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Cross-Layer Based QoS Aware Load-balancing Multi-Path Routing Protocol over Wireless Multimedia Sensor Networks

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Abstract: Currently, the utilization of WMSNs in different real-time and non-real-time applications requires an excessive amount of bandwidth for reliable data delivery. The unique features of WMSNs are significantly challenging in satisfying the QoS requirements in such application-specific environments and balancing the traffic load among the devices. The provision of reliable multipath routing is a cornerstone in fulfilling the QoS requirements of WMSNs. Selecting multiple optimal paths between a source and destination based on peculiar routing metrics enhances the performance of QoS routing. Generally, routing protocols exploit several routing metrics, such as delay, remaining energy of nodes, hop count, available bandwidth, and packet loss rate in path selection to attain high reliability in data delivery. Many existing routing protocols only consider the network layer parameters, whereas it lacks focus on the data link and physical layer parameters, which creates a severe impact on the degradation of QoS. In addition to that, varying bandwidth channels create interference in multimedia data delivery and degrade the network performance. Designing a multipath routing protocol by considering cross-layer parameters offer a promising solution to optimize the WMSN performance. In cross-layer design, diverse protocol layers support the routing decisions adaptively by perceiving the dynamic characteristics of the wireless medium, resulting in fair use of scarce resources with high QoS. A Cross-Layer Based QoS Aware Load-Balancing Multipath Routing Protocol over Wireless Multimedia Sensor Networks was the goal of the study's five design objectives. The study and analysis of QoS and cross-layer-based routing algorithms for WMSNs was the initial goal. Secondly, a Deep Learning prioritization-based packet classifier to divide traffic according to priority. To ensure fair resource consumption and distribution of multimedia traffic, the third goal was to design and create a cross-layer optimizer model for optimal multiple disjoint route selection using machine learning techniques. The development of a cutting-edge channel-scheduling algorithm was goal four. It was designed to efficiently assign low-interference channels to communication devices in order to lower the packet drop rate in real-time packet delivery. Last but not least, a security method for Wireless Multimedia Sensor Networks' Cross-Layer based multipath routing protocol.

I. INTRODUCTION

In recent years, technological advancement of the Wireless Multimedia Sensor Network (WMSN) facilitates several multimedia applications such as military surveillance, industrial monitoring, medical automation, and smart homes [1][2]. The WMSNs include tiny smart multimedia devices, such as microphones, cameras, and scalar sensors that can retrieve audio signals, video streams, snapshots, and scalar data from the real-time environment [3]. These wireless sensing devices are resource-constrained in terms of bandwidth, energy, storage, and channel capacity. The sensor devices interact with each other over a wireless link. Each device routes the sensed multimedia streams to the remote location through a sink node in a single or multi-hop manner. For effective multimedia data delivery, each sensor device exploits an efficient routing strategy [4][5].

In WMSN, the retrieved multimedia information is heterogeneous, and it generates high data traffic. Hence, multimedia data delivery in WMSNs imposes diverse stringent quality requirements such as high bandwidth, reliable data delivery, and lower end-to-end delay. Therefore, utilizing scarce network resources and achieving high reliability in multimedia applications is a challenging task due to interference between sensing devices and constrained bandwidth. Currently, the utilization of WMSNs in different real-time and non-real-time applications; hence, high-volume multimedia streams requires an excessive amount of bandwidth for reliable data delivery. The unique features of WMSNs are significantly challenging in satisfying the Quality of Service (QoS) requirements in such application-specific environments and balancing the traffic load among the devices.

Most of the conventional routing protocols utilize single-path routing strategies that have bottlenecks with different traffic loads, resulting in high packet loss in the networks. Unlike the single-path routing strategy, the multipath routing strategy evenly spreads multimedia traffic along multiple disjoint paths and improves network performance [6].

Therefore, providing reliable multipath routing is a cornerstone in fulfilling the QoS requirements of WMSNs. Selecting multiple optimal paths between a source and destination based on peculiar routing metrics resolves the performance of QoS routing [7]. Generally, routing protocols exploit several routing metrics, such as delay, remaining energy of nodes, hop count, available bandwidth, and packet loss rate in path selection to attain high reliability in data delivery [8]. Many existing routing protocols only consider the network layer parameters, whereas it lacks focus on the data link and physical layer parameters, which creates a severe impact on the degradation of QoS.

In addition to that, varying bandwidth channels create interference in the multimedia data delivery and degrade the network performance. Designing a multipath routing protocol by considering cross-layer parameters offer a promising solution to optimize the WMSN performance [9][10]. In cross-layer design, diverse protocol layers support the routing decisions adaptively by perceiving the dynamic characteristics of the wireless medium, resulting in fair use of scarce resources with high QoS.

A. Basics of Wireless Multimedia Sensor Networks

The emergence of affordable technology allows for the creation of Wireless Multimedia Sensor Networks (WMSNs), which are networks comprised of sensor devices that have constraints but are capable of retrieving multimedia and scalar data. Network nodes in these applications should ideally maximise perceived quality of service while minimising energy expense. Extensive study in recent years has shown difficult difficulties for WMSN implementation.

Maintaining connection and maximising network longevity are two of the most important factors when building architectures and protocols. The primary goal of maintenance is to ensure that a network operates reliably. Data collected from sensors in close proximity is usually related and of the same observation. Effective network strategies have been widely developed to eliminate such duplication and improve load balancing for providing Quality of Service (QoS). To that end, data fusion routing algorithms are critical because they specify the desired precise interaction of sensory devices. Recent developments in WMSNs have given rise to numerous particularly built new protocols for QoS-aware long-lived networks.

Wireless Sensor Networks (WSNs) combine numerous functions, including sensing, processing, and communication. They perceive and collect data from their surroundings and communicate it to more powerful nodes known as sinks, which do more complicated processing. Sensor-based uses include scientific exploration, military applications, disaster assistance, health care, industrial applications and in logistical operations. The advent of affordable semiconductors designed for gathering multimedia data from surroundings has benefited the growth of WMSNs. Many wireless network protocols need coordination, and clock synchronisation to establish collaboration across dispersed entities.

The primary power-consuming element in a node's operation is the radio interface, which is governed by the Medium Access Control (MAC) protocol. WSNs lifespan is greatly increased by an efficient MAC scheme. An efficient MAC protocol may decrease collisions and boost possible throughput, allowing for more flexibility in a variety of applications. In the beginning, effective data transmission was not a top focus. New protocols, however, are being developed to facilitate multitasking and the effective transmission of bursty data.

Since different nodes have restricted ranges and build ad hoc topologies across a shared channel, designing and implementing routing algorithms capable of effectively and efficiently supporting information flow and handling is a difficult challenge in WSN. To begin with, the processes used for transmitting information must be energy-efficient in order to maximise the network's lifespan. Secondly, since nodes often run unattended, the network is anticipated to display autonomic features, i.e., the employed protocol must be autonomous and fail proof. Finally, the routing protocol must be capable of handling big and dense networks, as well as the issues that come with interference and the requirement to identify, maintain, and employ potentially lengthy multi-hop pathways.

The development of effective routing methods for WMSNs has recently received a lot of attention. Wireless Passive Sensor Networks (WPSNs) are presented as an entirely new sensor-networking standard to address the limits on the system lifespan of WSNs. WPSNs are non-disposable, more functional, and cost-effective; and operates when power is given and stays inactive when not in use. Today, the emphasis is turning towards research focused at rethinking the sensor-networking paradigm in order to allow multimedia content delivery. With the advent of WMSNs, it is now feasible to offer multimedia on small sensing devices. WMSNs allow for the retrieval of multimedia streams as well as the storage, real-time processing, correlation, and fusion of multimedia material gathered from disparate sources. The amount and features of multimedia traffic vary significantly from those of WSN traffic. This has necessitated the investigation of communications protocols for multimedia transmission in WMSNs.

The introduction of the Internet of Things (IoT), which is expanding extremely quickly given the significant advances in the area of embedded systems, has recently accelerated research in WMSNs. This has opened up new opportunities for WMSNs to seek acknowledgment from the rest of the networking world for their separate initiatives. Furthermore, the use of IPv6 allows for the integration of WMSNs with the Internet, allowing for remote surveillance and monitoring. The bandwidth, power supply, computing, and other resources available to multimedia sensors are severely constrained. As a result, complicated encoding methods cannot be used. In WMSNs, the communication paradigm is similarly many-to-one, with a sink serving as the final destination for multiple sources and capable of executing complicated decoding operations.

Furthermore, due to the large number of node placement, sensor data exhibits significant spatial correlation. Transporting video with assured QoS, for example, is critical in WMSNs owing to greater rate needs on limited and changeable channel capacity. In terms of the metrics associated with each of these separate levels, a layered strategy may attain excellent performance. Given the limited capacity of WMSNs, collaborative optimisation of the networking layer, i.e. cross-layer design, is the most promising alternative to inefficient standard tiered protocol designs. There are many cross-layer protocols suggested. The primary goal is to provide Quality of Service to each node based on the existing network situation.

B. Wireless Multimedia Sensor Network Architecture

WMSNs are a group of sensor devices distributed to observe the physical world via several media. In addition, by combining technologies from telecommunications and networking, digital signal processing, vision-based surveillance, and automation, it is capable of processing and reacting to incoming data in real-time. To allow these applications the tasks may be roughly categorised in three:

1) *System:* Individual nodes have own system. New platforms, operating systems, and storage mechanisms must be designed for handling varied software programs on a sensor system.
2) *Protocols:* Make communication between sensor nodes possible.
3) *Services:* Designed to increase application performance.

Sensor nodes must be capable of self-organizing into a network in order to meet application and network administration requirements. As a result, individuals can effectively control and regulate themselves. Protocol implementation at various tiers may have a major impact on energy utilisation, delay, and overall system performance. Because they are not intended to satisfy these criteria, traditional networking protocols are unsuitable for WSN situations. The new energy-efficient protocols leverage cross-layer optimisation by permitting interactions between protocol levels. Protocol status data at one level is shared between all layers to meet certain requirements.

The number of active nodes and the network's connection determines the lifespan of a WMSN. As a result, in order to maximise network longevity, energy must be utilised effectively. Energy conservation extends network lifespan and is accomplished by efficient, dependable wireless connectivity, smart deployment of sensors for maximum coverage, protection, and smart memory management, as well as data consolidation and compression. For dependable communication, congestion control, buffer monitoring, acknowledgements, and packet-loss recovery are all necessary. The communication strength is affected by the position of the sensor nodes. Sparse sensor placement may result in long-range transmission and higher energy consumption, whereas dense sensor placement may result in short-range transmission and lower energy consumption. The position of the sensor affects coverage. The degree of network coverage is determined by the total number of sensors in the network and their location. Subject to the use case, more coverage may be required to increase data accuracy.

High bandwidth demand, high-energy consumption, QoS provisioning, data processing and compression methods, and cross-layer design are all challenges in WMSNs. To be delivered, multimedia material needs a large amount of bandwidth. As a consequence, high data rates use a lot of energy. Because of the changing latency and variable channel capacity, QoS provisioning is a difficult issue. A specific degree of QoS must be reached for dependable content delivery. Filtering and compression in network processing may considerably enhance network speed by filtering and eliminating unnecessary information and combining material. Similarly, layer-to-layer contact may increase processing and transmission.

Most scalar WSN solutions are simple homogeneous designs in which the sensor nodes are identical and carry out similar activities as well as communicating only to their neighbour. These topologies may not be suitable for WMSN applications. Similarly, the computing power needed for data processing and communications, as well as the energy necessary to run it, may not be accessible on every node. With the introduction of WMSNs, there has been an increase in the use of new types of sensor nodes with varied capabilities and purposes. This necessitates reconfiguring the network into alternative designs so that it can be more scalable and resilient.

There are many kinds of nodes in WMSN:

a) *Visual and Audio Sensors (VAS):* These record sound as well as still or moving picture.
b) *Scalar Sensors (SS):* Are another kind of sensor. These nodes detect scalar data as well as physical properties
c) *Multimedia Processing Hub) (MPH):* These have a great amount of processing power and are well suited for collecting multimedia feeds from individual sensor nodes.
d) *The Storage Hub (SH):* These enable data quarrying as well as feature extraction to discover relevant event features.
e) *Sink Node (SN):* This is in charge of translating high-level user requests into network-specific directives and returning to the user-filtered bits of the multimedia stream.
f) *The Gateway (GW):* This component is the sole IP-addressable component and connects the sink with the other networks.

WMSN network architectures may be classified into three types: single-tier flat topology, single-tier clustered design, and multitier topology with heterogeneous sensors.

The WMSN can be implemented in a single-tier flat design with homogenous sensor nodes that have identical sensing, computing, and communication and functions (Figure 1). In this approach, all nodes in the Multihop topology may accomplish any task, and relaying the data to the SN. Furthermore, the processing is dispersed across the devices, which extends the network's lifespan.

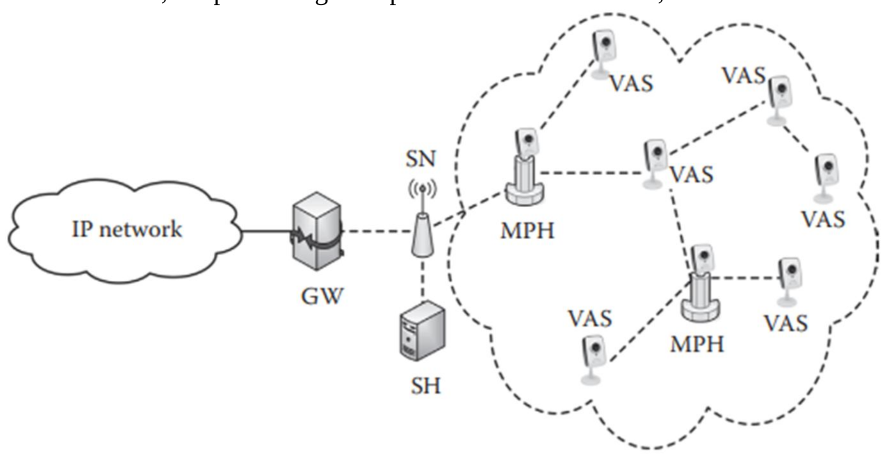

Figure 1 WMSN Flat Single-tier Topology

In a single-tier, clustered architecture scalar sensors inside individual clusters transmit gathered data to the cluster head. The MPH has greater resources and can handle intense activities. It communicates with the sink node or the gateway either directly or through other cluster heads in a Multihop method (Figure 2).

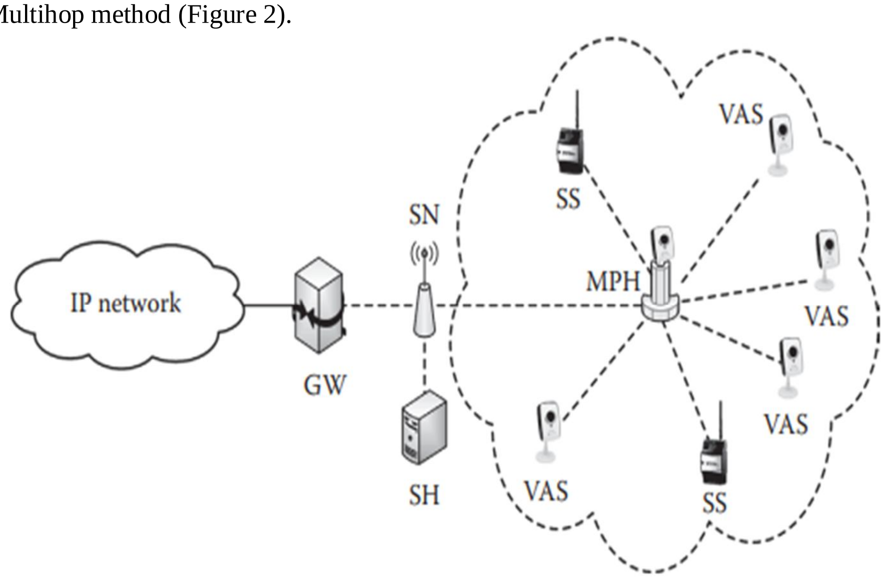

Figure 2 WMSN Clustered Single-tier Topology

The multitier topology with diverse sensors is the third approach shown in Figure 3. The first layer of SSs in this architecture performs basic functions but the second tier of VASs may do more complex activities, with the third tier handling tasks that are more sophisticated. This design can complete jobs with varying demands while maintaining a better mix of prices, coverage, functionality, and dependability.

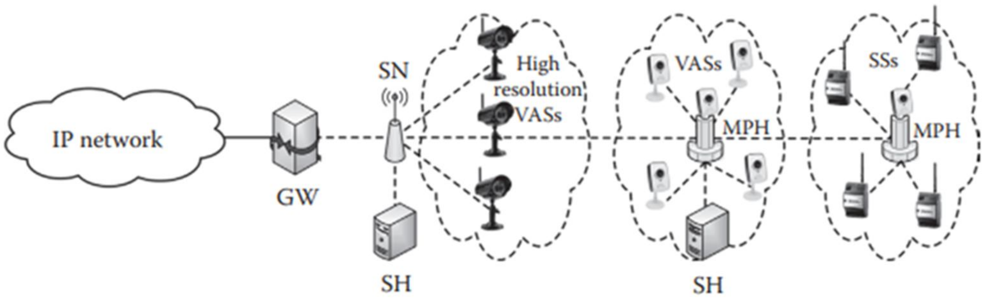

Figure 3 Multitier WMSN Architecture

C. Wireless Multimedia Sensor Network Node Internal Structure

The WMSN devices are made up of many fundamental components: a detecting unit, a Central Processing Unit, a communication subsystem, a coordinating unit, storage, and an optional mobility or actuation unit. Figure 4 depicts the design.

The sensing unit incorporates two parts: audiovisual, and/or scalar sensors, as well as an analogue-to-digital converter (ADC). The ADC converts the analogue signals generated by the sensors depending on the detected occurrence into digital signals, which are subsequently sent into the CPU. The CPU is connected to a memory and runs system software responsible for synchronising sensing and communication duties. A communication subsystem, which consists of a transceiver unit and communication software, connects the device to the network. This comprises the communication protocol stack as well as system software such as middleware, operating systems, and virtual machines. A coordination subsystem is in charge of the functioning of several network devices, such as network synchronisation and location management. Objects may be moved or manipulated with an optional mobility or actuation unit. A power supply unit (PSU) provided from battery power or solar energy powers the whole system.

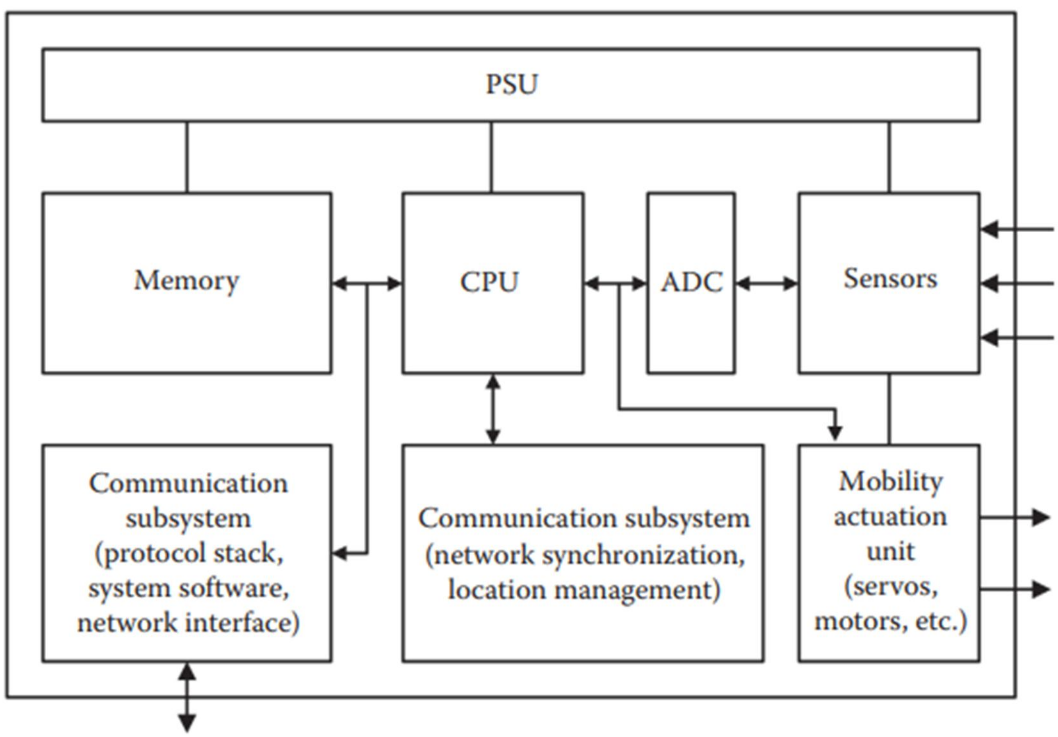

Figure 4 WMSN Node Internal Structure

D. WMSN Protocol Stack in Relation to QoS Assurance

The creation of a dependable and energy-efficient protocol stack is critical for the support of different WSN and specific WMSN applications. A network might have several nodes, subject to the application. To interact with one another and the SN, each sensor node use the protocol stack. As a result, the protocol stack must be capable of providing dependable QoS in terms of communication as well as working effectively across several sensor nodes. Table 1 summarises the research problems at various tiers.

Table 1: Challenges at Various Tiers of the WMSN

Layer	Challenges
Application	Strong compression performance, a simple encoder, and robust coding against errors.
Transport	Variations and adjustments to conventional protocols or the use of particular dependability and congestion control protocols.
Network	Energy-saving routing approaches with QoS guarantees.
Link	QoS must be supported by access to channel constraints, multiplexing and cache management, and correction of errors.
Physical	Efficient bandwidth and energy use. Spectrum agility and interference resistance.

1) Wireless Multimedia Sensor Network Physical Layer

The physical layer must be interoperable with higher levels in the protocol stack. A cross-layer method between the physical and MAC levels may do this with more efficiency.

The physical layer should make the maximum use of the available bandwidth and data throughput while also being more power efficient. According to the accessible literature on WMSN initiatives, physical layer technologies are mostly connected to the families of IEEE 802.15 and IEEE 802.11 standards.

Because of its simplicity, low cost, and low power, IEEE 802.15.4 commonly called ZigBee, is the most commonly used technology in WSNs. The ZigBee standard, on the other hand, is not appropriate for WMSN streaming or for ensuring application requirements for QoS. Other technologies, such as Bluetooth and Wi-Fi, offer faster data rates and coding efficiency but use more energy. Earlier phases of WMSN test bed deployment utilised Bluetooth transceivers, and Wi-Fi transceivers. Multi-antenna systems, such as antenna diversity, smart antennas, and MIMO systems, may be coupled with UWB to boost capacity, decrease the effects of fading, and co-channel interference.

2) Wireless Multimedia Sensor Networks Link Layer QoS

WMSNs that offer a variety of data, QoS assurance methods are used to prioritise and accomplish resource allocation based on the needs of each traffic class.

As a result, this layer is an excellent alternative for implementing QoS support. Link layer QoS research activities are usually categorised in three: channel access controls, scheduling and buffer management, and error correction.

Some MAC protocols are designed to provide high link-level throughput, reduce delays, or ensure QoS for a specific packet type based on the nature of channel access. They are classified into Contention-based Protocols and Protocols without Contention. Scheduling and buffer management in WMSNs is an open research problem that has piqued the interest of the academic community in recent years but has to be resolved. A potential remedy to the scheduling and cache control issue is based on the fact that different network applications require different degrees of QoS, such as packet delay, data loss, capacity, and stability.

3) Network Layer Quality of Service

In WSNs, the network layer is in charge of relaying sensed data from sources to the SN while taking into account many design concerns such as energy efficiency, connection quality, fault tolerance, and scalability. Although several routing protocols have been developed for regular WSNs, the creation of routing protocols for WMSNs remains an ongoing research topic. Because of the unique features and limits associated with multimedia content management, the suggested routing protocols for WSNs are not directly applicable to WMSNs.

Routing strategies for WMSNs may be roughly categorised into the following distinctive groupings, according to current research trends; Routing protocols with latency constraints, QoS-constrained routing systems and Routing for real-time streaming.

4) Wireless Multimedia Sensor Network Transport Layer

In real-time applications such as audiovisual video streaming, transport layer services such as E2E congestion management and reliability are critical. Because of their distinct properties and applications, WMSNs differ from networks that utilise packet switching. Typical protocols cannot be used directly.

Some WMSN characteristics that influence the creation of transport layer protocols are:

a) *Network Structure:* Changes in network architecture should be considered while developing a transport protocol for wireless multimedia sensor networks.
b) *Traffic Conditions:* The majority of traffic in WMSN is produced from the source nodes towards the sink, and this traffic might be persistent, dependent upon events, query-driven, or hybrid depending on the application. In many circumstances, the source node may deliver its multimedia traffic to the sink through multipath routes, which can be used to create an appropriate transport protocol to ensure the quality of multimedia streaming.
c) *Limited Resources:* Because sensor nodes are restricted in capabilities in respect to power supply, bandwidth, and memory, solutions for congestion management and dependability must be less costly and more energy-efficient.
d) *Application-specific Quality of Service:* WMSN offers a wide range of applications, that may concentrate on various types of sensory data and hence have distinct QoS requirements.
e) *Redundancy in Data:* Because acquired sensory data has a significant degree of redundancy, processing techniques such as extracting features, compression, data integration, and aggregation to reduce the quantity of data while retaining the critical information.

5) Wireless Multimedia Sensor Network Application Layer

Multimedia handling approaches strive to decrease the quantity of network traffic by extracting relevant information from collected pictures and videos while preserving application-specific QoS requirements. In the WMSN context, source code, as one of the application layer activities, incorporates both classic communication issues and concerns that are more generic. Because of the high needs for multimedia encoding, real-time streaming applications in WSNs are more demanding than data-sensing applications. Because of the limits of the sensor nodes, video coding/compression must be simple, generate a low output bandwidth, accept loss, and spend as little power as feasible.

E. WMSN Benefits and Applications

WSMNs offer the power and flexibility to combine and store multimedia material from several camera sources. Deploying several visual sensors as cameras not only enhances coverage and expands the field of vision (FOV), but it also increases redundancy and dependability. WSMNs provide the following advantages:

1) *Improved FOV:* This may be done by employing several cameras. When the FOV is limited, combining cameras to display the infrared and visible spectrums in the targeted scene is advantageous.
2) *Wider FOV:* Using several cameras allows for a wider FOV. The fundamental concept is to employ a number of low-resolution cameras to trigger a small number of high-resolution cameras. Using their pan-tilt-zoom capability, these smart cameras can then target the desired event. This method will deliver the required quality at a lesser cost.
3) *Several View Points:* When a large area, such as a street, has to be watched, one camera is insufficient, thus numerous cameras are added to give flexibility and multiple angles.

These advantages have led to the use of WSMNs in a range of applications:

a) *Surveillance and Monitoring Applications:* WSMNs are very useful for monitoring streets, public places, museums, and borders.
b) *Recording Odd Events:* WSMNs may capture accidents, robberies, and traffic offences.
c) *Avoiding Traffic Congestion:* Traffic in big cities may be monitored, which will be quite beneficial, particularly during peak hours.
d) *Medical Applications:* Remote monitoring might be accomplished by employing motion sensors in combination with video and audio sensors, in addition to detecting scalar data pertinent to the patient, such as blood pressure, ECG, and heart rate. The recording of older people's behaviours might be valuable for medical and healthcare studies.

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e) *Environmental Applications:* WSMNs may be used to monitor the environment and warn of potential hazards like as global warming. The polar ice caps, for example, might be monitored to forecast the consequences of global warming on the Earth's water levels.
f) *Monitoring of Habitats:* Observing animals in certain regions might help researchers better understand the behaviours of wild animals and creatures that prefer peaceful environments.
g) *Localization:* The processing of collected photos and video may result in the location of lost things or children, as well as sought offenders.

One of the difficult difficulties in WSMNs is ensuring QoS by routing data acquired from several cameras, particularly if high resolution is needed. Although higher-quality photos and videos are required, they reduce network lifespan since batteries deplete quicker. As a result, reducing energy usage and creating energy-efficient methods have become critical in WSMN.

F. WMSNs Characteristics and QoS Design Requirements

WMSNs are a new technology that has emerged from standard WSNs. As a result, they inherit many of the constraints that present in traditional networks, as well as additional issues and needs that arise because of the need for real-time multimedia services and the management of larger data quantities. Because of the nature of the applications that need the data, the acquired data traffic managed by these networks must be sent in real-time. Because the multimedia data acquired by the camera sensors is large for a specific occurrence, the bandwidth needs for transmissions are raised. Because of their qualities and capacities, WMSNs have opened several avenues to study, as outlined in Table 2. The features, design requirements, and recommended methodologies of WMSNs are highlighted.

Table 2: Characteristics and Design Requirements of WMSNs

Characteristics	Requirements	Design Approaches
Power Constraints	Energy Efficiency	Energy-efficient computations • Image compression algorithms • Video compression algorithms
		Dynamic power management
		Energy-efficient communication • Transport Protocols • Routing protocols • MAC protocols
Real-time Multimedia Data	Quality of Service	Delay • Routing protocols • MAC protocols
		Reliability • Routing protocols • MAC protocols
		Prioritisation and service differentiation • Routing protocols • MAC protocols
Volumes of Multimedia Data	Reduction of Data Redundancy	Local processing
		Multimedia in-network processing • Multimedia data fusion • Multi-view video summarization
		Distributed source coding
		In-network data storage and query processing
	Higher Bandwidth Requirement	Multipath routing
		Multi-channel MAC protocols
		Ultra Wideband technique

1) Power Constraints

The camera sensor nodes in WMSNs are generally battery-powered. The batteries should power the sensor nodes for protracted periods without replacement. Therefore, the functionality of such nodes should take into cognizance these power constraints and limit energy consumption in its computations and communication. In traditional WSNs, energy drain due to computations can be insignificant compared to WMSNs where computations tend to consume extremely high energy. It is therefore recommended to adopt energy-efficient algorithms in image processing and likewise in video compression. Due to the large volumes of multimedia data to transmission, it is prudent that the communication protocols at every layer be energy-efficient. For example, the transport layer protocols reduce the number of control messages according to desired levels of reliability, with routing protocols employing load balancing and energy estimation techniques across the network and at the MAC layer protocols can avoid idle listening by inactive nodes. Dynamic power management is another important technique to be used as it ensures that idle components of a sensor node are selectively shut down or hibernated to prevent unnecessary power consumption.

2) Real-time Multimedia Data

In most applications involving multimedia data, QoS is difficult to achieve. Transmission of data to the sink without any packet loss or delays above the threshold is very crucial in WMSNs. Therefore, there is a need to impose severe QoS demands on the networks. Applications that involve multimedia data for example in security surveillance or traffic management systems cannot tolerate delays. This implies that prioritisation and service differentiation will play a pivotal role in these real-time systems. MAC protocols should give access or assign greater quality channels to higher-priority data. Routing protocols need to select paths that will have the least delay to meet the required QoS. Reliability is also crucial in ensuring QoS to WMSNs. Retransmissions are done at the transport layer for example in TCP while redundancy is at the bit level or at the packet level. However, these methods must be used with consideration that they increase traffic and hence consume more network resources. The heterogeneous traffic in WMSNs that include multimedia and scalar data intended for different applications with varying QoS demands will require varying levels of priority even within the same traffic type.

3) Volumes of Multimedia Data

Typically, WMSNs have limited bandwidth hence transmission of large volumes of sensory data presents a major challenge to QoS guarantees. Techniques for data compression and redundancy reduction are vital to decrease data volumes prior to transmission. One such technique is local processing where on-board analysis of the captured images is used to extract only important events. The downside of local processing is the requirement for added hardware resources. Another technique is In-network processing of multimedia data that encompass data fusion where the sink node collects heterogeneous data from various nodes and create a summarised version of events to reduce data redundancy and enhanced inferences. To deal with the resource limitation problems associated with centrally coding data from multiple sensor cameras, WMSNs use distributed source coding (DSC) where encoding of data is done independently at each sensor before transmission to the sink for decoding. This reduces the power consumption as well as required hardware resources. Typically, WSNs transmit all collected data to the sink for subsequent processing and querying. Due to technological advancements, it is now possible to equip sensors with processors and flash memory that enable them to process and store data. After processing, only analysed data transmits to the sink. In terms of queries, only the result goes to the network after querying historical data. However, proper data ageing schemes need to be incorporated into the local databases as they fill up in order to maintain data integrity. It is also important to note that the sensors will form distributed databases which require efficient query engines to retrieve the data efficiently. Mitigating the bandwidth constraint that is extreme in WMSNs due to the large volumes and nature of traffic is also an important factor in achieving QoS communications. At the MAC layer, sensor nodes can communicate simultaneously using different channels. Data traffic can be routed through multiple paths. However, radio equipment that has considerable bandwidth such as ultra-wideband (UWB) can be utilised in WMSNs.

II. MOTIVATION

The rapid development of WMSNs lead to a different kind of real-time data transmission that anticipates precise levels of QoS, especially in video applications which leaves bottlenecks in current approaches. Also, the multimedia traffic flows are heterogeneous, hence, it is essential to provide priority to the traffic flow that requires strict deadlines in packet delivery [11]. In WMSNs, the wireless sensor devices have a low-cost camera, microphones, and scalar data measuring devices. Such devices are resource-constrained in battery power, bandwidth, and storage. The limited capabilities of these sensing devices restrict the QoS requirements. To avoid this issue, the QoS routing protocols determine multiple disjoint routing paths with the knowledge of network conditions and QoS requirements of specific applications but still other layers impose restrictions.

Taking into account only the routing layer parameters cannot meet the QoS requirements in totality since the cross-layer parameters such as channel interference and signal strength create a significant impact on reducing real-time network performance. In order to address both the utility maximization and QoS optimization issues, the cross-layer design assists the routing protocol in making routing decisions by considering interdependence among the various layers in the network.

However, conventional QoS routing protocols lack to achieve a better tradeoff between QoS performance and complexity. In addition to that, the routing protocols make routing decisions by selecting a highly energetic node as a forwarding node, resulting in unbalanced energy consumption among nodes. Thus, it increases network throughput, whereas it attains only partial development in QoS. Therefore, the routing mechanisms in WMSNs require improvements to attain desired application-specific QoS requirements. This is most important since the usage of WMSN is rapidly increasing in various sectors such as medical, military, transportation and so on. Improving the QoS will ultimately benefit a number of applications in various industrial sectors.

III. GAP ANALYSIS

Initially, the design of routing protocols considers the fundamental characteristics of WMSNs. Most of the existing protocols in WMSNs select routing paths using various routing metrics such as path length, node energy, communication delay, and throughput. Adding a large number of routing metrics in route evaluation results in increased complexity, overheads and inequitable energy distribution among the devices in the network. However, the conventional QoS routing protocols lack to achieve a better tradeoff between QoS performance and complexity.

In addition to that, the frequent selection of the same sensor device attains inequitable energy consumption in the network. The existing routing protocols make routing decisions by selecting a high energetic node as forwarding node, resulting in unbalanced energy consumption among nodes. Thus, it increases network throughput, whereas it attains only partial development in QoS. Frequent selection of a routing path containing high energetic nodes may become invalid due to drained battery power or node failure and dynamic characteristics of a network channel.

Therefore, some recent works utilize several algorithms that jointly optimize cross-layer parameters such as channel scheduling, node capacity, and interference level in the routing path selection, which results in high performance WMSNs. However, the classification and scheduling mechanisms for multimedia traffic that require application-specific delay bound data delivery still need improvements.

IV. PROBLEM STATEMENT

Initially, the design of routing protocols considers the fundamental characteristics of WMSNs. Most of the existing protocols in WMSNs select routing paths using various routing metrics such as path length, node energy, communication delay, and throughput. Adding a large number of routing metrics in route evaluation results in increased complexity, overheads and inequitable energy distribution among the devices in the network. However, the conventional QoS routing protocols lack to achieve a better tradeoff between QoS performance and complexity.

In addition to that, the frequent selection of the same sensor device attains inequitable energy consumption in the network. The existing routing protocols make routing decisions by selecting a high energetic node as forwarding node, resulting in unbalanced energy consumption among nodes. Thus, it increases network throughput, whereas it attains only partial development in QoS. Frequent selection of a routing path containing high energetic nodes may become invalid due to drained battery power or node failure and dynamic characteristics of a network channel. Therefore, some recent works utilize several algorithms that jointly optimize cross-layer parameters such as channel scheduling, node capacity, and interference level in the routing path selection, which results in high performance WMSNs. However, the classification and scheduling mechanisms for multimedia traffic that require application-specific delay bound data delivery still need improvements.

The WMSN application consists of different traffic flows that include audio, video, text, and scalar sensor data with varying QoS requirements. Some real-time applications such as military surveillance, smart homes, and health care systems need delay-aware packet delivery, whereas the scalar sensor data such as temperature and humidity related applications demand less QoS requirements. Therefore, it is a critical problem to design a multi-path routing protocol suitable for diverse traffic and application environments. Although current routing protocols focus on evaluating optimal routes in varying network conditions to achieve high network performance, they exist some bottlenecks to application-specific QoS requirements. Generally, wireless sensor devices compete to access wireless channels for communication, resulting in high network interference. Therefore, it is crucial to design a peculiar cross-layer-based QoS-aware load balancing multipath routing protocol that aims to attain a better tradeoff between high QoS performance in various multimedia applications and equitable resource consumption among the network devices.

V. RESEARCH OBJECTIVES

This study seeks to design and develop a cross-layer based QoS aware load balancing multipath routing protocol suitable for WMSNs over erratic communication links and real-time applications. To achieve this, there is a need to accomplish the following objectives:

1) Study and Analyse QoS and cross-layer-based routing algorithms for WMSNs.
2) Design and develop a Deep Learning prioritization-based packet classifier to segregate traffic based on precedence.
3) Design and develop a cross-layer optimizer model for optimal multiple disjoint route selection using Machine Learning techniques to ensure equitable resource consumption and distribution of multimedia traffic.
4) Development of a modern channel-scheduling algorithm for effective allocation of low interference channels to communicating devices to reduce packet drop rate in real-time packet delivery.
5) Security for Cross-Layer based multipath routing protocol over Wireless Multimedia Sensor Networks.

VI. RESEARCH METHODOLOGY

Considering only the routing layer parameters cannot meet the QoS requirements in totality since the cross-layer parameters such as channel interference and signal strength create a significant impact on reducing real-time network performance. To address both the utility maximization and QoS optimization issues, the cross-layer design assists the routing protocol in making routing decisions by considering interdependence among the various layers in the network. The work incorporates three mechanisms to achieve its objectives that are prioritization-based packet classifier, optimal disjoint route selection, and a modern channel scheduling algorithm. The block diagram in Figure 5 shows the proposed work.

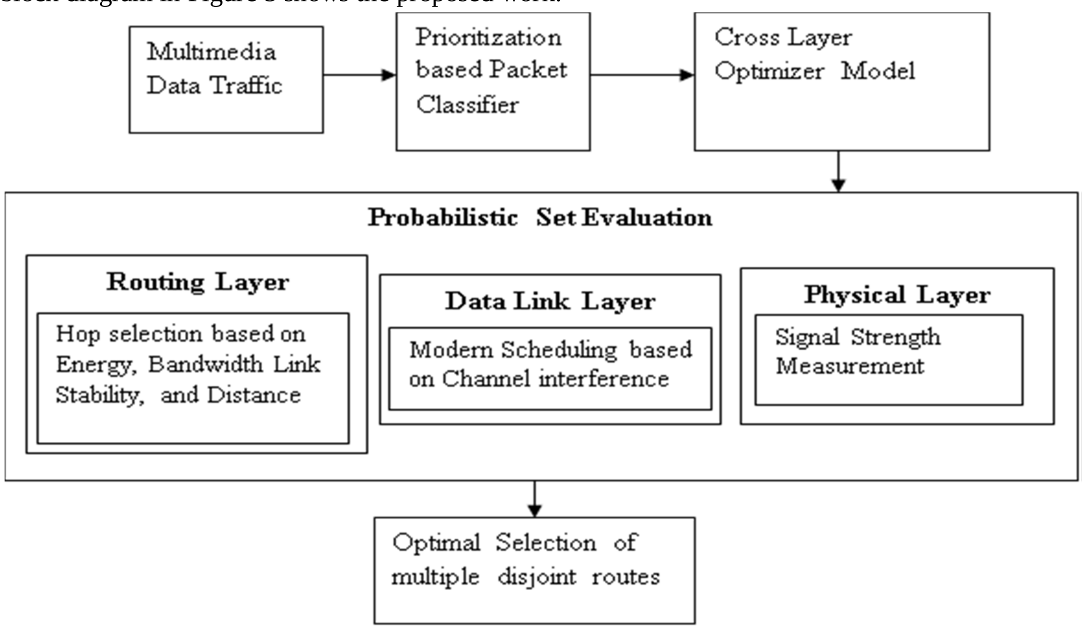


Figure 5 Block Diagram of Proposed Multi-path Routing Protocol

The projected work utilizes a prioritization-based packet classifier that assigns a priority level to the incoming multimedia traffic, according to its application types such as real-time and non-real time. Consequently, the packet classifier determines the real-time delay-sensitive packets like video streams with high priority level packets for immediate transmission. Accordingly, the work utilizes a Machine Learning (ML) and Artificial Intelligence (AI) based cross-layer optimizer model for optimal route selection. The ML and AI-based cross-layer optimizer dynamically adjusts its parameters in route evaluation and assigns multiple shortest earlier routes to high-priority packets. The anticipated work evenly spreads the multimedia traffic among discovered disjoint routes to improve real-time network performance. For a practical route evaluation, the optimizer considers the cooperation of routing, data link, and physical layer parameters such as the remaining energy of sensors, available bandwidth, distance, link stability, interference level, and signal strength. The model stochastically estimates the expected packet drop rate by utilizing a set of probability values that are mathematically calculated using different layer parameters.

Subsequently, the channel-scheduling algorithm effectively allocates low interference channels to the communicating devices to reduce the packet drop rate in real-time packet delivery. Thus, the algorithm reduces the number of retransmissions and minimizes the energy expenditure at each device. Moreover, the proposed work achieves significant QoS improvement and equitable resource consumption by selecting multiple disjoint routes for multimedia data delivery. The work utilised MATLAB to evaluate the performance of the multipath routing protocol with dynamic network characteristics.

A. Performance Metrics

The performance estimation of the proposed cross-layer-based multipath QoS routing protocol uses diverse metrics that are Packet Delivery Ratio, Throughput, End-to-end Delay, Energy Consumption, and Packet Loss Rate.

1) Packet Delivery Ratio: the ratio of data packets received by the destinations to those generated by the sources.
2) Throughput: The amount of data packets transmitted from a source to destination at a particular time
3) End-to-end Delay: The time taken for a data packet to transmit over the wireless link in a source-destination pair.
4) Energy Consumption: The amount of energy taken by a node to deliver a packet successfully to the destination.
5) Packet Loss Rate: The number of packets dropped due to dynamic network conditions.

VII. REVIEW OF LITERATURE

The summarised Review of the Literature will be divided into Data Traffic Classification and Optimal Route Selection and Data Flow Allocation, Channel Assignment, and Scheduling.

A. Data Traffic Classification and Optimal Route Selection

Various researchers have paid attention to WMSNs' prioritized packet classification [12] and optimal route selection due to diverse features and challenges that need to be considered for future study. Table 3 depicts the review of existing research works. Authors in [13] mainly aim to provide less packet loss, minimum congestion rate, and minimum transmission delay. Issues like the adjustment of transmission rate for prioritization need further improvement and energy consumption [14] of the system is more. The Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)-based fuzzy logic [15] algorithm is applied for reducing the delay and enhancing the performance, thereby the QoS metrics are improved. The Multi-MISO [16] is formulated to cater for reliability, energy efficiency, and delay. The energy consumption and latency are low during transmission.

Optimized Quality of Service-based Multipath Routing Protocol [17] is developed for attaining enhanced communication reliability with the lowest delay and load balancing. Although, route detection is difficult and QoS highly needs further improvement. Triangle link quality metric and minimum inter-path Interface-based Geographic Multipath Routing (TIGMR) [18] is implemented for improving the network lifetime. The optimization performance is enhanced, which is dependent on the quality of links [19]. For the Dynamic Path Selection [20] algorithm the minimum requirement needed for energy consumption and computational power also need to be reduced. The level of link quality needs to be considered and the power consumption for reception and transmission processes need improvement.

The Ant Colony Optimization (ACO) [21] algorithm achieves better convergence and performance, hence better QoS is achieved. However, it needs further improvement in traffic classification and overall network efficiency. Spectrum Aware-Outage Minimizing Opportunistic Routing (SA-OMOR) [22] algorithm is proposed for solving the curved optimization issues as well as improving the performance of the system. It needs further development for the dynamic channel allocation method and routing. These challenges need to be considered for upcoming research to develop novel well-performing models in WMSNs.

The Rider Optimization Algorithm (ROA) [23] is based on a unique computing technique called fictional computing, which uses made-up information and concepts to solve optimization problems. ROA depends on the teams of riders who work hard to reach the goal. To win, ROA uses rider teams that travel together to a shared destination. In ROA, there are four groups with equally matched riders. Attacker, overtaker, follower, and bypass rider are the four groups that ROA has adapted to. To reach the goal, each group employs several different techniques. Additionally, it oversees starting the multidirectional search using fast search to speed up search times. Even if riders use a specific strategy, the correct driving of cars and good control of the accelerator, steering, brake, and gear are the main strategies used to attain the goal. By controlling these variables and adhering to the recommended strategy while using the current success rate, the riders adjust their position toward the target in each occurrence. The success rate in the current instance is used to define the leader.

A meta-heuristic that takes its cues from nature, the Butterfly Optimization Algorithm (BOA) [24] imitates the foraging and mating behaviour of butterflies in their natural habitat. The foundation of BOA is based on the scent that butterflies generate, which aids other butterflies in their search for food and a mate. The fragrance intensity of the butterfly represents its objective function, and it attracts other butterflies according to the magnitude of the fragrance. The algorithm adopts three phases namely the global search, local search, and solution evaluation. During the global search phase, each butterfly emits fragrance when it moves which attracts other butterflies according to the magnitude of the fragrance. The local search is when the butterflies fail to sense the fragrance of other butterflies and begin to move randomly in the search space. The final phase is the evaluation of the solution where the stopping criteria is defined. In its hunt for the best answer to the issue, BOA conducts both a global and a local search. BOA occasionally becomes trapped in local optima that cause sluggish or subpar convergence. However, to improve convergence, this study incorporates the bidirectional search through ROA into the BOA structure.

Table 3: Features and Challenges of the Routing Approaches

Author [citation]	Methodology	Features	Challenges
Young-Long Chen, and Hung-PinLai [13]	FEWPBRC	Reduced congestion. Less packet loss and minimum transmission delay.	The adjustment of the transmission rate for prioritization needs further improvement. Energy consumption is more.
Bouazzi *et al.* [15]	CSMA/CA-based fuzzy logic	Provides enhanced performance in terms of energy utilization. QoS is improved and delay is minimized.	Fuzzy rules are robust. It has low prioritization capability.
Zhihua Lin *et al.* [16]	Multi-MISO	Improved reliability, energy efficiency, and reduced delay. Energy conservation and reduced latency during transmission.	Hardware complexity is more. MIMO-based systems are costly.
O.Deepa,and J.Suguna [17]	OQoS-MRP	It attains enhanced communication reliability with very low delay. Load balancing enhancement.	Route detection is demanding. QoS improvement is highly desired.
Shailendra Aswale,and Vijay R.Ghorpad [18]	TIGMR	The lifetime of a network is improved. The optimization performance is enhanced depending on the quality of the links.	Inter-path interference effect. The classification of links is reliable.
Khernane *et al.* [20]	Dynamic Path Selection	Minimum requirements handled to avoid energy consumption. Reduced computational power.	Dependent on the level of link quality. The power of reception and transmission processes needs further improvement.
Luis Cobo *et al.* [21]	ACO	Better convergence and performance attained. Improved QoS obtained using ACO.	The traffic classification may be improved. The network efficiency of the system needs further development.
Surajit Basak and Tamaghna Acharya [22]	SA-OMOR	The curved optimization issues are solved. The performance is improved.	The dynamic channel allocation method needs further development. Some routing issues were raised.

B. Data Flow Allocation, Channel Assignment and Scheduling

In wireless networks, an improved throughput capacity region can be achieved by equipping with multiple channels. However, such an approach inevitably brings the issue of solving the coupled channel assignment and scheduling problem. Some common challenges now with the development of WMSNs are considered that also require to be addressed, which are high bandwidth demand, heterogeneous multimedia reliability, coverage area, in-network processing, application-specific QoS constraints, etc.

Numerous methods are proposed in the channel scheduling approaches in wireless networks that have diverse features and challenges as given in Table 4. Low Duty Cycling (LDC) [25] attains better throughput performance and achieves lower complexity. However, this model is restrictive in maintaining the network. Link-Quality-Aware Capacitated Minimum Hop Spanning Tree (LQ-CMST) and Priority and Channel-Aware Multi-Channel (PCA-MC) [26] can efficiently minimize communication delay and improves the performance of the network. Though, it is not suitable for integrating with weighted fair scheduling schemes. OR+SCP [27] is proposed for minimizing computational complexity, end-to-end transmission delay, and energy consumption. Conversely, it can cause a longer interference range. Distributed Congestion-Aware Channel Assignment (DCACA) [28] attains increased aggregate throughput and minimizes the average packet round-trip time. However, it attains the congestion-aware channel assignment problem. Link Quality Aware Channel Assignment (LACA) [29] improves the Packet Delivery Ratio (PDR) and efficiently prioritizes the paths. Though, the major limitation of this work is the global optimum. JMR [30] is developed to minimize spatial reuse and attain maximum capacity. On the other hand, it needs to enhance the physical layer and CSMA. Distributed algorithms [31] effectively solve the problem of optimizations and attain faster solutions. It impacts the actual system performance. The generalized Bender's decomposition approach [32] obtains optimal solutions and improves the network utility. Though, it cannot transmit with multiple links. Hence, these challenges are observed for developing a new model in WMSN.

Table 4: Features and Challenges of the Channel Scheduling Approaches

Author [citation]	Methodology	Features	Challenges
Xu *et al.* [25]	LDCS	• It attains better throughput performance. • It achieves lower complexity.	• This model is restricted in maintaining the network.
Yigit *et al.* [26]	LQ-CMST and PCA-MC	• It can efficiently minimize communication delays. • It improves the performance of network.	• It is not suitable for integrating with weighted fair scheduling schemes.
Li *et al.* [27]	OR + SCP	• It minimizes computational complexity. • It minimizes end-to-end transmission delay and energy consumption.	• It can cause the longer interference range.
Mohsenian and Wong [28]	DCACA	• It attains increased aggregate throughput. • It minimizes the average packet round-trip time.	• However, it attains the congestion-aware channel assignment problem.
Gao *et al.* [29]	LACA	• It improves the packet delivery ratio. • It efficiently prioritizes the paths.	• The major limitation of this work is the global optimum.
Gálvez *et al.* [30]	JMR	• It minimizes spatial reuse. • It can attain maximum capacity.	• It needs to enhance the physical layer and CSMA.
Lin and Rasool [31]	Distributed Algorithms	• It effectively solves the problem of optimizations. • It attains faster solutions.	• It impacts the actual system performance.
Roh and Lee [32]	Generalized Benders decomposition approach	• It obtains optimal solutions. • It improves the network utility.	• Though, it cannot transmit with multiple links.

VIII. OVERVIEW OF THE THESIS

The Thesis of the work is organized, as shown below:

1) Chapter 1: Introduction

The chapter delivers basic information about the thesis background, which includes the definition of WMSNs and the architectures, the protocol stack in regards to Quality of Service assurances, benefits and applications of WMSNs followed by the research problem, objectives of the research work, and adopted Methodology. The chapter concludes with the organization of the thesis.

2) Chapter 2: Review of Literature

The chapter describes the existing methods of contemporary QoS routing protocols by considering diverse metrics. The main focus is mainly on QoS-based routing protocols and cross-layer-based QoS routing protocols.

3) Chapter 3: Data Traffic Classification and Optimal Route Selection

The chapter introduces a Machine Learning and Deep Learning prioritization-based packet classifier to segregate traffic based on precedence and a cross-layer optimizer model for optimal multiple disjoint route selection using a hybrid metaheuristic algorithm to ensure equitable resource consumption and distribution of multimedia traffic.

a) Research Problem

Solutions that incorporate Deep Learning (DL) models have an enormous social impact in terms of cost reduction, improvement of quality or service provision as well as development time. The cost required to develop and deploy DL models has proved to be much less than the traditional solutions in terms of QoS improvement in various domains including Future Wireless Communications (FWCs). Furthermore, DL solutions can be subjected to further performance tuning even after deployment to achieve the required quality without significant cost. DL models also allow for quick deployment of solutions which saves time on critical systems and real time solutions with minimum manpower requirement.

Low packet loss ratio, huge bandwidth demand, bounded delay, and acceptable jitter are some of the features of WMSNs in addition to WSNs issues and challenges. Furthermore, WMSNs routing has some challenges such as shortest path and optimal route selection, which are going to be resolved in the present research. In summary, the major contributions of this chapter are:

- To develop a word embedding mechanism and a Long short-term memory (LSTM)-based deep learning approach for priority-based packet classification considering various features of the data packets header, and therefore decide the priority of each packet.
- To introduce a cross-layer optimization-based optimal route selection to the prioritized packets using the proposed Butterfly-based Rider Optimization Algorithm (B-ROA) algorithm by considering the parameters such as distance, energy, delay, security, and packet drop ratio to derive the multi-objective function. Furthermore, evaluate the efficiency of the developed hybrid meta-heuristic algorithm against conventional heuristic algorithms by analyzing discrete performance metrics.

b) Proposed Architectural Model

The model aims to improve QoS in WMSNs by introducing a word embedding mechanism to extract packet semantics and an LSTM which is a specific Recurrent Neural Network (RNN) to define packet features and classify them according to transmission priority requirements followed by the selection of the optimal route. For performing the prioritized packet classification, gaining knowledge regarding the characteristics of data or packets in the network is essential.

The LSTM classifier is trained based on the discrete characteristics of packets such as queue in source, priority in source, packet lifetime, the maximum delay that packet can experience, packet transmission rate, data rate, and transmission rate by the source. The above-mentioned parameters are considered by the LSTM as inputs and priority classification is considered as the target. In this research problem, route selection is performed only after prioritization and classification of the packets to be transmitted. The proposd architecture of WMSNs with the optimal route selection with prioritization packet classification is shown in Figure 6.

c) Data Characteristics for Packet Priority Classification

There are various types of data attributes such as flow identity, queue in source, priority in source, packet lifetime, maximum delay packet can experience, actual delay, packet reception rate, data rate, transmission rate by the source, and protocol, which are used for packet priority classification.

- Queue in source: Data packets waiting to be transmitted.
- Priority in source: The packets need to be flagged at the source before transmission.
- Maximum delay packet can experience: Allowable delay for transmitting the data (flow duration).
- Delay: The time required to send the packets to the destination from the source (time to live).
- Packet received rate: Successfully delivered data packets.
- Data Rate: It is also termed as transmission speed. The number of packets transferred in a second.
- Transmission rate by source: It represents the total amount of data transferred from source to destination in the given amount of time.

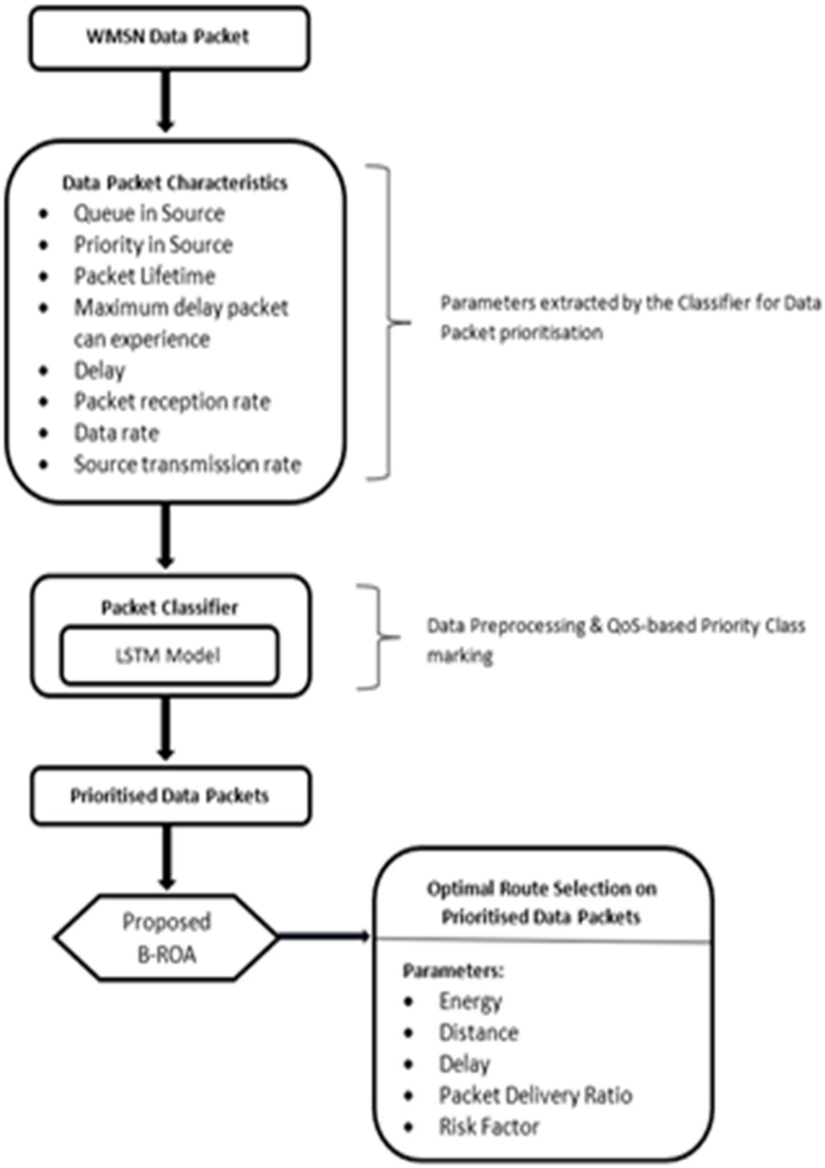


Figure 6 Packet Prioritisation and Optimal Route Selection

d) Results and Conclusion

The overall performance analysis of the proposed and the conventional algorithms by varying the number of nodes is shown in Fig. 7. In 7(a) we can observe that the proposed BROA achieved the shortest path. From Fig. 7 (b), the energy of the suggested B-ROA is more when compared to other models at any number of nodes. Fig. 7 (c). In 7(d), packet drop ratios for all algorithms is generally in the same range. In Fig. 7 (e), the risk factor of the suggested B-ROA is superior to BOA and ROA. Thus, it is confirmed that the improved B-ROA is acquiring the best results when compared to other algorithms.

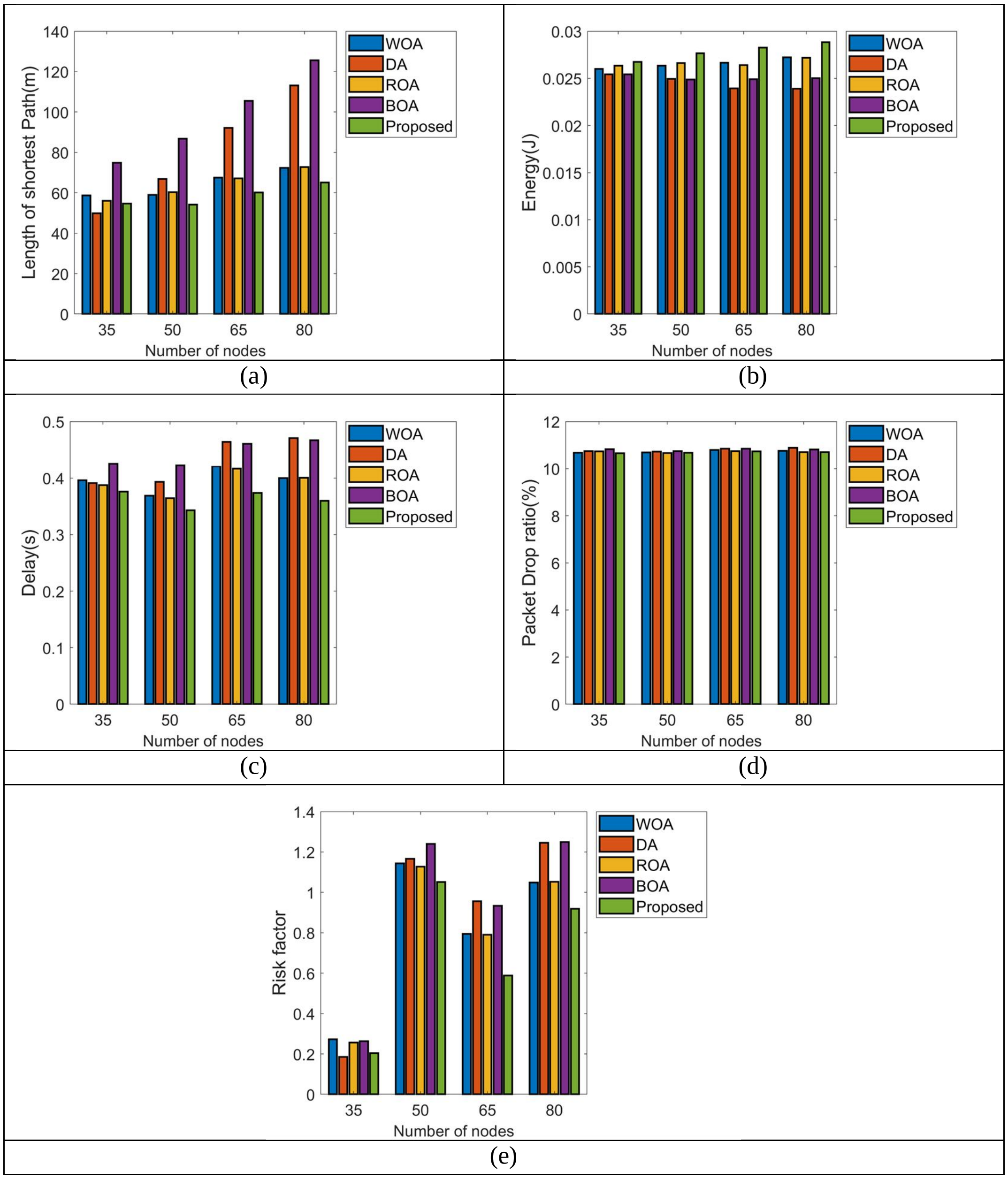


Figure 7 . Analysis of proposed and the meta-heuristic models for optimal route selection with prioritized packets in WMSN concerning (a) Length of the shortest path, (b) Energy, (c) Delay, (d) Packet drop ratio, (e) and Risk factor

4) Chapter 4: Data Flow Allocation and Channel Scheduling

The chapter introduces a modern channel scheduling algorithm for the effective allocation of low interference channels to communicating devices to reduce packet drop rate in real-time packet delivery and reduces the number of retransmissions and minimizes the energy expenditure at each device.

a) Research Problem

In wireless networks, an improved throughput capacity region can be achieved by providing multiple channels. However, such an approach inevitably brings the issue of solving the coupled channel assignment and scheduling problem. Some common challenges with the development of WMSNs need to be considered, which are high bandwidth demand, heterogeneous multimedia reliability, coverage area, in-network processing, application-specific QoS constraints, etc. Numerous methods are proposed in the channel scheduling approaches in wireless networks that have diverse features and challenges.

b) Methodology

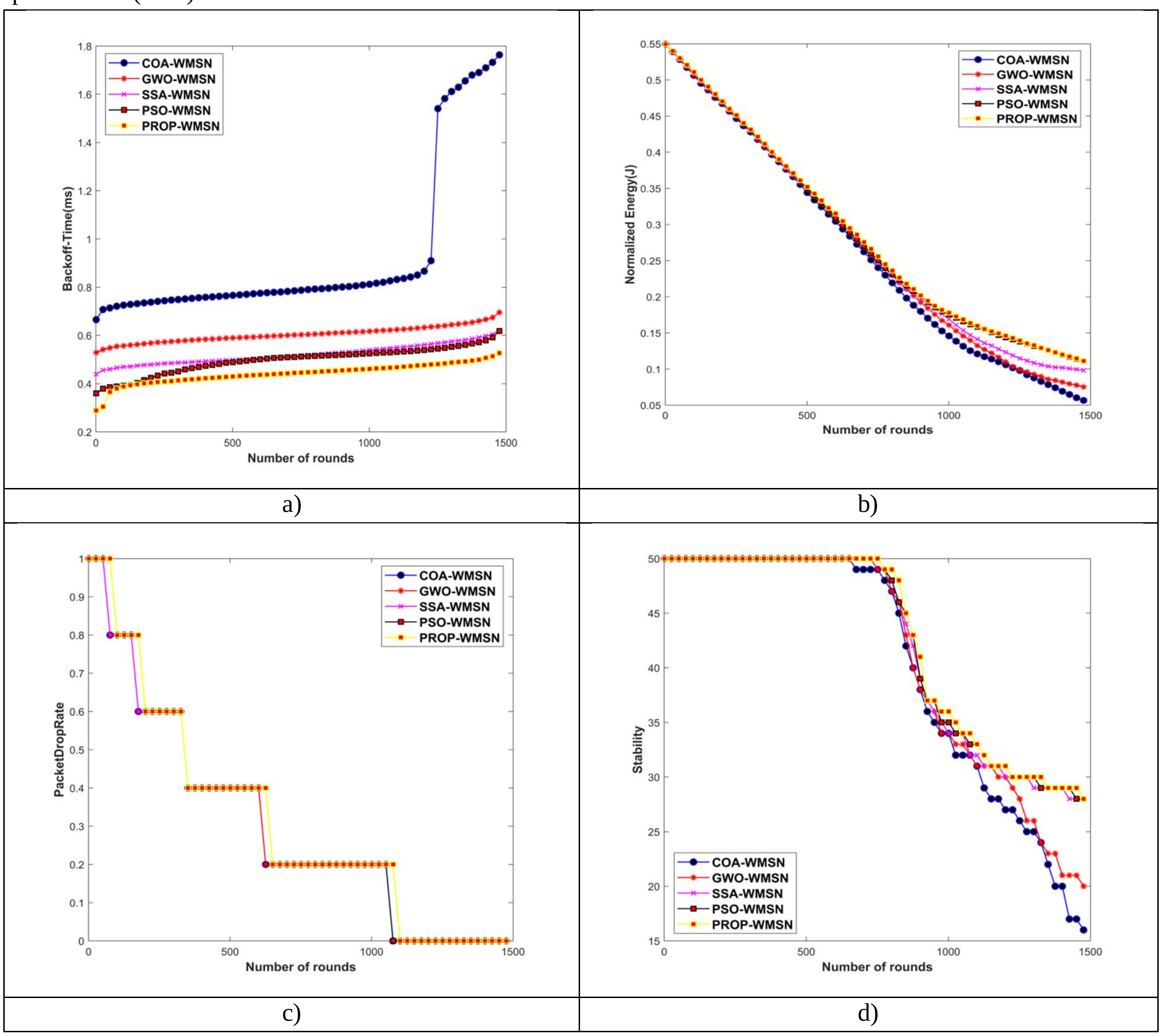
An intelligent channel assignment and channel scheduling algorithm on WMSN will be proposed. The proposed model will mainly cover two phases: one will be the data flow allocation, and the other will be the Channel Assignment and Scheduling. In the first phase, data flow allocation will be performed by the Adaptive Deep Neural Network (ADNN), which will be done based on the available channel queues. Further, the channel Assignment and Scheduling will be accomplished by the improved Sail Fish Optimization (SFO) [33]. This optimal channel Assignment and Scheduling will be performed by an objective model considering the back-off time, stability, packet drop rate, and throughput through theoretical analysis and simulation experiments on WMSNs.

In multichannel scenarios, it is truly difficult to guarantee the throughput performance (characterized by capacity region) in a distributed manner. The objective of this issue is to maintain the system stable with finite queue lengths inside a specific capacity region. The implementation of scheduling algorithms should be combined with data flow allocation and channel assignment because of channel diversity.

c) Results

- *Comparative Analysis for Channel 1*

The comparative analysis of the WMSN model for Channel 1 is illustrated in Figure 8. The result obtained by the comparative model at the 1500th iteration is provided in Table 5. For the comparative analysis, the existing models such as Coyote Optimization Algorithm (COA)-WMSN, Grey Wolf Optimization (GWO)-WMSN, Sparrow Search Algorithm (SSA)-WMSN, and Particle Swarm Optimization (PSO)-WMSN were used as the benchmark.



a) b) c) d)

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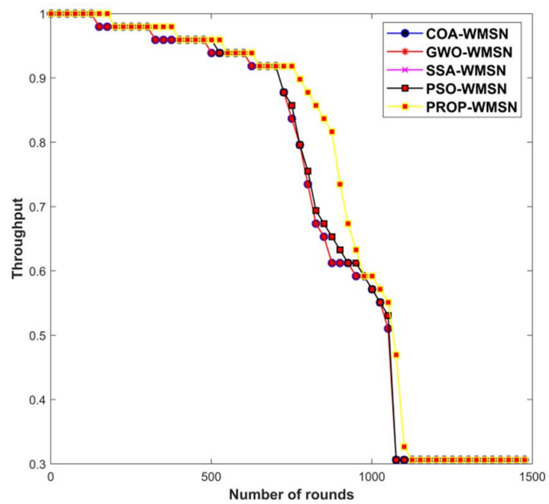

e)

Figure 8 Comparative analysis for channel 1 in terms of a) Back Off-Time, b) Normalized energy, c) Packet Drop Rate, d) Stability and e) Throughput.

Table 5: Comparative results of WMSM for Channel 1

Methods	Back off-Time (ms)	Normalized energy (J)	Packet drop rate (At var 36)	Stability(At var 60)	Throughput (At var 60)
GOA-WMSN	1.87962	0.052689	0.2	16	0.27551
GWO-WMSN	1.16469	0.073883	0.2	20	0.27551
SSA-WMSN	0.99619	0.098002	0.2	28	0.306122
PSO-WMSN	0.831425	0.108298	0.2	28	0.306122
Proposed WMSN	0.653935	0.108793	0.2	28	0.306122

The table demonstrates that the proposed model attains quite satisfactory performance in Channel 1 conditions in terms of back-off-time, normalized energy, packet drop rate, stability, and throughput. This performance is attributable to the data being trained first by the Adaptive Ensemble Deep Neural Network, after which the scheduling is carried out via Improved Sail Fish Optimization. It is therefore recommended that this approach be used in applications that mainly involve WMSNs. These are mostly real-time and do not require any delay. It automatically offers great efficiency in non-real-time traffic.

5) Chapter 5: Malware Detection Using Machine Learning Algorithms

The chapter presents a lightweight security mechanism suitable for malware detection in Cross-Layer based multipath routing protocol over Wireless Multimedia Sensor Networks.

a) Research Problem

Deep learning algorithms have been used in the classification of malware. Traditional artificial intelligence algorithms, especially gadget learning, are not able to detect all new and complicated malware variants. To correctly fight new malware variants, novel strategies that might be exceptional from conventional strategies have to be used. The experimental consequences display that the proposed approach can correctly classify malware with excessive accuracy, outperforming contemporary strategies advanced by different researchers. On a massive scale domain, the proposed approach is efficient and decreases function space.

b) Methodology

A dataset consisting of data with numerous types of malware along with the characteristics undergoes a lot of methods to identify the best algorithm that can be used for malware detection. These methods are represented in the flowchart in Figure 9.

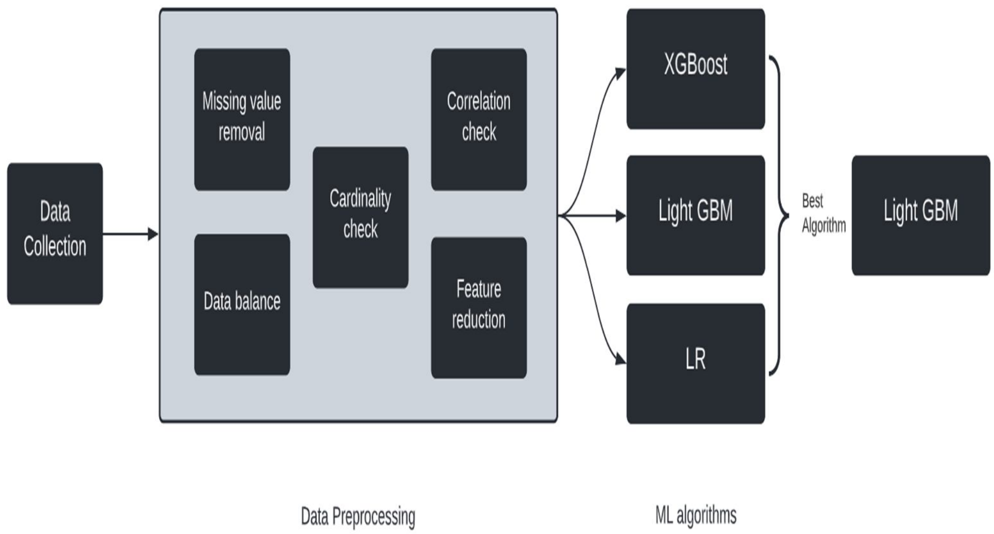

Figure 9 Workflow of the Study

c) Results

The results obtained from the models are represented in the graph on Figure 10.

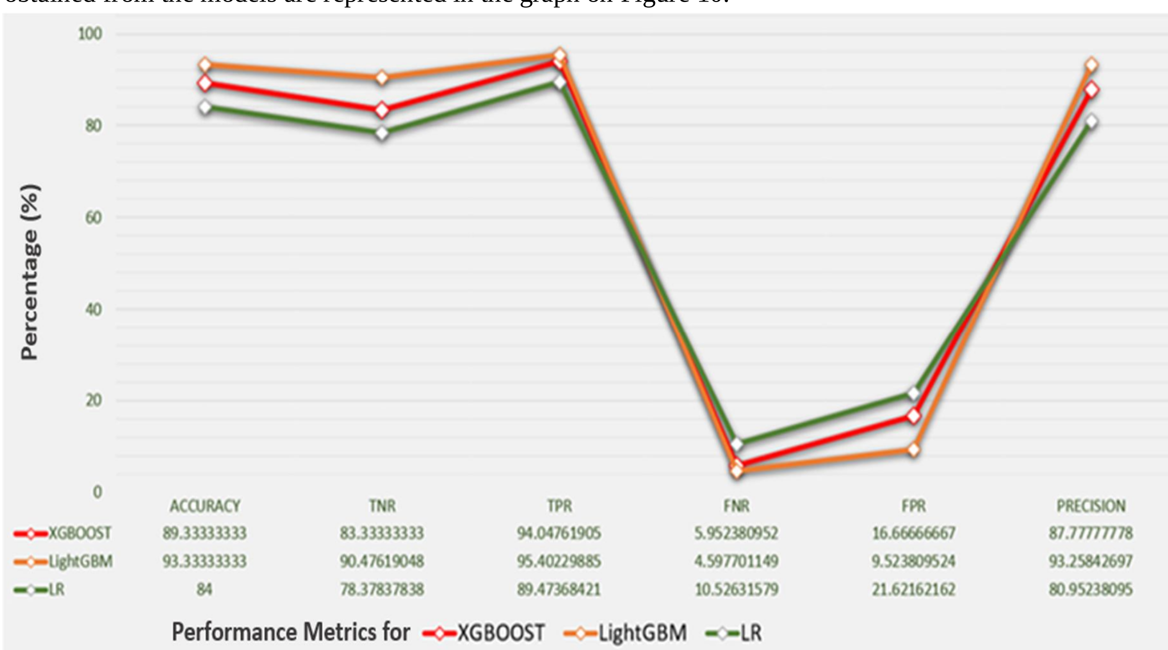

Figure 10 Performance of all Algorithms

The XGBoost, LightGBM, and Logistic Regression algorithms were used to construct three different machine learning models that were trained and validated on Kaggle's Malware dataset. A graph was used to compare the performance of all three algorithms using the test.csv dataset provided on the same platform. Based on our findings, the LightGBM algorithm is best suited for this use case of malware detection and classification. LightGBM exhibited superior performance in terms of precision, true positive rate, false positive rate, true negative rate, and false negative rate over the other two algorithms. Therefore, this model can be deployed on a website or software application to detect malware and classify it in real-time. To improve results, hybrid approaches can also be considered.

6) Chapter 6: Conclusions and Future Direction

This chapter includes the concluding lines of the thesis and brief notes on the scope and application and future extensions of the work are discussed.

a) Conclusion

The study was set with five design objectives to develop a *Cross-Layer Based QoS Aware Load-balancing Multipath Routing Protocol over Wireless Multimedia Sensor Networks*. The first objective was the study and analysis of QoS and Cross-layer-based routing algorithms for WMSNs. Secondly, designing and developing a Deep Learning prioritization-based packet classifier to segregate traffic based on precedence. The third objective was to design and develop a cross-layer optimizer model for optimal multiple disjoint route selection using Machine Learning techniques to ensure equitable resource consumption and distribution of multimedia traffic. Objective four was to develop a modern channel-scheduling algorithm for effectively allocating low interference channels to communicating devices to reduce packet drop rate in real-time packet delivery. Lastly, a security mechanism for Cross-Layer based multipath routing protocol over Wireless Multimedia Sensor Networks. All the objectives were successfully met and research papers were published for each objective to highlight the results, analysis, conclusions and future scope.

b) Future Scope

The suggested future scope of the present research work is listed below.

- Packet header information was used for the priority classification. The usage of header information sometimes gives the same priority to packets from the same application protocol even though they might not necessarily have the same priority. In future, if datasets containing payload as a feature can be acquired, analysis including the actual payload as part of the features will reduce these misclassifications.
- The proposed data flow allocation, channel assignment and scheduling algorithm employs random access and back-off time techniques. The maximal matching process can be experimented with using deep learning techniques.
- Malware detection and classification can be tested on real-time threats and evaluate real-time security concerns.
- Additionally, all the designed solutions should be combined into a single protocol and tested on real-time traffic.

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