QoS Strategies for Wireless Multimedia Sensor Networks in the Context of IoT

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Abstract. Wireless multimedia sensor network (WMSN) can collect not only scalar sensor data, but also multi-dimensional sensor data. It is regarded as the foundation of IoT (Internet of Things). A lot of Quality of Service (QoS) indicators (e.g. energy-efficiency, real-time, reliability and so on) are used to evaluate data collection. This paper presents different QoS strategies for WMSNs in the Context of IoT from the network layer, transport layer and cross-layer. As for QoS Strategies at the network layer, many routing protocols are introduced, and their characteristics are compared. This paper also discusses congestion control protocols, error recovery protocols and priority-based protocols at transport layer. Cross-layer QoS strategies play an important role for system optimization. Three cross-layer strategies are discussed. For each layer's strategies, the challenges and opportunities are compared. Finally, the potential future directions of QoS strategies are discussed for research and application.

Keywords: Wireless multimedia sensor networks · Internet of Things · Internet of Multimedia Things · Media access control · Quality of service · Cross-layer · Time division multiple access · Code division multiple access

1 Introduction

As the monitoring environment of Wireless Sensor Networks (WSNs) becomes more complex, scalar data such as temperature, location, pressure, cannot cope with the demand for accurate environmental monitoring which necessitates support for multimedia, so as to improve information gathering and environmental monitoring. Hardware items such as cameras, microphones, S.D cards, memory cards, smart phones, have significantly reduced in cost due to the recent development in technology making them drastically increase in application; wireless communication capabilities have also increased due to the improvement in bandwidth capabilities [1]. Subsequently, WSNs are evolving into WMSNs which have capacity to transmit instantaneously, store, compare and combine data that originates out of heterogenous origins.

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WMSNs are networks for wireless embedded devices which can enable users to retrieve multimedia info out of their surroundings [2]. A WMSN may interact with its physical environment through observation using multiple media and performance of internet content editing [2]. WMSNs have drawn attention from many researchers and scholars because of the high number of low-cost smart phones, cheap imaging sensors, digital cameras, microphones, among other gadgets, which can be used to capture multimedia content from the fields with ease coupled with the enormous available devices for storage including Hard discs, memory cards, S.D cards, DVDs, CD-ROMs among others. The WMSNs have a number of applications including but not limited to usage in surveillance and environmental monitoring systems, traffic monitoring and target tracking, intrusion detection systems, telemedicine for advanced health care.

Advantages of WMSNs include [3]: (i) Enlargement of the scenery making it better if many cameras are used, (ii) Enhancement of the view through provision of an enormous Field of View in watching an event (iii) Provision of many points of view of a similar incident. The FOV for a fixed camera limits coverage. But despite the above advantages, there is a problem of too much network traffic that subsequently consumes more energy of the network.

1.1 Architecture of WMSN

The WMSN architecture is divided into three categories depending on application characteristics:

(a) single-tier flat architecture – comprising homogeneous multimedia nodes that can carry out any function to the sink using multihop route;
(b) single-tier clustered architecture – nodes are heterogeneous passing sensed information to the cluster head for processing; and
(c) a multi-tier architecture – also heterogeneous and does object sensing, target capturing and target tracking.

Figure 1 is a typical example of a WMSN architecture.

WMSNs have been widely deployed to provide infrastructural support and sensor accessibility making them handy for IoMT transmission [4]. Most of the applications in IoMT e.g., wearable devices make use of the WMSN technology.

1.2 The Internet of Things (IoT)

IoT envisages a scenario where all smart objects are linked to one network – the Internet. The IoT has today gained more popularity and recognition than ever before. Most of the recent applications that are rapidly evolving are in the IoMT category with at least four distinct features namely [5]: (i) video-oriented apps with incoming streams (ii) video-oriented apps with outbound streams; (iii) speedy mobile sensors, e.g., sensors on automobiles, aero planes, etc.; and, (iv) many distributed endpoints having the above three features, e.g., stationary traffic monitoring/security cameras in a city, high-density ring-of-steel surveillance applications [5]. IoMT has however not yet got a lot of momentum in the research fraternity leaving a lot yet to be done.

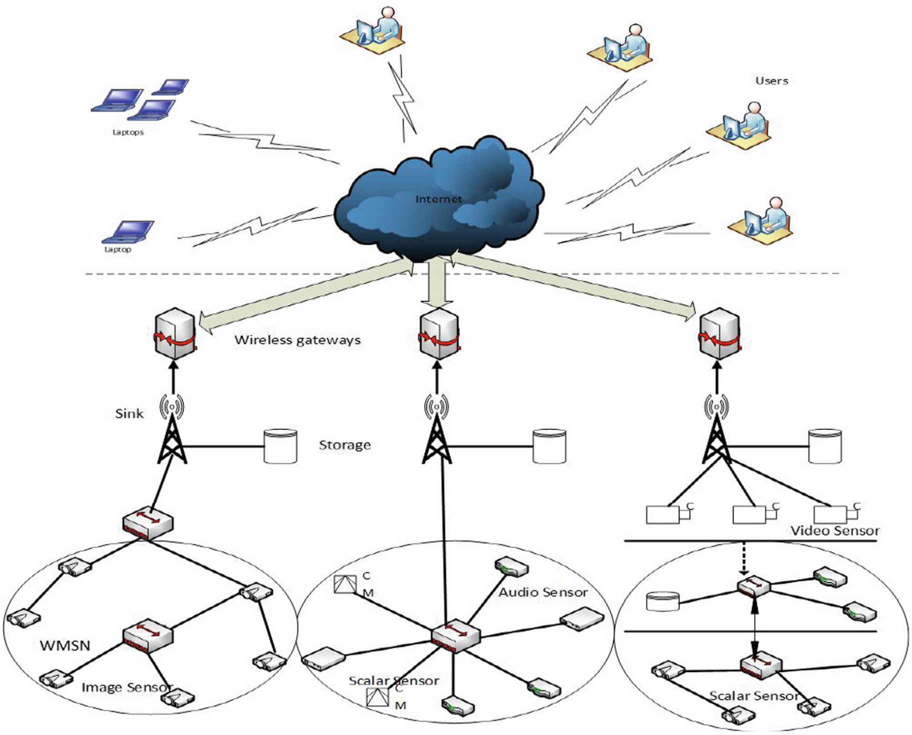

Fig. 1. Architecture of a WMSN

Many applications based on IoTs and IoMTs are recently emerging and have attracted a lot of attention [5]. They include among others, Smart Cities, Smart vehicles, homes, factories, (Fig. 2), GPS tracker devices, [5, 6] attracting a number of innovations in the Americas, Asia, Europe and elsewhere.

Figure 2 is a typical architecture of the IoT that can be enabled by RFID, optical tags and QR codes, Bluetooth low energy, Wi-Fi direct, LTE-Advanced, etc. A number of researchers on IoT focus on better efficiency on how to handle enormous real-time info but hardly address the issues with multimedia communication [7, 8]. The desire to make smart devices able to observe, sense and understand the world through multimedia data efficiently, moves the research direction from traditional IoT to multimedia-based IoT [9, 10] hence emerging of the field of Internet of Multimedia Things (IoMT).

IoMT is "*the IoT-based paradigm that enables objects to connect and exchange structured and unstructured data with one another to enable multimedia-based services and applications*" [3]. To attain a favorable QoS during transmission of multimedia data, the devices need high processing power and memory as well as a high amount of bandwidth compared to scalar data transmission in a typical IoT environment. A number of commercial and military applications come up due to introduction of multimedia objects in transmission of data such as remote patient monitoring in telehealth and telemedicine, traffic management systems enhanced by smart video cameras,

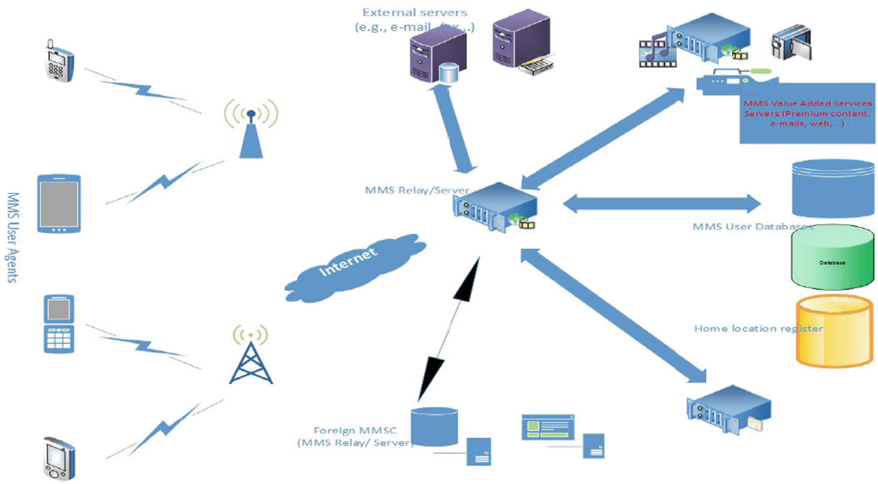

Fig. 2. Example of multimedia service architecture in the context of IoT.

among others [4]. This thus calls for an upgrade in functionality of IoT systems to IoMT. IoT compares with IoMT in some ways including [7]:

i. IoT has standardized communication protocols whereas IoMT's protocols are non-standardized.
ii. In terms of QoS, IoT requires low bandwidth whereas IoMT requires higher bandwidth.
iii. IoMT transmits heterogenous multimedia data whereas IoT data transmitted has limited heterogeneity.
iv. IoT sensor nodes consume less energy than IoMT sensor nodes.
v. IoT devices are deployed in application-dependent RFID tags but IoMT are in video and audio sensors.
vi. In terms of service composition, IoMT has no available specialized middleware whereas IoT has specialized Service Oriented Architecture-based and event-based middleware.

We discuss a number of strategies for QoS in WSNs and WMSNs in IoT context. **Quality of service (QoS)** may refer to the capacity of a network to achieve maximum bandwidth for the end-users and manage the performance metrics of a network such as delay, bit rate, jitter, throughput, uptime, etc. To ensure a high QoS in IoMT applications, high level multimedia supported routing is becoming significant among researchers in the field of WMSNs on routing protocols, algorithms and techniques basing on network architectures and other application requirements to ensure best-effort services and energy efficiency. For high QoS and a reliable route, transmission of multimedia traffic in WMSNs will depend on the routing protocol employed [1]. The resource efficiency includes both effective bandwidth utilization, and lowest energy consumption possible hence requiring many special considerations when developing routing protocols.

This paper mainly discusses QoS strategies for WMSNs in the Context of IoT from network, transport and cross-layer in each of which we discuss different types of routing protocols for both WSNs and WMSNs and thereafter the challenges and opportunities involved therein. As for QoS Strategies at the network layer, we discuss many protocols and their characteristics compared. We also discuss congestion control protocols, error recovery protocols and priority-based protocols at the transport layer.

The rest of the paper flows as given: In Sect. 2, we discuss the QoS Strategies at the Network Layer. In Sect. 3, we discuss the QoS Strategies at Transport Layer. In Sect. 4, we review Cross-Layer QoS Strategies, in Sect. 5, we give some future research directions and in Sect. 6, we conclude the paper.

2 QoS Strategies at the Network Layer

2.1 Network Layer Protocols for WSNs

Data Centric Routing Protocols

Since nodes do not have global identification numbers, they employ DCRPs to control data redundancy. Unlike traditional address-centric protocols, in data centric routing, a sink requests for data from the nearest node which subsequently sends the requested data if available. So, data is from the source node to sink [11].

SPIN (Sensor Protocol for Information via Negotiation)

This protocol is appropriate for small and medium size WSNs making it more effective with increased energy in a particular environment. SPIN performs better than other protocols for energy and bandwidth consumption [12]. It exchanges its metadata among sensors using an advanced advertisement mechanism in which nodes advertise to neighbors newly available data and those that need it send a request for the same. The messages used include: **ADV message** which allows sensor nodes publicize certain data; **REQ message:** for requesting particular data; **DATA message:** for carrying real data [13]. SPIN is advantageous over others in that a node needs to only know the next-hop neighbors, and no useless info passing making it highly efficient [11].

SPIN-1

This "*is a data centric, flat routing, source initiated and data aggregation protocol*" according to [14] that uses the three-way handshake to establish a connection with the following assumptions [11]:

i. Nodes have the same initial energy with symmetrical link;
ii. Other nodes do not interfere when two nodes are communicating,
iii. No power constraints and nodes remain stationary;
iv. Signals use the same amount of energy,
v. Nodes are strategically located on path to sink to receive packets transmitted.

SPIN and SPIN-1 differ in the sense that in SPIN, if a node already had data, it makes no further response.

M-SPIN (Modified - SPIN)
This protocol transmits information only to the sink node other than the entire network. Fewer packets are transmitted thus saving a lot of energy. Energy is consumed during data sensing, processing, transmission and reception of the packets from neighboring nodes, hence these should be controlled to save energy [11]. This protocol is a good choice therefore in emergency response apps like security and telemedicine responses.

Flooding and Gossiping
These mechanisms don't use routing algorithms and topology maintenance during data transmission as discussed:

Flooding: Before they reach the destination, the sensor node continues to send packets to all its neighbors. It can easily be implemented though it's affected by implosion due to replica messages. In addition to that, there also exists the overlap problem whereby **multiple** nodes sense an event as a result of overlapping of different coverage regions leading to energy wastage and reduced network lifetime due to the many redundant transmissions [12].

Gossiping: A random neighbor receives a packet from a node that selects other neighbors to whom it sends the data. It avoids implosion though this delays data transmission among nodes [15].

Directed Diffusion
Data is transmitted using a data-naming scheme. Any node will seek the information it needs from its neighbors by using broadcast messages to all. Attribute pairs are used by on-demand basis to query the sensor using queries that are created by use of attribute value pairs like object name, interval, duration, geographical area etc. Matching data to queries requires extra overhead hence the protocol is not good for rapid response applications [12]. Other Data-centric routing protocols include Energy-aware routing, Rumor routing, constrained anisotropic diffusion routing, etc.

Hierarchical Routing Protocols

Hierarchical Routing
This is built on hierarchical addressing whereby routers are hierarchically arranged e.g., in a corporate intranet. In this architecture, high-energy nodes may process and forward information whereas those with lower energy can sense near target. Hierarchical routing can efficiently reduce the energy consumed in a cluster and reduce the messages transmitted to Base Station through data aggregation [16]. We discuss some hierarchical routing protocols.

Low Energy Adaptive Clustering Hierarchy Protocol (LEACH)
To communicate between nodes, it uses adaptive clustering and for timeline operation, it uses TDMA scheme to reduce collisions. Some nodes are randomly selected to act as Cluster Heads (CH), which role is rotational so as to manage the energy load in participating sensor nodes. This is done in order to makes use of local CHs as routers to the sink and to form clusters depending on the received signal strength. LEACH

operates in 2 phases [16]; setup phase and steady state phase. Clusters in the setup phase, are arranged to randomly select the CHs according to Eq. 1 below:

$$T(n) = \begin{cases} \frac{p}{1-p\left(r mod \frac{1}{p}\right)}, & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

where *T(n)* = threshold value, *P* = probability that a given node is selected as CH, *r* = current round number, *n* = given node, and *G* = set of nodes that haven't acted as CHs in previous *1/P* rounds.

A node randomly picks a digit from 0 to 1, which in case it's below *T(n)*, it becomes CH, i.e., the node with the highest energy becomes CH, invites nodes in its cluster to join and then assigns TDMA scheme to those that send acknowledgements [16, 17]. Common nodes receive information from all nodes and wait for a message from the CH to which it sends a joining request. After joining the cluster, all nodes wait for TDMA slots from the CH. The process becomes steady for one round. Some characteristics and drawbacks of LEACH include [16, 18]:

Characteristics:

i. It randomly rotates the cluster heads for stable consumption of energy,
ii. Sensors are designed with synchronized clocks for determining the new cycle beginning,
iii. Sensors need not know the info about location.

Drawbacks:

i. It's not applicable in big networks because it makes use of single-hop routing.
ii. Dynamic clustering leads to additional overhead, reducing gain in energy.
iii. Since CHs are elected randomly, they may all be concentrated in the same area.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

This protocol is an improved version of LEACH. Nodes are assembled in form of a chain as opposed to a cluster in LEACH. The farthest node sends its data via its neighbor forming a chain in which the last node is the leading node that transmits the information to the BS (Fig. 3) which saves energy since each station only communicates with its neighboring station and thus improves the lifetime of the network. In this protocol, nodes use signal strength in measuring the distance to the neighboring nodes to locate the nearest one, alters signal strength such that 1 node only is heard [16]. The protocol uses two ways to conserve energy [16]:

i. The head node at most receives two data messages.
ii. The data is transmitted to the next-hop neighbor in a very short distance meaning that energy is conserved in this protocol and the head node has few data messages.

Significant features of PEGASIS:

i. It employs only one node for transmission to the BS thereby avoiding cluster formation.
ii. Using collaboration, it enhances the lifetime for the participating nodes.
iii. It minimizes energy for data transmission by uniformly distributing the power draining across the nodes.

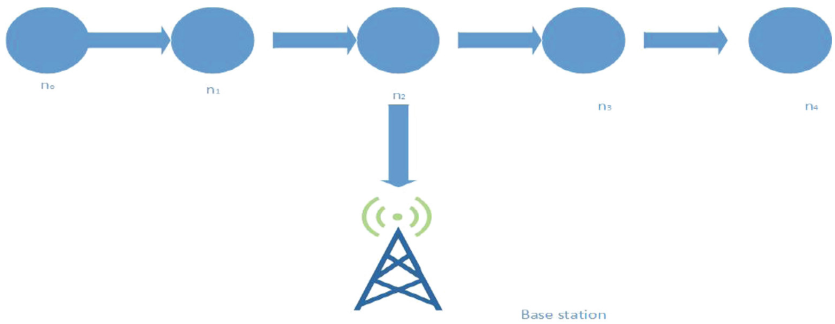

Fig. 3. Chaining in PEGASIS protocol.

Hierarchical-PEGASIS

This was developed to reduce the delay in packets during transmission to BS.

Other protocols here include Hybrid, Energy-Efficient Distributed Clustering (HEED) [16], Energy-aware routing protocol for cluster-based sensor networks (EARP) [16], Threshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN): [19], Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN) [19].

Location-Based Routing Protocols

Here we refer to sensor nodes basing on location and use signal strength for incoming signal to estimate distance between adjacent nodes.

Geographic Adaptive Fidelity (GAF)

This is an energy-aware routing protocol adopted for Wireless Networks having been originally developed for MANETs. GAF saves energy by turning off redundant nodes in the network while at the same time preserving routing fidelity. A virtual grid is formed and the network is subdivided into fixed zones with each having one node awake for purposes of monitoring the network and reporting to the BS while others are in sleep mode to save energy [19]. Nodes are connected to the virtual-grid points through GPS-indicated location information. GAF comprises three states namely; (i) active state, (ii) sleeping state and (iii) discovery state. In sleeping state, energy is saved by the sensor turning off its radio; then in discovery state, each sensor determines its neighbors in its grid; and in active state, the sensor reflects participation in routing [19]. The time spent in each state depends on needs and sensor mobility. Much as this protocol is location-based, it may also be categorized hierarchical [20].

***Geographic and Energy Aware Routing (GEAR) Protocol* [19]**

This protocol employs an energy-based geographical neighbor selection to direct the packets to the destination. It only sends interests to a certain region of the whole network so as to limit the interests in directed diffusion implying more efficient utilization of power. For nodes to reach the destination, they go thru the neighbors and have got to keep both estimated and learning costs of doing so. The estimated cost is comprised of residual energy as well as the distance from source to destination whereas the learned cost is simply an increment of the estimated cost making up for any possible network routing holes. There are 2 phases:

i. Forwarding packets to target region: Here station receives data packet and looks for next hop creating a hole in case they are all further than the station itself.
ii. Forwarding packets within region: A data packet already in the region may be diffused there by recursive geographic forwarding or restricted flooding [19].

The Greedy Other Adaptive Face Routing (GOAFR) Protocol

This protocol is a combination of greedy and face routing. It selects the nearest neighbor to the next routing node but may get stuck at some local minimum in case there isn't a neighbor nearer to the node compared to the current one [21]. Average-case performance can be enhanced. GOAFR performs better than GPSR and AFR algorithms [19].

Other location-based routing protocols include: Coordination of Power Saving with Routing, Trajectory-Based Forwarding (TBF), Bounded Voronoi Greedy Forwarding (BVGF), Geographic Random Forwarding (GeRaF), Minimum Energy Communication Network (MECN), Small Minimum-Energy Communication Network (SMECN) [20]. Table 1 summarizes some protocols with their advantages and disadvantages.

Table 1. Some advantages & disadvantages of location based routing protocols.

S. No	Protocol	Advantage(s)	Disadvantage(s)
1	Geographic Adaptive Fidelity (GAF)	Optimizes WSN performance Good scalability Maximizes network lifetime Conserves energy	Limited mobility Limited power management Ignores data transmission QoS
2	Geographic and Energy Aware Routing (GEAR)	Reduces energy consumption Increases the network lifetime	Not so scalable and mobile Power management issues High overhead and no QoS
3	Coordination of Power Saving with Routing	Less overhead Supports data aggregation Low node energy consumption	No QoS Limited scalability
4	Trajectory Based Forwarding (TBF)	Increases reliability and security Increases network management	High overhead

Negotiation-Based Routing Protocols

They remove idle data transmission by negotiation using data descriptors and communication decisions can be made based on accessible resources [19]. The SPIN family of routing protocols are one major example of such protocols since they are made to disseminate data from sensor to sensor being potential Base Stations. Other negotiation-based, SPIN protocols are discussed:

SPIN-PP

Uses a 3-way handshake (ADV–REQ–DATA) and is designed point-to-point transmission media networks where two stations can directly communicate without interfering with other stations. A node advertises new data to be transmitted through an ADV message sent to the neighbors (ADV stage). If the contacted node has not received the data, it sends REQ message to sender requesting for missing data (REQ stage). The protocol ends with the initiator responding by sending the missing data (DATA stage) [13].

SPIN-EC

This too uses a three-stage handshake but only when the energy is enough to complete the process, otherwise it doesn't take part in protocol [13]. It thus adds an energy-conservation heuristic to SPIN-PP.

SPIN-BC

It also uses a three-way handshake. Designed for broadcast media, network nodes share one single channel for communication, so all nodes will receive any packet broadcast over the channel and will first listen to ensure the channel is free before transmitting [13].

***SPIN-RL* [13]**

This a more reliable version of SPIN-BC designed for efficient data dissemination through a broadcast network, though it may suffer data losses. It includes some adjustments to SPIN-BC to achieve reliability.

Multipath-Based Routing Protocols

Developed to protect against route failure by providing alternative paths in case the primary route fails. During route rediscovery, fault tolerance and reduction of routing frequency can be done via alternate path routing [22].

Sensor-Disjoint Multipath Routing

A simple technique in which a few alternate paths are constructed from node to sink to be used if primary path fails whereby, the sink and sensor nodes determine the best neighboring node where there is less delay and this goes on until the primary path is established after which the process is repeated by the sink which sends out the reinforcement path to the next preferable sensor node [23]. The technique provides fault tolerance by identifying alternate disjoint paths. However, the alternate paths are less efficient in terms of energy since they are longer.

REAR: Reliable Energy Aware Routing Protocol

When establishing routes, this multi-path routing protocol considers sensor nodes' residual energy capacity and also supports the DATA-ACK oriented packet transmission thus enabling sensor nodes to confirm if data transmission to other sensor nodes was successful [24].

Braided Multipath Routing

Alternate routes to the primary path are constructed but may not be disjoint. It begins with computation of the primary path and on all its nodes the most optimal path from sensor to sink is computed. Alternative paths are on or close to this path saving more energy compared to other mutually disjoint paths. But the method lowers the fault-tolerance since there may be a single point of failure for nodes that are shared by many paths [23].

Multi-constrained QoS Multipath Routing (MCMP)

Delivers packets to sink nodes by using intertwined routes. This is done in terms of reliability and delay [22]. MCMP aims at utilizing the multiple paths to enhance network performance at low energy cost. But information is routed over the shortest path to satisfy QoS, leading to more energy consumption at times [25].

N-to-1 Multipath Discovery

It uses flooding to discover many node-disjoint routes from the sensor to sink [26]. It has a mechanism that comprises two phases, i.e., branch aware flooding and multipath extension of flooding in both of which it broadcasts the same messages flooded in the network with this message format {mtype, mid, nid, bid, cst, path}, whereby mtype = message type, mid = sequence number of the current routing update, nid = Sender ID, bid = branch ID, path = sequence of node visited by this message, and cst = cost of the path. When a node gets this message, it appends its ID to the path, updating its cost and then broadcasts to its neighbors an update of the message. The protocol generates multiple node-disjoint paths for all sensors [23] but disregards node-energy level.

Other protocols include: Reliable Information Forwarding using Multiple Paths in Sensor Networks, HDMRP; An Efficient Fault-Tolerant Multipath Routing, Multipath Multispeed Protocol (MMSPEED), Energy-Efficient and QoS-based Multipath Routing Protocol (EQSR), Delay-Constrained High-Throughput Protocol for Multipath Transmission (DCHT).

Mobility-Based Routing Protocols

Data Mules (Mobile Ubiquitous LAN Extensions)

MULES has a 3-layer architecture [27] with the bottom layer having stationary WSN nodes for sensing the environment, middle layer having mobile units (MULEs) moving around the sensor field to collect information from the nodes to nearby access points; the upper layer has got units connected to the Internet and connects to the central data warehouse via the network access points which subsequently synchronizes the collected data, identifies redundant data and acknowledges data sent by MULEs for transmission reliability [28]. It achieves affordable connectivity in small WSNs, saves power due to short-range data transfer and requires less infrastructure. But it has a high latency, and limited mobility due to change in terrain which might cause unexpected failures [27].

Scalable Energy-Efficient Asynchronous Dissemination (SEAD)
This is a location aware protocol suitable for saving energy and minimizing delay. It mainly has three steps, namely: (i) dissemination tree construction (ii) data dissemination (iii) link maintenance to mobile sink nodes. The working assumption here is that sensor nodes know their physical positions [27]. It operates at a low cost yet distributes most of its data successfully though there is a problem of delay in delivering packets to the sink [28].

Tree-Based Efficient Data Dissemination Protocol
It creates a tree with a root node in the network that has a relay node for data transfer between 2 nearby nodes and a unidirectional non-relay node both of which can work as gateways. This gateway changes when the sink is out of range [27]. The protocol gives very high throughput and low overhead for control packets. Nevertheless, tree construction and node organization require a lot of memory.

Mobility Based Clustering Protocol (MBC)
MBC threshold is changed to include residual energy and mobility factor (Eq. 2) and a new threshold is as given

$$T(n)_{new} = \frac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} * \left(\frac{En_{current}}{E_{\max}}\right)\left(\frac{v_{\max} - vn_{current}}{v_{\max}}\right), \forall n \in G \tag{2}$$

where $E_{n_{current}}$ is the current energy, E_{max} is the initial energy, $v_{n_{current}}$ is the current speed and v_{max} is the maximum node speed. This protocol supports longer lifetime for the network and is efficient in energy consumption. Packets are also well delivered at a relatively high frequency and the stability of the connection is reliable. For this protocol, the following are assumed [29]:

i. A symmetric model of the receiver.
ii. All WSNs are standardized and synchronized with time.
iii. Each WSN is aware of its position and speed.
iv. The Base Station is static.
v. Packet transmission time for each WSN can be approximated.

2.2 Network Layer Protocols for WMSNs

Ant-Based Service-Aware Routing Algorithm (ASAR)
ASAR is a QoS-based routing protocol designed for WMSNs. It has a cluster-head that is responsible for moving different data classes as well as the sink node [30]. For network optimization and algorithmic speedy convergence in ASAR, the sink's

pheromone values are quantified decreasing the control message sending frequency. In most metrics, ASAR is significantly more advantageous over Dijkstra and Directional Diffusion (DD) though it has a higher delay and packet loss rate [31].

Two-Phase Greedy Forwarding (TPGF)
This geographic routing protocol is designed for WMSNs to support multipath broadcast. This it does by executing the algorithm several times so as to discover the remaining on-demand routes available in the network for resource maximization when many more routes are discovered [32]. Nodes are assumed to know their position co-ordinates and those of the base station. Discovery of the route happens in phase one of the protocol through greedy forwarding and/or step back and mark steps, while route optimization of the discovered route happens in phase two through label-based optimization method [31]. TPGF attains a more optimal (shorter) average path length than GPSR [33].

Multimedia Enabled Improved Adaptive Routing (M-IAR) Protocol
This protocol is designed to handle multimedia content by regulating delay and jitter [34]. It assumes nodes know their locations and those of the close neighbors and sink and can thus discover the shortest path with fewer nodes from source to sink, thus exploiting the physical position of WSN nodes, the reason it's called a flat multi-hop routing protocol [31]. The protocol employs the forward ant for source node and backward ant for the sink [34].

Multimedia-aware Multipath Multi-speed (Multimedia-aware MMSPEED)
It's a newer version of MMSPEED protocol where the closest optimal route is earmarked for I-packets whereas the marginal routes are for P-frames [31]. MMSPEED [36], also an extension for SPEED protocol [37] was developed for WSN and is handy for video transmissions though MMSPEED is not good for multimedia traffic like advanced video frame rate and packet's information reliance [35].

2.3 Challenges and Opportunities

Some of the challenges include [29]:

i. There is a decline in quality of the connection leading to more possible dropped packets and subsequently increasing packet retransmission rate.
ii. Flexibility brings regular variations in the routes, resulting in considerable delay in the delivery of packets.
iii. A mobile node on joining a network takes some time to begin data transmission since its neighbors need to first discover its presence before deciding on collaboration with it, which requires some time.

In light of these challenges, Khan et al. [38] have proposed two protocols – power controlled routing (PCR) and enhanced power controlled routing (EPCR) that work for mobile and static WSNs with a mechanism for recovering lost packets although it only supports homogenous networks. Ali et al. [39] have also proposed a distributed grid based robust clustering protocol for mobile sensor networks that sends aggregated data to neighbor CH with the help of guard nodes thereby decreasing packet loss during inter-cluster communication, though it only supports homogeneous networks.

3 QoS Strategies at the Transport Layer

3.1 General Transport Layer Protocols

The traditional Internet transport layer protocols include UDP and TCP which nevertheless can't be directly applied in WSNs and WMSNs [40] due to the distinctive characteristics of these networks and the many applications with specific requirements [31].

Congestion Control Protocols

In communication networks and queuing theory, network congestion occurs when too much data is transmitted over a given link node causing its QoS to deteriorate leading to queuing delay, packet loss or blocked connections. Here we discuss some of the available Congestion Control Protocols.

Datagram Congestion Control Protocol (DCCP)

This protocol is designed for apps that may require running a session as well as congestion control and are tolerant to unreliable communication without retransmission. These may have a tradeoff between delay and in-order delivery [41] like streaming audio and on-line gaming. It can control datagram congestion and provide an excellent procedure to stop internet failure due to congestion. DCCP is different from UDP, since it encompasses a way of controlling congestion and also differs from TCP, since it doesn't guarantee reliability. It implements bidirectional connections between two hosts, either of which can initiate the connection comprising two unidirectional connections, called half-connection [42]. DCCP provides primitive support for multihoming and mobility via connection endpoint transfer between addresses. Although DCCP doesn't guarantee cryptographic security, highly security sensitive applications can use IPsec or any end-to-end security. It can however protect against some attacks like session hijacking [42].

XCP (eXplicit Control Protocol)

This protocol has high scalability, stability and efficiency when deployed in higher bandwidth-delay product routes in routers. It further has superior performance in satellite IP networks although it exhibits lower performance when subjected to high-link error rate circumstances though this is addressed with the emergence of P-XCP. So, it's a good option for congestion control over IP [43].

Variable-Structure Congestion Control Protocol (VCP)

VCP possesses TCP characteristics like sliding window though it applies a different window management mechanism [44]. It has 3 congestion levels: low-load, high-load, and overload for encoding into IP packet headers. VCP enabled routers usually calculate Load Factor (LF) mapping it to a congestion level [45]. The router's upstream link congestion level is examined when the packets are delivered and if down-stream link is more congested, ECN bits are updated. The receiver will then notify the sender of the link congestion status using ACK packets and thus the sender responds with 3 strategies of congestion control namely: the low-load region's Multiplicative Increase, high-load region's Additive Increase, and the overload region's Multiplicative Decrease. It has a low rate of packet loss and low persistent queue length and is highly utilized for homogeneous networks making it very practical for deployment despite less feedback delivery to end nodes [44].

TCP-Tahoe
This protocol uses 'Additive Increase Multiplicative Decrease' (AIMD) for congestion control and any packets lost will be considered as congestion. With half the current window as the threshold, it sets cwnd = 1 and by slow start, it increments linearly after reaching the threshold until packet loss occurs for it to slowly increase the window before reaching bandwidth capacity. The protocol is costly since it takes a lot of time to detect packet losses [43].

TCP-RENO
Here there is early detection of lost packets and always pipeline retains some packets even after a loss. In the 'Fast Re-Transmit' algorithm, receiving 3 duplicate ACK's signals loss of the segment, so the segment is retransmitted before timeout. Reno performs far better than TCP in limited packet losses. Under multiple packet losses in one window, RENO performs almost like Tahoe [43].

TEAR (TCP Emulation at Receivers)
This comprises window-based and rate-based congestion control making it a hybrid. The source node will thus change its transmission speed. TEAR calculates TCP sending rate other than using the congestion window (cwnd) [43].

3.2 Error Recovery Protocols

Stop-and-wait ARQ
It ensures that information sent between two devices is not lost due to dropped packets and that packets get delivered in correct order [40]. The source node sends one frame at a time with transmit window size = 1 and receive window size more than one. After sending each frame, no further frames are sent before acknowledgement is got, and if ACK doesn't come before the timeout, the frame is retransmitted.

Go-Back-N ARQ
The source node sends many frames according to window size, before receiving ACK packets from the receiver and N frames can be transmitted before an ACK is sent. The receiver keeps track of next frame's sequence number, which it sends with every ACK it sends; and discards any frame that does not have the expected sequence number and also resend an ACK for the last correct in-order frame [46]. When all frames are sent, it returns to the last received ACK's sequence number and fills its window starting with that frame and repeats the process. Since it doesn't wait for each packet's ACK, this protocol uses the connection more efficiently than Stop-And-Wait ARQ.

Hybrid Automatic Repeat-Request (HARQ)
This protocol is a combination of both ARQ and FEC. No retransmission is necessary to fix small errors but major ones are corrected by retransmission [40]. A system that incorporates this protocol change the coding scheme to adapt to conditions of the channel. This protocol consumes a lot of energy and is suitable in delay-tolerant applications. Other protocols in this category include Forward Error Correction (FEC), Selective Repeat ARQ/Selective Reject ARQ [47].

3.3 Transport Layer Protocols for WSNs

Priority-Based Protocols

Pump Slowly Fetch Quickly (PSFQ)
This protocol is designed for WSNs. It addresses some issues such as point-to-multipoint reliability. It can be employed both in multicast and unicast applications. It's a hop by hop protocol where there is data reconstruction over each node and so doesn't guarantee reliable connection [48]. It is useful in transmitting messages, recovering errors and selective status reporting which three functionalities are referred to as pump, fetch and report operations respectively. This protocol was developed for applications that need reliable packet delivery and transmits binary images but is inefficient for multipoint-to-point sensor transmissions [49]. For Loss Detection, PSFQ uses NACK-based quick fetch mechanism to achieve reliability and gap detection to detect losses. It assumes light traffic in a WSN and so detecting and controlling congestion is not a very big issue here and it employs TTL field in the header to sort this [49].

Reliable Multi-segment Transport (RMST)
This protocol is designed for WSNs and does fragmentation and segment reassembly and reliable delivery of messages [50, 51]. It is selective NACK-based extension of directed diffusion applicable to a sensor node and configurable with no need to recompile. It can be configured at run-time to enable end-to-end recovery, guaranteed delivery, fragmentation and reassembly to some applications and can detect packet loss at the sink. Congestion control arises from use of directed diffusion, for reliability, a timer-driven NACK is sent to the previous node for missing packets using hop-by-hop method. End-to-end retransmissions are reduced through storage of unacknowledged packets in caches and it uses ARQ for lost packet retransmission [49].

Improved Pump Slowly Fetch Quickly (IPSFQ)
It's designed to deal with the shortcomings of PSFQ to enable it perform better via error tolerance and mean latency [48].

Event to Sink Reliable Transport (ESRT)
It enables reliable event detection from source to sink and permits the course description for an event but doesn't provide details making it inapplicable to apps requiring full message delivery. The essential features of this protocol include congestion control, energy awareness, self-configuration, biased implementation and collective identification. It has a loss detection mechanism that depends on the congestion control and doesn't provide guaranteed delivery or loss prevention for messages but determines the right frequency, f for message delivery [49].

Priority-Based Congestion Control Protocol (PCCP)
In this protocol, the usefulness of sensor nodes is reflected by the node priority index [52]. The degree of congestion is computed as the ratio of packet inter-arrival time to packet service time and it's on this basis that it exploits cross-layer optimization and does congestion control using hop-by-hop mechanism and flexible weighted fairness for single and multipath routing is achieved. This brings about increase in energy efficiency and better QoS in terms of packet loss rate and delay. Other priority-based protocols include **DB-MAC;** a contention-based scheduling protocol in which packets from a node close to the source are more highly prioritized; **GTS (Guaranteed Time Slot)** in which prioritization is done using a toning signal, **RAP** whereby with higher requested velocity, a packet is assigned a higher priority, etc.

3.4 Transport Layer Protocols for WMSNs

Queue-Based Congestion Control protocol with Priority Support (QCCP-PS)
This protocol utilizes the length of the queue to indicate the degree of congestion [53] which subsequently together with the priority index determines the assignment rate to each traffic source. It achieves highly when it comes to congestion detection and priority and is efficient for WMSNs multimedia traffic. With fewer packet losses and retransmissions, a lot of energy at nodes is saved [56]. It focuses on transport layer congestion control since WMSN supports different applications [31]. The mode of congestion control here has 3 units based on hop-by-hop approach and are congestion detection, congestion notification, and rate adjustment unit. Congestion is detected using the length of the queue indicating congestion degree. Input packets from each child node and that source traffic from the receiving node are stored in separate queues. Nodes are assumed to have different priorities which together with the congestion degree determines the sending rate of a given node.

Multipath Multi-stream Distributed Reliability (MMDR)
This is designed for WMSNs for video transmission and exploits multi-stream coding of video and multipath routing. Source coding methods like Layered Coding, Multiple Description Coding, Distributed Video Coding [54] are used to partition the source-encoded video data into many streams. To do channel coding of the many video streams to cover up for errors in some wireless links, the protocol employs Low Density Parity Check codes. Bit errors are recovered using progressive error recovery algorithm (D-PERA). Other protocols here include Load Repartition based Congestion Control (LRCC), Reliable Synchronous Transport Protocol (RSTP), etc.…

3.5 Challenges and Opportunities

i. Performance and Robustness: There should be trade-offs in congestion control, e.g., high link utilizations and fair resource sharing should be allowed and algorithms be robust enough. Routers may improve performance, though may cause more complexity and control loops which requires careful algorithmic design to ensure stability and avoid oscillations. Excessive congestion may further delay feedback signals and so, robust congestion control mechanisms with significant benefits with less additional risks should be designed.

ii. Congestion control mechanisms usually interpret packet loss to be due to congestion whereas for wireless networks, dropped packets may be due to corruption. For corrupted packets, most congestion control mechanisms will react as if there are no dropped packets. There is need to design mechanisms that can be able to detect corruption though this is not easy especially for cross-layer interactions.

iii. Most data in multimedia streaming belongs to control traffic. Minor packet congestion control mechanisms should be enhanced, tightly coordinated and controlled over WANs.

iv. Additional router processing is a challenge for scalability of the internet and may increase end-to-end latency. This should be further investigated as no known full solution that does not require per-flow processing. Without affecting Internet scalability, there should be some realizable granularity for router processing.

v. We need to define the protocol layer at which feed-back signaling occurs and the optimal feedback frequency.

4 Cross-Layer QoS Strategies

4.1 Cross-Layer MAC Protocols

Adaptive Cross-Layer Forward Error Correction (ACFEC)

This is realized in Access Point (AP) that adaptively adds FEC to video data, in infrastructure mode. Nodes exchange data packets with each other via the access point [55]. Video data is encapsulated by the streaming server in RTP packets via the wireless AP to the receiver node. The packet header is retrieved from UDP by the adaptive FEC controller that will detect the packet type from the RTP header [56]. The block's source packet number determines the number of error correction packets generated by the Packet-level FEC encoder. Adaptive FEC controller monitors video data transmission results by snatching up MAC layer failure information and the controller's failure counter will be incremented by one in case the transmission flops. When a block is transmitted, the controller adjusts number of generated redundant FEC packets using the failure counter. When packet losses are detected, redundancy rates are adjusted, more packets generated to compensate for lost packets and meet receiver needs [55].

MAC-PHY Cross-Layer Protocol

The authors in [57] propose a cooperative cross-layer protocol for cooperation at physical layer in next generation WSNs and provision of full MAC layer algorithm supporting the PHY-MAC layer cooperative structure. The scheme used is similar to CoopMAC's which depends on an intermediate node for inter-node communication.

Modification of the MAC layer protocol has enabled it to take control of the Physical layer communication. By the new scheme, the destination node can get two copies of the original packet, from source and helper for decoding [57].

Cross-Layer Cooperative MAC (Coop-MAC)

Here a source node uses the two-way handshake (RTS/CTS) to establish a link with the destination node after a random back off. On getting the CTS packet and the short inter-frame space (SIFS), the source will directly send the packets to destination node in case the cooperation is not beneficial, and when there is a cooperation opportunity, the source and the destination first establish, using a Helper Indication signal, whether there is a helper to confirm the feasibility of a cooperative transmission. In case there's a signal, a cooperative communication is initiated, otherwise, direct transmission is triggered. Since there is an RTS/CTS exchange, the helper-initiated cooperation is preferred in a distributed wireless system [58]. Spatial diversity between the 3 nodes (faster two-hop "alternative path" via the helper compared to direct path) puts this protocol at an advantage [57]. Other protocols here include EC-MAC Protocol in which besides the 3 control frames (RTS, CTS and ACK) supported in IEEE 802.11MAC, 3 new frames (Cooperative Request-to-Send, Helper-to-Send – HTS, and Cooperative Clear-to-Send – CCTS frame) are introduced in [54].

4.2 Cross-Layer Network Layer Protocols

Cross-Layer and Multipath based Video Transmission (CMVT)

This is designed as a collaboration between the application and network layer. In the application layer, the protocol encodes video streams into video data frames (I-frame, P-frame and B-frame) by using MPEG-4 encoding scheme. The core of the protocol is the network layer design where route discovery and data transmission take place. Under route discovery, many paths from the source node to the sink node are found through two schemes namely: greedy forwarding and rollback [59]. A given node i uses Eq. 3 to compute the evaluation of its neighboring node j

$$f_{ij} = (1-\alpha)\frac{d^2(j,D) - d^2_{min}(i)}{d^2_{max}(i) - d^2_{min}(i)} + \alpha\frac{e_{init}(j) - e_{res}(j)}{e_{init}(j)} \tag{3}$$

where, f_{ij} = evaluation value of node i to node j, $d^2(j,D)$ = distance from node j to destination node D, $d^2_{min}(i)$ is minimum distance for neighbors of node i to D, $d^2_{max}(i)$ is maximum distance for neighbors of node i to D, $e_{init}(j)$ is initial energy of node j, $e_{res}(j)$ = current residual energy of node j, and α is energy coefficient, given by:

$$\alpha = \frac{e_{max}(i) - e_{min}(i)}{e_{max}(i)} \tag{4}$$

where, $e_{max}(i)$ = maximum remaining energy of all neighbors of node i, $e_{min}(i)$ = minimum remaining energy of all neighbors of node i. The network layer also sends video data whereby CMVT does status evaluation to select a suitable transmission path for the given type of packets and the QoS guarantee level of a path i is computed using Eq. 5:

$$f_i = (1 - \omega)\frac{h_i}{\sum h_i} + \omega\frac{n_i}{\sum n_i}, \quad (5)$$

where, f_i = path i evaluation value, h_i are the hops for path i, n_i = sum of packets sent via i, Σn_i = sum of packets sent by sources, and ω = energy consumption factor.

Network Layer QoS Support Enforced by a Cross-Layer Controller

It enables packet-level service differentiation as a function of throughput, end-to-end packet error rate and delay [60] (Fig. 4).

This improves QoS at the network layer. It has a cross-layer control unit (XLCU) to configure and control networking functions at physical, MAC, and network layer basing on a unified logic which decides for application layer requirements and status of functional blocks that implement networking functions thus, cross-layer interactions can be controlled with no compromise on the upgradeability, modularity, and ease of system design [60].

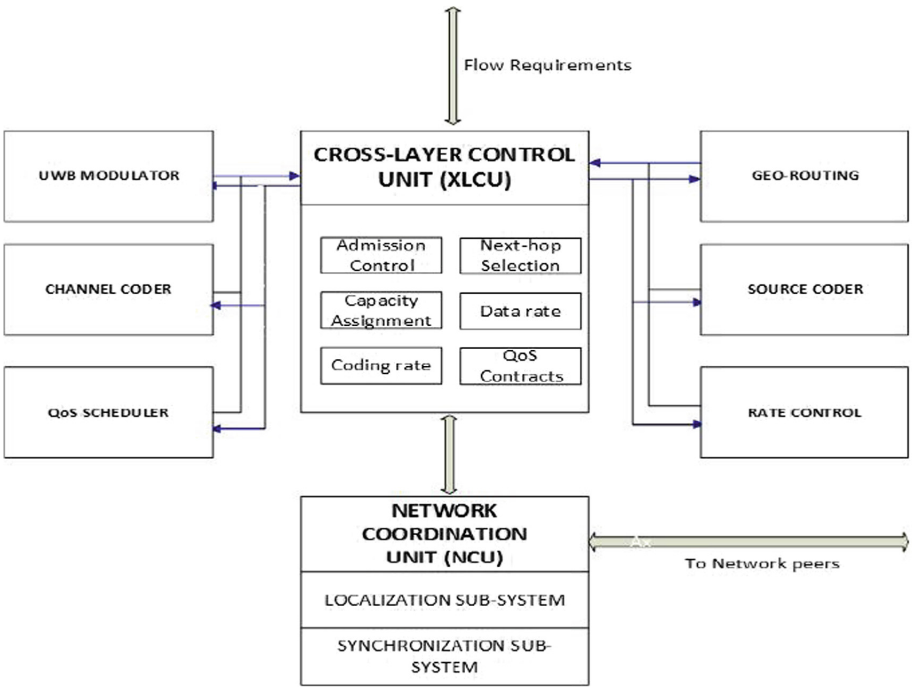

Fig. 4. Cross-layer controller Architecture.

4.3 Cross-Layer Protocols for WMSNs

Multi-path Multi-priority (MPMP) Transmission Scheme

A context-aware cross-layer optimized scheme that employs multipath routing in routing layer and multipath selection in transport layer [32]. To discover the highest number of sensors of node-disjoint routing paths, we use Two-Phase geographic Greedy Forwarding (TPGF) routing protocol and to select the number of optimal paths for data delivery to the sink, Context-Aware Multipath Selection (CAMS) algorithm is employed which further guarantees node-to-node transmission delay [31]. Depending on the multimedia content to be transmitted, end-to-end transmission delay-based priority for real-time video, CAMS will choose the right path for routing the WMSN data. To do data gathering in WMSNs, we use a CLD whereby RRA scheme that is adaptive alters dynamically the radius of transmission as well as the data generation rate adjustment. The RRA scheme's cross-layer framework takes place in four steps name: (i) the optimal transmission radius at physical layer is chosen for the nodes, (ii) use of multipath routing protocols such as TPGF to construct numerous routing paths, (iii) do path selection at the transport layer from among the discovered paths by the routing protocol (iv) for source nodes at physical layer, their data generation rate is adjusted [31].

Time-Hopping Impulse Radio Ultra-Wide-Band (TH-IR-UWB)

This is a cross layer, QoS model in WMSN applications based on TH-IR-UWB technique. It employs the admission control protocol with the source node initiating requests by telling the neighbors it's needs and then selects the best path to sink satisfying its needs depending on the responses before beginning to transmit [31]. This kind of admission control guarantees end-to-end QoS for multimedia content, high throughput, reduced error rate and delay. Problems like random timer variable and uncontrollable access delays, carrier sense idle listening, and enhanced energy consumption as a result of the hidden node problem are eliminated [60]. The cross-layer system further offers receiver-centric arrangement due to the impulse radio's time hopping arrangement which enables many simultaneous broadcasts, eliminates collisions, and saves energy through avoiding idle listening and wasteful transmissions.

MAC Centric Approach

It's an MPEG-4 cross layer algorithm for multimedia/video communication, with 4 Access Categories (AC3 – AC0) in order of transmission priority and developed to support varying QoS requirements of emerging video applications, enabling differentiation of MAC layer H.264 partitions [61]. A wireless channel has issues affecting QoS for efficient multimedia transmission e.g., low bandwidth, latency leading to many proposed advanced mechanisms that depend on IEEE 802.11e in supporting quality video communication [55]. The AC is chosen basing on QoS measures like one-way loss rate and latency, hence Parameter Set Concept maps to the highest-priority Access Category (AC3) due to the stream's sensitivity to loss of transmission bits since a parameter missing causes video transfer latency [61].

Minimum Hop Disjoint Multipath Routing Algorithm with Time Slice Load Balancing Congestion Control Scheme
MHDM routing algorithm is divided into 2 phases: (i) path build up phase, (ii) path acknowledgment phase with 3 disjoint paths built up per source since there are multiple sources. The paths are primary path, alternate path and backup path. Considering the 2 phases, in the path build-up phase, when the source sensor node is activated, it sends requests to build up a path to the smallest hop count neighbor compared to sender node [62]. (a) The first step in path build-up phase is that when a source is activated, it sends a request package for path build up to the neighbor node which upon receipt of it adds its node number and timestamp before forwarding it to its smaller hop count neighbor until it reaches the lowest time latency sink with primary route info to build up the primary route [63]. (b) The second step under this phase is such that on arrival of a new package from another route, the route is extracted and compared to primary route and package discarded in case of a shared node, or an alternate path is found. Then a back-up path is found by further comparing the previous two paths. Under the second phase of path acknowledgement, (c) the third step after path build-up is that the sink sends back to the source an acknowledgement message (ACK) comprising the path info that includes the nodes and the related time info calculated from the timestamp by the sink. MHDMwTS protocol reduces the end to end delay and controls and prevents congestion [62].

4.4 Challenges and Opportunities of the Cross-Layer Design (CLD)

i. The physical layer plays a major part in CLD which is highly invaluable. Functions like rate adaptation, channel allocation are provided at the physical layer through signal processing. CLD bases on physical layer features for improved QoS. Variations in wireless medium affect end-to-end performance if network layer protocol functionality is affected. CLD offers solution for power conservation, …. , making it an opportunity for designers to consider other layers. There is also need to determine CLDs that affect performance of network and get closer attention.
ii. Coexistence of different CLD Solutions: Major concern is if CLD solutions meant for a similar challenge can be independently applied, e.g., if there are common mechanisms to use by different CLD approaches.
iii. Standardizing interfaces for CLD: CLD architecture needs to provide functionality for its modules though there is a question on potential interfaces between modules which interfaces will be determined by the need to exchange and share info between non-adjacent protocol layers. Technical challenges include developing, designing, and standardizing of cross-layer interfaces and algorithms that meet cross-layer optimization requirements.

5 Future Research Directions

i. QoS and Energy efficiency are important aspects in WMSN mostly real-time applications needing guaranteed bandwidth and throughput during network lifetime. Many protocols don't consider Base Station and multimedia sensor nodes' mobility. Applications like traffic management, telemedicine, battlefield surveillance need node or Base Station mobility hence need for designing dynamic routing protocols that can be adaptable in such conditions. For CLD, we need to investigate how different CLD proposals will coexist.
ii. Security of information carried on WMSNs, e.g., patients' data, data in military surveillance, e-commerce, etc. is paramount with QoS and energy efficiency and so requires more attention by the research community.
iii. We need to investigate, specify, develop, and standardize cross-layer algorithms that will meet cross-layer optimization standards.
iv. There is need to develop energy efficient MAC protocols since power management and saving schemes have challenges of throughput, protocol overhead, and prone to channel errors.

6 Conclusion

We have reviewed the different QoS strategies for WMSN in the Context of IoT from the network layer, transport layer and cross-layer paradigm. For network layer, we have discussed many protocols with their characteristics including general network layer protocols, protocols suitable for WSNs and WMSNs. We reviewed data centric, Hierarchical, Location-based, Negotiation-based, Multipath-based, and Mobility-based Protocols. We have then discussed transport layer protocols like congestion control, error recovery and priority-based protocols. For these we reviewed general, WSN and WMSN protocols. For system optimization, Cross-layer QoS strategies are important. We have seen three cross-layer strategies for each of which challenges and opportunities were compared. These are: Cross-Layer MAC, Cross-Layer Network Layer and Cross-Layer Transport Layer Protocols. Finally, some possible future directions of QoS strategies have been discussed for research and application.

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