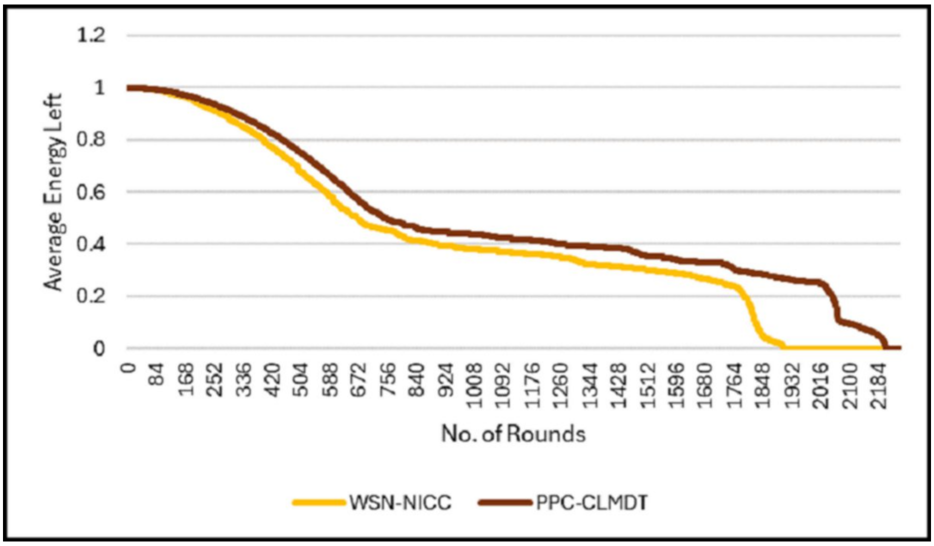

FIGURE 12: Total no. of rounds over average energy left of WSN-NICC vs PPC-CLMDT

WSN-NICC, Wireless sensor network-Nature-Inspired Algorithm-Based Cross-layer Clustering; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 13 shows the average energy left of CSO-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the average energy remaining of the network with respect to the number of rounds for CSO-CLMDT by taking the total initial energy of the network. This energy saving, greater lifetime WIFI enhancements, is related to CSO-CLMDT having less lifetime in comparison to the PPC-CLMDT.

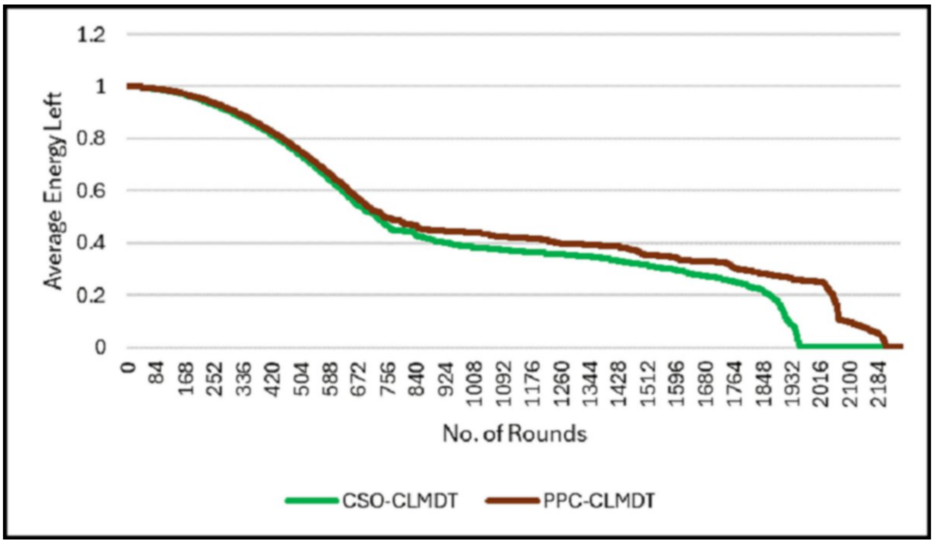

FIGURE 13: Total no. of rounds over average energy left of CSO-CLMDT vs PPC-CLMDT

CSO-CLMDT, Cat Swarm Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 14 shows the average energy left of PSO-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the average energy remaining of the network with respect to the number of rounds for the PSO-CLMDT by taking the total initial energy of the network. This energy saving, greater lifetime WIFI enhancements, is related to PSO-CLMDT having less lifetime in comparison to the PPC-CLMDT.

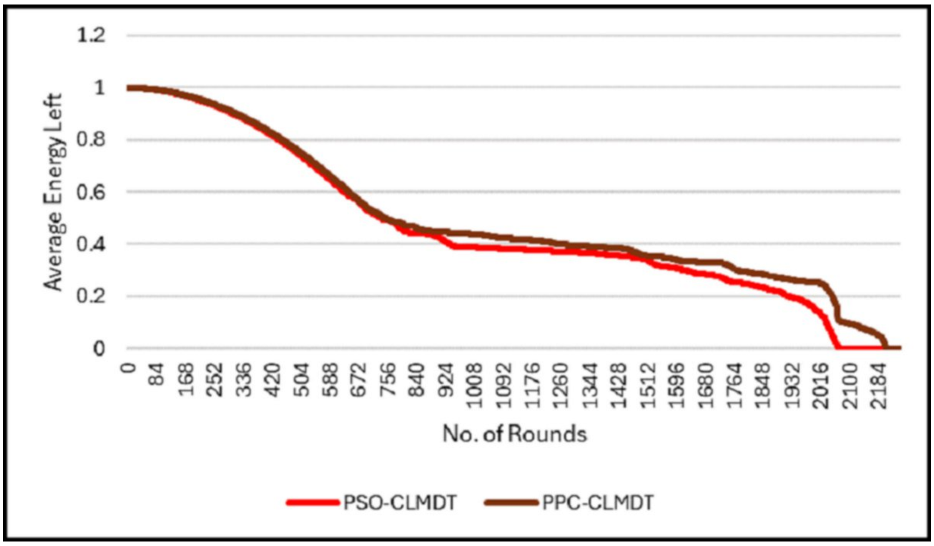

FIGURE 14: Total no. of rounds over average energy left of PSO-CLMDT vs PPC-CLMDT

PSO-CLMDT, Particle Swarm Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

Figure 15 shows the average energy left of WSO-CLMDT vs PPC-CLMDT over 500 nodes. It demonstrates the average energy remaining of the network with respect to the number of rounds for the WSO-CLMDT by taking the total initial energy of the network. This energy saving, greater lifetime WIFI enhancements, is related to WSO-CLMDT having less lifetime in comparison to the PPC-CLMDT.

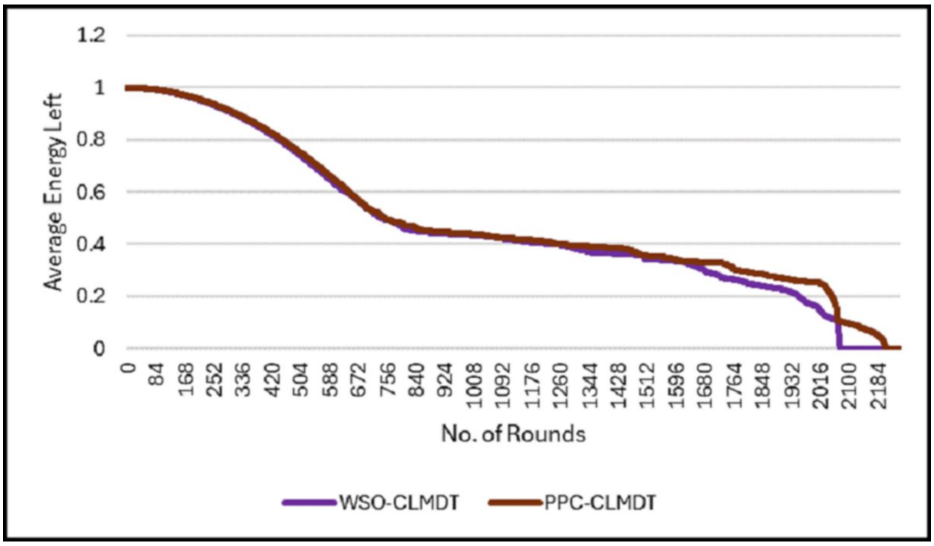

FIGURE 15: Total no. of rounds over average energy left of WSO-CLMDT vs PPC-CLMDT

WSO-CLMDT, Wireless Sensor Optimization-Cross-Layer Multimedia Data Transfer; PPC-CLMDT, Prey-Predator Chasing-Cross-Layer Multimedia Data Transfer

These, different metrics will be analyzed in instruction to regulate if the PPC-CLMDT method increases the efficiency of multimedia data transmission, energy savings, and increases the global lifetime of the network.

Discussion

The evaluation of the proposed PPC Optimization-based-CLMDT strategy was conducted using three main performance metrics-throughput, alive nodes count, and average energy left. The usage of these metrics provided a better all-round perspective for showcasing the overall efficiency, reliability, and energy sustainability of the multimedia data transmission in a WSN. To assess the PPC-CLMDT algorithm scalability and robustness, the number of nodes in the WSN was systematically varied across four different constraints; 50, 100, 150, and 200 nodes. For all configurations, simulation rounds of 2000 were run to assess the algorithm in sparse and dense networks while maintaining temporal consistency. In order to assess reliability and efficiency of the data transmission, throughput was selected as a measure of the packets successfully transmitted from sensor nodes to the BS. Subsequently, it was observed that PPC-CLMDT was achieving high throughput at all node densities. The PPC-CLMDT method adjusted effectively with the increased number of nodes for consistent packet delivery, thus demonstrating its capable of handling increased levels of network congestion and increased level of data traffic in a larger WSN network. The number of alive nodes was used to determine network lifetime and node longevity for the 2000 rounds of simulation. PPC-CLMDT displayed greater energy balancing skills because of enhancements in routing and transmission paths preventing nodes from dying prematurely. Although there were still 200 nodes, a large number of them were still functioning at or near the end of the simulation, demonstrating the energy-efficient features of the methodology. The average energy remaining per node was evaluated by reviewing the average energy remaining per node. As an adaptable component of the algorithm, the nodes used a flexible treatment to be influenced by the mutual transformations of the prey-predator interactions. This allowed the algorithm to evenly allocate total energy consumption across the total number of nodes. The overall curtailment in total energy consumed depending on the number of interactions is reduced considerably in terms of average residual energy than traditional approaches, which is especially evident in dense arrangements where energy loss typically occurs faster.

Conclusions

In conclusion, this research described provides a detailed answer to the fundamental problems of MMT in WSNs by looking at the CH selection process and routing in an optimized fashion. Due to the resource limited nature of the nodes in a WSN, power, processing, and communication bandwidth, the multimedia data size (video, audio, images) produces quick energy loss and delays, which leads to potential congestion periods in a network. This situation indicates the need for a complete, multi-layer optimization method that can work across all parts of the protocol stack. The document introduces a new method to address this issue called the PPC optimizer in the context of CLMDT. The PPC optimizer is inspired by biology and can simulate the interactions of predator-prey found in nature, to find optimal or nearly optimal solutions for clustering, and for route selection. It allows for the CHs to be selected as a function of energy levels, distance, and communication cost as well as spreading the load through the network and increasing WSN lifetime.

The PPC-CLMDT model works with a dual optimization to attain two goals: optimizing the formation of clusters and optimizing the routes to transfer multimedia data. Synchronization at these layers helps to reduce extra transmissions and energy expenditure, as it has the capability to make informed decisions based on physical issues (i.e., range), data link states (i.e., when to sleep), and the routing needs from the network layer. Layer coordination is viable through PPC optimization for the different layers because it can adapt based on the behavior of the network as it operates in real-time. This way guarantees effective and strong data delivery. The efficacy of being able to optimize clusters and routes was confirmed via a detailed series of simulations with different sized network topologies (50, 100, 150, and 200 nodes). Each of the network sizes was applied to an extensive testing of over 2000 rounds of performance measure including; energy spent, throughput, packet delivery ratio, and latency for the different nodes and flows. The resulting outputs indicated noticeable improvement related to overall network performance. Additionally, the model demonstrated an overall lower total amount of energy consumed, reflecting good efficiency use of primary network resources and extension, in the life of the network. Moreover, increases in these key performance indicators for throughput, along with reduced measurable latency, affirm the model can reasonably accommodate the stringent QoS requirements necessary for multimedia applications.

The findings highlight the robustness and potential for expansion of the PPC-based optimization approach in numerous situations that have different data necessities and different concentrations at its nodes. Multimedia content must be required more by applications like remote surveillance, telemedicine, and environmental monitoring, and therefore, most improvements of WSNs will be needed. In terms of the future, this study opens up many pathways of future research. One promising area of consideration is to build in machine learning methods, for example, reinforcement learning and federated learning, into clustering and routing. Reinforcement learning can equip individual nodes to have a flexible way to learn, based on feedback from the environmental situations, to derive the best probable actions, while federated learning can be a way for the nodes to collectively train a model, without the expectation of centralized data, but also can retain privacy and lessen communications and to the environment. In addition, one of the main areas of expansion will be to develop an expanded view of PPC-CLMDT to applications in the real world. Possible applications include aspects of intelligent health systems, that require reliable real-time transmission of biometric data and video; environmental monitoring requires scale and long duration implementation; and smart cities where video and other data from multimedia sensors can be used for decision-making related to traffic management and public safety. These applications present both the need and experimental conditions to further develop and augment the proposed model.

Appendices

Experimental Dataset

https://drive.google.com/drive/folders/1hXLcXVsxg3ArUi_BMo3eW2buq6s6Lk22?usp=drive_link

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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