IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 1, May 2025

Impact Factor: 7.67

Transmission of Multimedia in Wireless Sensor Networks using Cross-layer Optimization

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Abstract: *Transmission of multimedia data in wireless sensor networks (WSNs) presents unique challenges and considerations due to the resource-constrained nature of these networks. Wireless sensor networks are typically composed of numerous small, low-power, and low-cost sensor nodes that collaborate to gather and transmit data from their surroundings. To overcome this issue this paper proposes a novel approach for multimedia transmission in WSNs through cross-layer optimization for cluster head selection and optimal routing of multimedia data without delay. The proposed methodology integrates Particle Swarm Optimization (PSO), Wolf Search Algorithm (WSA), and Cat Swarm Optimization (CSO) into a unified framework known as the Particle Cat Wolf Optimization (PCWO) model. PCWO is designed to enhance network clustering methods, offering robust solutions for the efficient transmission of multimedia data within WSNs. The synergistic integration of these optimization algorithms harnesses their collective strengths, enabling improved resource allocation, data routing, and network performance. By employing PCWO, this research advances the capabilities of WSNs in handling multimedia traffic, contributing to the development of more reliable and efficient wireless sensor networks with both energy efficiency and minimum data transmission delay..*

Keywords: Wireless Sensor Network, Cross-Layer Optimization, Particle Cat Wolf Optimization, Network clustering, Optimal data routing

I. INTRODUCTION

Due to the constrained resources and energy of the individual sensor nodes, multimedia transmission in a wireless sensor network (WSN) poses special difficulties. WSNs are intended to gather and transmit data from the environment in which they are deployed, typically for uses like surveillance, healthcare, and environmental monitoring [5]. Images, audio, and video are examples of multimedia data that are data-intensive and require careful consideration to ensure effective transmission and energy conservation. Because multimedia data can be quite large, it is essential to use effective compression algorithms. By reducing the amount of data that needs to be transmitted, compression lowers the energy requirement and boosts network capacity. WSNs can be configured to use well-known compression formats like JPEG for images and MPEG for video [6]. The quality and delay needs for various multimedia applications vary. To save energy or increase transmission reliability, it might be acceptable in some circumstances to slightly lower the quality. It's crucial to strike a balance between QoS demands and energy restrictions. By putting adaptive transmission schemes into place, the network can modify its behavior in response to the situation. The amount of data transmitted over the network can be significantly decreased by aggregating data from multiple sensor nodes before transmission [5]. Only pertinent information or condensed data is sent, rather than the raw multimedia from each node [8][12]. WSNs have multiple layers of communication, including physical, MAC (Medium Access Control), and network. Combining these layers' optimizations can improve transmission effectiveness. To save energy, sensor nodes can be put into sleep mode. To acquire and transfer multimedia data, nodes can awaken in turn. To make sure that nodes with multimedia data to transmit are alert when required, careful scheduling is required [1].

Multimedia transmission may not be a good fit for conventional routing protocols. To guarantee that multimedia data is delivered with a minimum amount of delay and acceptable quality, QoS-aware routing protocols should be used [2].

DOI: 10.48175/IJARSCT-26137

ISSN
2581-9429
IJARSCT

Wireless channels are noisy, so mistakes can happen during transmission. It's critical to implement mechanisms for error detection and correction as well as retransmission techniques to guarantee the integrity of multimedia data. Processing that takes place in-network can cut down on the amount of information that must be sent. Before transmitting pertinent data, some processing tasks, such as feature extraction from image data or stereo, can be carried out locally on the sensor nodes. Multimedia transmission can be effectively accomplished by combining various sensor nodes with different capabilities. To ensure that crucial multimedia content is transmitted with higher priority and lower the chance of losing important data, multimedia data can be prioritized according to its importance [4]. Data quality, energy conservation, and network efficiency must all be carefully balanced when sending multimedia data over a wireless sensor network [7][11]. The requirements of the application and the properties of the sensor network itself will determine the precise strategies that are used. Lossless multimedia transmission in a WSN is the practice of sending multimedia data (like images, audio, or video) over a network without suffering any data loss. This is crucial in applications like medical image analysis, monitoring systems, and empirical studies data where data accuracy and integrity are essential.

In a WSN, where resources are limited, achieving lossless transmission necessitates careful consideration of several factors. While conventional lossy compression techniques, such as JPEG and MPEG, are frequently used for multimedia data, lossless compression algorithms should be taken into account for applications requiring accurate data reproduction [9][13]. WSNs can be configured to use lossless codecs for audio and video and PNG for images. Even though lossless encoding might not be able to achieve as high ratios as lossy compression, it guarantees that no data is lost during decompression. Identification and correction of transmission errors can be aided by putting error detection and correction mechanisms in place at the physical layer. To make sure that the received data precisely matches the transmitted data, strategies like Forward Error Correction (FEC) and Automatic Repeat request (ARQ) protocols can be used. Implement trustworthy communication protocols that ensure the delivery of data packets to their intended location [3]. Error checking and retransmission of lost packets are features of protocols like TCP (Transmission Control Protocol). Ensure that your routing protocols reduce the possibility of data loss or corruption. Lossless data can be given priority over less important traffic by QoS-aware routing algorithms. The communication protocol should include acknowledgment mechanisms. Create the WSN topology to reduce signal interference, boost signal power, and improve network performance as a whole. This may result in data transmission that is more dependable and lossless. Data compression, error detection and correction, dependable communication protocols, and careful network design are all necessary for uncompressed multimedia transmission in a wireless sensor network [10].

This research represents a vital contribution to the ongoing evolution of Wireless Sensor Networks by significantly enhancing their capabilities in managing multimedia traffic. By optimizing energy efficiency and minimizing data transmission delays, these advancements promise to make WSNs more reliable and efficient. The main contribution of this research is as follows;

Cross-layer optimization: The integration of a cross-layer approach across the Network layer, MAC layer, and Physical layers achieves a balance between optimizing energy consumption and preserving data quality. By employing cross-layer parameter optimization, it becomes possible to reduce transmission durations and elevate the overall Quality of Service (QoS) for every node in the network. The node with the maximum optimal index in the cluster is selected as cluster head (CH), and within a WSN the CHs with the maximum optimal index are selected for data routing.

Particle Cat Wolf Optimization (PCWO):

II. LITERATURE EVALUATION

To define non-correlated as well as node-disjoint paths to simultaneously transfer media content from source materials to the receiver, Imen Jemili et al. [1] developed a cross-layer multi-path routing approach. To properly adjust and control the woke planning of implicated nodes in the outbound phase, the method depends on close coordination between the routing and MAC layers. When choosing the best next-hop from among the eligible predecessors, additional contextual information, such as residual energy and implications for alternative routes, may be taken into account. A fusion-based WMSN framework was created by Adnan Yazici, et al. [2] to minimize transmitted over the internet amount of data that must be by intra-node processing. It demonstrates how multimodal data gathered with multimedia sensors that can record, store, and transmit multimedia data can be helpful for the early detection of objects and actions. One of the issues with WMSNs is the transmission of large amounts of multimedia data to the CHfor processing. Another significant issue for the WMSNs is the effective transmission of data by the WMS nodes to the CHdue to the WMS nodes' limited energy. A proposed work by S. Ramesh1 and C. Yaashuwanth [3] was created that relies on trust values to guarantee the security of the video sensor networks. The project's primary goal is to enable secure communication over radio-enabled video sensor networks by developing a compact and trustworthy trust framework for WSNs to protect them from various attacks introduced by eavesdroppers from various locations. A novel trust-based communication platform is proposed for more effectively transferring multimedia content by thwarting active attacks, with a focus on secure data transfer. Although attackers can launch attacks at any time, the adversary can be prevented from taking part in the network by using trust calculations. For QoS clustering, a novel lightweight framework for trust decision-making has been developed to provide secure routing for both intercluster and intracluster interaction. The communication virtual machine infrastructure for application predictive delay-bounded quality of service (QoS) pro-visioning more than 5G multimedia big data wifi networks was created by Xi Zhang and Qixuan Zhu [4]. The information-centric networks (ICN), network functions virtualization (NFV), and software-defined networks (SDN) are three methods and mechanisms integrated into this wireless big data multimedia network. The best caching localization for popular data contents is used to optimize the ICN mechanism. Three virtual networks and transmit power allocation mechanisms are created to implement the NFV and SDN techniques, taking into account, respectively, the effective capacity of a single user, the aggregate effective capacity and power allocation fairness tradeoff, and the non-cooperative gaming among all users. A brand-new Density-Based Clustering (DBC) method is presented by G. Kadiravan et al. [5] to improve the energy efficiency of WMSN. The remaining energy level, distance, and node centrality are the three input parameters that the DBC technique primarily depends on when collecting data in the healthcare environment. Additionally, two static Super Cluster Heads (SCH) are installed, which collect data from regular CHs and send it straight to the base station (BS). Multi-hop data transmission is supported by SCH, which helps to efficiently balance the available energy. To solve hot-spot issues and increase network lifetime, the DBC technique's performance can be further improved by merging with bio-inspired algorithms. Jianbo Du et al. [6] suggest a method to jointly optimize the viewport rendering offloading and downlink transmit power control to reduce the long-term energy usage of wireless access-based MEC systems for elevated interactive Virtual video services support. An asynchronous advantage actor-critic-based joint optimization algorithm is used to learn the best frame providing offloading and transmit power control policies, taking into account the time-varying nature of wireless channel conditions. The effectiveness of video streaming applications for dependable CoAP communications is evaluated by Waqas Ur Rahman et al [7]. For dependable communications between IoT devices, the Constrained Application Protocol (CoAP) offers a congestion control mechanism. Some of the default settings for the congestion control mechanism were a result of the wireless sensor network's ability to have delayed responses. Applications that stream video, however, are delay-sensitive. To assess the performance of the streaming application over CoAP, various experiments are conducted while varying the various parameters of the CoAP congestion control mechanism. However, considering CoAP transmission parameters along with the throughput and buffer in the case of streaming over CoAP can increase the effectiveness of the quality adaptation algorithms. For secure data transmission over a network, Siddharth Singh and Raaghavv Devgon [12] established an assessment of encryption and lossless compression methods with additional safety. The JPEG XR encoding technique and block scrambling for image cryptography were the most effective standards used.

Challenges

Low latency is necessary for real-time multimedia applications, but WSNs may incorporate significant delays to routing, aggregation of data, and resource constraints, making it difficult to maintain low latency while preserving data integrity.

Signal intervention, noise, and packet loss are common in wireless communication, which can lead to corrupted multimedia data. It can be difficult to guarantee lossless or acceptable loss transmission, especially for delicate applications.

Scalability problems may result from the deployment of sensor nodes on a large scale. The network may have trouble efficiently handling multimedia transmission, routing, and aggregation as the number of nodes rises.

DOI: 10.48175/IJARSCT-26137

WSN deployments take place in dynamic environments where network conditions are subject to quick changes. It is a difficult task to adjust the QoS parameters, compression algorithms, and transmission strategies to changing circumstances.

WSNs may involve a variety of multimedia data types, including audio, video, and images. The network design is made more complex by the need for unique compression methods and transmission strategies for each type.

Wireless channels may experience interference, which weakens and reduces the signal's strength. It becomes challenging to keep up trustworthy communication channels, especially in demanding environments.

Motivation

The potential advantages and applications that can significantly advance various fields are what drive the transmission of multimedia in WSNs. Simple scalar sensor readings do not offer a complete picture of the environment's multimedia data, such as images, audio, and video. For applications like environmental monitoring, wildlife tracking, and disaster response, these richer data may provide insightful information. Real-time situational awareness can be provided by multimedia data in applications like security and surveillance. Video feeds are more effective than conventional sensor data at identifying anomalies, intrusions, and potential threats. Multimedia data transmitted by WSNs can act as remote sensors in remote or inaccessible locations, allowing scientists and researchers to gather data without being present in the area. WSNs with multimedia data can support interactive applications like augmented reality, virtual reality, and immersive experiences, increasing user interaction and interaction. The ability to collect rich, visual, and auditory data that can revolutionize a variety of industries and applications is what drives the transmission of multimedia in wireless sensor networks. This data allows individuals to make informed decisions, advance scientific knowledge, and develop novel experiences.

III. PROBLEM STATEMENT

In a WSN, the network is typically organized into different layers, such as the physical layer, data link layer, network layer, and application layer. Each layer has its own set of protocols and functions. Cross-layer communication in WSN involves taking into account information and requirements from multiple layers simultaneously when making decisions. The primary objective of WSNs is to efficiently collect and transmit data from sensor nodes to a CHor data collection point while conserving the limited energy resources of the sensor nodes. This is a fundamental trade-off in WSN design because more aggressive data transmission can lead to higher energy consumption. The cluster head (CH) is a key node within a cluster of sensor nodes and plays a crucial role in managing intra-cluster communication and relaying data to the sink. These are nodes responsible for forwarding data from source nodes to the CH or from the CH to the sink. The choice of data forwarder nodes is equally important as CH selection because they contribute to the overall routing and data transmission process. In a WSN, energy efficiency is a critical concern. Sensor nodes are typically powered by batteries and have limited energy resources. Therefore, prolonging the network's lifetime by conserving energy is a top priority. Energy-efficient CH and data forwarder selection involve choosing nodes that can perform their roles while consuming the least amount of energy possible. Data transmission delay is the time taken for data to traverse the network from source nodes to the sink. Minimizing delay is important in applications where real-time data is crucial. However, reducing delay often comes at the cost of increased energy consumption due to more frequent data transmission.

Therefore, the research objective emphasizes the need to consider requirements and constraints from multiple layers of the WSN protocol stack. This means taking into account factors from the WSN layers when selecting CHs and data forwarder nodes. By considering all these cross-layer requirements, the objective is to strike a balance that optimizes both energy efficiency and minimum data transmission delay. Where the overall fitness value of the i th sensor node in a WSN network is given by;

$$O_{ij} = Max\left[F\left(Ni\right)\right] \quad (1)$$

$$F\left(Ni\right) = \max\left(E_{ij}, Q_i, T_{ij}\right) \quad (2)$$

DOI: 10.48175/IJARSCT-26137

where E is the energy of the sensor node, Q is the quality factor of the sensor node regarding transmission delay, throughput, and traffic rate, and T is the direct and indirect trust of the node.

IV. WSN SYSTEM MODEL

A Wireless Sensor Network (WSN) is designed to serve as a distributed and interconnected infrastructure for transmitting data in various applications such as surveillance, environmental monitoring, and healthcare. In this system model, sensor nodes equipped with multimedia sensors capture and process data locally, and then cooperatively relay this data to a central CH or base station for further processing or storage. The challenge in such networks lies in efficiently managing the high data rate, latency-sensitive nature of multimedia, and the resource-constrained nature of sensor nodes while optimizing energy consumption and ensuring reliable data delivery. Cross-layer optimization is essential for multimedia transmission in WSNs due to the unique requirements and challenges posed by multimedia data. Cross-layer optimization allows for the efficient coordination of multiple layers of the communication protocol stack to meet these multimedia-specific requirements. It can dynamically allocate network resources, such as bandwidth, power, and routing paths, to prioritize multimedia data streams. This ensures that multimedia packets are transmitted with low latency, minimal jitter, and minimal packet loss, meeting the stringent quality of service (QoS) demands of multimedia applications. Furthermore, Cross-layer optimization enables intelligent adaptation to changing network conditions, such as varying link quality or congestion. Additionally, multimedia transmission in WSNs often involves data compression, error correction coding, and energy-efficient data sensing and processing. Cross-layer approaches allow for the seamless integration of these techniques across multiple layers, optimizing energy consumption while preserving data quality. Figure 1 represents the sensor node and CH in the base station of a WSN.

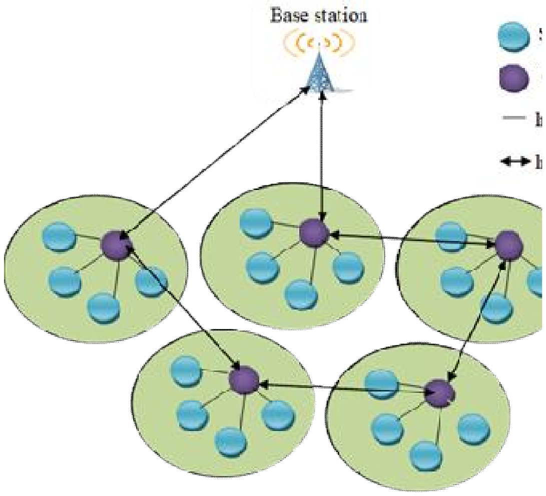

Fig. 1 Wireless Sensor Network

Energy modeling of WSN

In wireless communication, the characteristics of the wireless channels are such that they are flexible and allow bidirectional communication between both the sender and receiver. This bidirectional communication is essential for the exchange of information between devices in the network. When considering the energy consumed by the transmitter in the network model, it becomes apparent that this energy expenditure is a crucial aspect of the system's operation. The transmitter's energy consumption is a critical factor that influences the overall performance and sustainability of the wireless network. It is essential to carefully manage and optimize the energy usage of the transmitter to ensure efficient and reliable communication within this bidirectional, wireless network environment [14]. The energy consumed during data transmission is denoted by,

$$\Xi_T(i,j)=\Xi_{T-elec}\times i+\mathrm{E}_F\times i\times D^2,\ D<D_0 \qquad (3)$$

$$\Xi_T(i,j)=\Xi_{T-elec}\times i+\mathrm{E}_M\times i\times D^4,\ D\geq D_0 \qquad (4)$$

where, the energy expended during the transmission of l bits of data, denoted as Ξ_{T-elec} is influenced by factors E_F and E_M related to the chosen transmission energy consumption model. E_F represents free-space transmission, while E_M multipath loss represents attenuated transmission. The distinguishing factor between the two models lies in the boundary condition expressed as D_0. Specifically, when the transmission distance, D, surpasses the threshold D_0, there is an observable increase in the transmitter's energy consumption. This phenomenon can be attributed to the fact that as the transmission distance grows beyond *d*_0, the signal propagation and amplification require more energy.

On the receiving end, the energy consumption for receiving 'l' bits of data can be described using the following equation (as
expressed in Eq 5). This equation quantifies the energy expenditure at the receiver,

$$\Xi_R(i,j)=\Xi_{T-elec}\times i \qquad (5)$$

Delay Analysis:

Delay analysis in WSNs involves the evaluation of various factors that contribute to delays within the network. Analyzing delays in WSNs is essential for designing efficient communication protocols, optimizing network performance, and meeting application-specific requirements. The total delay can be represented mathematically as follows:

$$D_T=D_{Tx}+D_{ptop}+D_{\mathrm{Pr}oc}+D_{que}+D_{wait} \qquad (6)$$

where the total delay is calculated by combining transmission delay, propagation delay, processing delay, queuing delay, and waiting or synchronization delays.

Throughput analysis:

Throughput analysis in a WSN typically involves calculating the rate at which data can be successfully transmitted through the network. It measures the rate at which data packets are successfully transmitted from sensor nodes to the CHor destination. Throughput analysis considers factors such as network topology, routing protocols, data packet size, and communication overhead. A higher throughput indicates a more efficient use of the network's resources, which is essential for applications demanding timely data delivery. Accurate throughput analysis helps in optimizing the network's design, choosing suitable routing strategies, and ensuring that the WSN can meet the data transfer requirements of multimedia transmission. The mathematical equation for throughput in a WSN can be expressed as:

$$T=\left\{\left(\frac{S}{N*P}\right)*\left(1-e^{\wedge}\left(-\lambda*T_{packet}\right)\right)\right\} \qquad (7)$$

where T is the throughput, S is the packet size, N and is the number of nodes. P is the packet error rate (PER), representing the probability that a packet is received correctly, λ is the packet generation rate (packets per second), and T_{packet} is the packet transmission time (in seconds), which is calculated as;

$$T_{packet}=\frac{S}{R} \qquad (8)$$

where R is the data rate of the communication link (in bits per second).

This equation takes into account the packet size, the number of nodes in the network, the probability of successful packet transmission (accounting for possible errors), and the packet generation rate. It provides a measure of the network's data transfer capacity, considering factors that affect the successful delivery of data in a WSN.

Traffic rate control:

Traffic rate control in WSNs typically involves managing the data rate at which sensor nodes transmit information to the CHor data collection point. It is a critical aspect of network management and optimization. It involves mechanisms and strategies to regulate the rate at which data is generated, transmitted, and processed within the network. The primary goal of traffic rate control is to ensure efficient utilization of the limited network resources, including energy, bandwidth, and processing capacity while meeting application-specific requirements. The coordination between layers, such as network and data link layers, allows for intelligent decisions regarding frame sizes, duty cycling, and route selection to achieve efficient traffic rate control.

Trust degree of WSN nodes:

Calculating the trust degree of nodes involves assessing the reliability and trustworthiness of each node based on various factors and metrics. Trust management in WSNs is critical for ensuring the integrity and security of data in a network where sensor nodes may be susceptible to various attacks and failures.

The trust score for a node can be calculated as follows:

$$Trust_{node} = \{(W_1 * N_1) + (W_2 * N_2) + (W_3 * N_3) + \cdots (W_n * N_n)\} \tag{9}$$

Where W are the weights assigned to the trust metrics, and N are the normalized values of the trust metrics. A high trust degree implies confidence in the integrity and authenticity of the information exchanged between nodes, ensuring that data is not compromised or tampered with. By incorporating trust-awareness into cross-layer design, WSNs can enhance network performance, security, and overall reliability, ultimately leading to more robust and efficient sensor network deployments.

a) Direct Trust Model: Direct trust refers to the trustworthiness of a node based on its past interactions and behavior. Let's denote direct trust as $DT(i)$ for node i as

$$DT(i) = [\alpha * ST(i)] + [\beta * R(i)] + [\gamma * SB(i)] \tag{10}$$

where α, β, γ are weight coefficients that determine the importance of each factor, $ST(i)$ represent the number or percentage of successful interactions involving the node i, $R(i)$ assess how often the node i is available and responsive, and $SB(i)$ measure the node's adherence to security protocols and absence of malicious behavior.

b) Indirect Trust Model: Indirect trust considers trust recommendations from other nodes in the network, often based on their direct trust values. It can be calculated as an aggregation of trust values received from neighboring nodes. Let's denote indirect trust as $IDT(i)$ for node i as

$$IDT(i) = \sum DT(i) * W_{ij} \tag{11}$$

where $IDT(i)$ is the indirect trust of the node i, $DT(i)$ is the direct trust of the node j, and W_{ij} represents the weight assigned to the trust recommendation from node j to node i.

Cross-Layer Optimization and Factors Optimized through the Proposed Algorithm

Cross-layer optimization plays a vital role in facilitating the transmission of multimedia data within WSNs. This significance arises from the unique demands and complexities associated with multimedia content. Cross-layer optimization allows for the efficient coordination and collaboration among various layers within the network's communication protocol. Moreover, the Cross-layer approach across the network, MAC, and Physical layers achieves a balance between optimizing energy consumption and preserving data quality.

Cross-layer parameter optimization:

In the following subsection, we will provide a detailed explanation of the procedure involved in calculating the cross-layer probability values for individual sensor nodes while performing the tasks of clustering and routing in a wireless sensor network. When it comes to managing and optimizing the communication within a WSN, the determination of cross-layer probability values plays a crucial role. These values are essential for making informed decisions regarding the selection of cluster heads, routing paths, and data transmission.

a) Network layer parameters:

i) *Intra-Cluster Distance*: Intra-Cluster Distance (Intra-CD) refers to the distance between sensor nodes within the same cluster. It is used to assess the compactness or spread of nodes within a cluster. A smaller Intra-Cluster Distance indicates that nodes are tightly clustered, while a larger distance suggests that nodes are more spread out. Intra-CD is also measured in physical units (e.g., meters) and can be represented mathematically as:

$$Intra-CD=\frac{1}{N}\sum\left[d\left(node\_i,center\_cluster1\right)\hat{}2\right] \qquad (12)$$

This metric helps assess the degree of node dispersion within a cluster.

ii) *Inter-Cluster Distance*: Inter-cluster distance (ICD) refers to the separation or spacing between individual clusters within a WSN. ICD refers to the distance between the centers of different clusters in a WSN. It is a crucial parameter for cluster-based routing protocols, as it affects the overall network performance, data aggregation, and energy efficiency. ICD is typically measured in physical units and can be represented mathematically as:

$$ICD=d\left(center\_cluster1,center\_cluster2\right) \qquad (13)$$

Where ICD is the Inter-Cluster Distance, d is a distance metric, $center\_cluster$ are the coordinates of the centers of the cluster's distance being compared. N is the number of nodes in a Cluster.

iii) *Trust:* Trust is used to evaluate and quantify the trustworthiness of nodes within the network. These models are essential for addressing security and reliability concerns in WSNs, where nodes often operate in unattended or hostile environments.

b) Medium Access Control (MAC) layer:

The MAC layer is responsible for establishing reliable and efficient communication links between WSN nodes. The MAC protocol is a set of guidelines that dictate how each node should transmit data over the shared wireless medium.

i) *Delay*:

MAC layer delays can collectively contribute to the overall latency and performance of a network. Minimizing and managing these delays is essential for ensuring efficient and reliable cross-layer communication. The initial access delay is denoted with D_0 the delay of i^{th} retransmission D_i. In general form, the total access delay in case of R retransmissions in a sensor node is,

$$D=\sum_{i=0}^{R}D_i \qquad (14)$$

ii) *Congestion factor:*

The MAC layer is responsible for managing access to the shared communication medium. Congestion in the MAC layer can significantly impact network performance by causing delays, packet collisions, and reduced throughput. A mathematical model for the congestion factor in the MAC layer is denoted as,

$$CF=\left(\frac{\lambda*T}{N*C}\right) \qquad (15)$$

where, N is the total number of nodes in the network, λ is the arrival rate of new packets per second, T is the MAC layer frame duration, and C is the MAC layer channel capacity. The congestion factor in the MAC layer for cross-layer communication plays a crucial role in managing network congestion and optimizing communication in wireless networks, which is represented as,

$$CF=\left(\frac{P\_busy}{P\_total}\right) \qquad (16)$$

DOI: 10.48175/IJARSCT-26137

where, P_busy represents the portion of time when the channel is busy or occupied by ongoing transmissions. It can be calculated as the product of the average packet transmission time and the transmission rate. P_total represents the total time available in a given time interval for communication on the channel.

c) Physical Layer:

The Physical Layer plays a critical role in facilitating communication among sensor nodes. It's essential to monitor and manage various parameters at this layer to ensure efficient network operation. Among the key parameters, two significant boundaries are meticulously tracked for each sensor node: leftover energy and Received Signal Strength Indicator (RSSI).

i) Energy:

Leftover energy is a crucial metric as it directly influences a sensor node's role within the network. Nodes with higher remaining energy levels tend to be preferred for tasks such as CH selection and routing decisions. This preference is driven by the need to prolong network lifetime and ensure reliable data transmission. Let $E_i(t)$ represent the leftover energy of the i^{th} sensor node at a time t can be expressed as,

$$E_i(t) = E_i(0) - \sum_{j=1}^{k} P_{ij}(t) \cdot \delta t \qquad (17)$$

where $E_i(0)$ is the initial energy of the i^{th} node, $P_{ij}(t)$ represents the power consumption of the i^{th} node for a specific operation or communication with the j^{th} node at time t, and δt is the time interval.

ii) Received Signal Strength Indicator:

RSSI estimation has been calculated individually for each sensor node within the network. These RSSI values are then used to compute a threshold-based likelihood estimate for the RSSI boundary associated with each sensor The RSSI threshold at the current time t is determined by analyzing the reception rate of signal packets from the neighboring nodes. This threshold provides a valuable measure of the network's signal quality and reception capabilities, aiding in efficient management and optimization.

$$RSSI_{ij}(t) = (RSSI\_0) - 10 \cdot n \cdot \log_{10}\left(\frac{d_{ij}(t)}{d_0}\right) \qquad (18)$$

where $(RSSI\_0)$ is the RSSI value at a reference distance d from the transmitter, and n is the path loss exponent, which depends on the environment and frequency, and $d_{ij}(t)$ is the distance between the i^{th} node and j^{th} nodes at the time t.

Evaluation of optimal index:

The cross-layer evaluation of the optimal index involves a holistic assessment of sensor nodes' capabilities and attributes across the network, physical, and MAC layers. The resulting cross-layer likelihood value plays a crucial role in selecting sensor nodes for CH within the cluster network, ultimately enhancing its overall performance and efficiency. The optimal index of these layers is calculated using,

$$I = \alpha_1 P_N + \alpha_2 P_M + \alpha_3 P_P \qquad (19)$$

where P_N is the network layer parameter, P_M is the MAC layer parameter, and P_p is the physical layer parameter. The value of $\alpha_1 + \alpha_2 + \alpha_2 = 1$, and is randomly decided by the user. The node with the maximum optimal index in the cluster is selected as CH, and within a WSN the CHs with the maximum optimal index are selected for data routing, in which both of these functions are optimally tuned by the proposed PCWO optimization technique. The evaluation of the optimal index inside a node is shown in Figure 2.

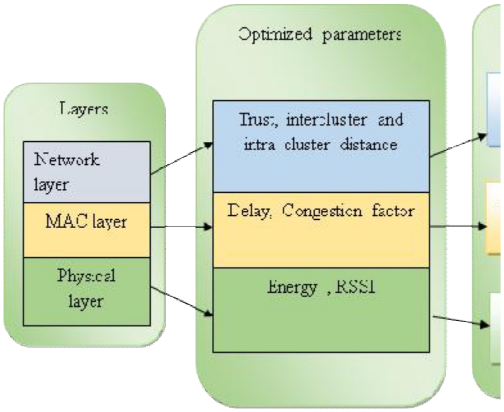

Fig. 2 Optimal index evaluation inside a node

Network Clustering:

In network clustering, a novel optimization strategy by drawing inspiration from three distinct optimization algorithms: Particle Swarm Optimization (PSO), Wolf Search Algorithm (WSA), and Cat Swarm Optimization (CSO) is used for optimal routing. This innovative approach plays a pivotal role in determining the CH nodes by taking into account an optimal index assessment and various parameters associated with the WSN node layers. The amalgamation of PSO, WSA, and CSO optimization techniques combined to form the Particle Cat Wolf optimization (PCWO) model, which serves as a robust foundation for network clustering methodology. These algorithms enable enhanced efficiency and accuracy in the selection of CH nodes within the WSN. This combined optimization approach not only offers a comprehensive and efficient solution for CH selection but also adapts to the dynamic nature of WSNs, ensuring optimal performance under varying conditions. Through the utilization of PSO, WOLFES, and CAT optimization techniques, our methodology paves the way for more robust and intelligent network clustering in wireless sensor networks. The cross-layer parameter optimization is used to decrease the transmission time, reduce delay, improve the QoS of each node, and enhance optimal data routing.

Network Multimedia transmission using PCWO optimization

Network path

In a multimedia network, data transmission often involves a complex path from the source to the destination, typically comprising three key components: the sensor nodes, CH, and the Base Station (BS). The journey begins at the sensor, where multimedia content is generated or sourced. From there, the data is relayed to a Cluster Head, which acts as a local coordinator within a cluster of interconnected devices. The CH optimizes data aggregation and routing decisions before forwarding the multimedia content to the Base Station. This three-tiered network path ensures efficient data management and delivery in multimedia applications, balancing the distribution of processing tasks and optimizing bandwidth usage to maintain quality and reliability throughout the transmission process**.**

Fitness Evaluation for Path Selection:

Fitness evaluation for path selection is a crucial aspect of optimizing routing and pathfinding algorithms, which plays a fundamental role in guiding the search for optimal data routing. Each potential solution is assigned a fitness score based on the optimal index. Path selection can be formulated as optimization problems and fitness functions are used to quantify the quality of paths based on their attributes. The fitness evaluation of the j^{th} path is represented as,

$$F_j = a_1\sum E_{ij} + a_2\sum Q_{ij} + a_3\sum T_{ij} \qquad (20)$$

where $\sum E_{ij}$ is the energy of all the nodes in the j^{th} path, Q_{ij} and is the QoS of transmission delay, throughput, network energy, and traffic rate. T_{ij} is the direct and indirect trust of all the nodes in the j^{th} path.

Particle Cat Wolf Optimization (PCWO) model:

The PCWO is modeled based on the characteristics of

Motivation:

Particle Swarm Optimization (PSO), Wolf Search Algorithm (WSA), and Cat Swarm Optimization (CSO) all emerged as innovative optimization techniques driven by the need to address complex problems in various domains. PSO draws inspiration from the social behavior of birds flocking and fish schooling, aiming to harness collective intelligence for optimization tasks. It was motivated by the desire to find efficient solutions for optimization problems with multiple variables and nonlinearities. WSA, on the other hand, takes inspiration from the predatory behavior of wolves in their hunting strategies, offering an approach to solving optimization problems that require exploration-exploitation balance and adaptability. Lastly, CSO takes cues from the hunting behavior of cats, which combines stealth, coordination, and agility, making it suitable for solving optimization problems involving dynamic and non-convex landscapes. These algorithms can tackle diverse and challenging optimization problems by emulating nature's elegant solutions, ultimately offering new tools for optimization in wireless sensor networks.

V. CONCLUSION

The difficulties of MMT in WSNs based on their limited resource environment have been tackled in this paper by applying a cross-layer methodology. The methodology maximizes CH selection and delay-free routing of multimedia information to facilitate effective communication between the heterogeneous sensor nodes in WSNs. The proposed method makes use of PPC optimizer, in order to maximize network clustering and path selection mechanisms, thus obtaining efficient solutions to transmit multimedia data in WSNs. By applying PPC, this study has made enormous contributions to the performance of WSNs in managing multimedia traffic towards enabling more efficient and more reliable WSNs to attain energy efficiency and minimum data transmission delay. The PPC-CLMDT model is tested against other approaches for different nodes of 50,100,150, and 200 nodes for approximately 2000 rounds. The experimental findings validate the efficiency of the cross-layer optimization approach by showing decreased node power consumption and increased throughput. Additionally, the future research could involve adding the conventional machine learning such as federated learning or reinforcement learning to further enhance the routing and dynamic clustering in multimedia WSNs. Additionally, the field deployment scenarios, like environmental scenarios and smart healthcare will be investigated to place the use of PPC into context

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