

A Review on Cross-Layer Design Approach in WSN by Different Techniques

Sultana Parween*, Syed Zeeshan Hussain

Department of Computer Science, Jamia Millia Islamia, New Delhi, 110025, India

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ABSTRACT

Wireless Sensor Networks (WSN) include a large number of sensor nodes that are connected to each other with the limitations in energy sources, battery life, memory, mobility and computational capacity. Since the traditional layered architecture was appropriate only for the wired network. It works within a strict boundary that leads to more energy usage as well as more communication traffic. It also impacts on the overall network lifespan and performance of the system. Energy efficiency and network lifespan are the primary concern of WSN due to the fact that each node in the network operates with extremely limited energy. Recent studies have shown that the Open System Interconnection (OSI) model cannot meet the demands of the wireless sensor network.

To overcome such limitations, the cross-layer design has been introduced. It allows direct interactions between protocol at non-adjacent layers. In this paper, we present different types of cross-layer design techniques in Wireless Sensor Network (WSN) and discusses several cross-layer proposals given by researchers. At the end, the paper highlights some challenges faced in implementing CLD in Wireless Sensor Networks.

1. Introduction

Nowadays WSN has evolved into one of the “on-demand” wireless systems that can be generally used in many fields like environmental monitoring, habitat monitoring, military surveillance, smart spaces and medical systems, and so on [1]. The key purpose of the WSN is the detection, collection, computation and transfer of the data to the sink node.

Normally, sensor nodes are powered by batteries, that are difficult to replace or recharge. Power limitation is to be considered one of the most significant factors while designing a sensor network. However, as interference, fading and noise are common in wireless network communication. To overcome the error caused by the above reason during the data transmission, sensor nodes need to use more energy [2]. There are many techniques and protocols used by several researchers to reduce energy consumption. There are still many open challenges to developing an appropriate energy-saving technique for sensor nodes in WSN. Increasing the lifespan of nodes in the wireless sensor network is important as the usage of this network is unreliable for much of the time and it is difficult to repair the batteries or faulty nodes. Thus, several researchers have carried out various solutions for an energy-efficient model in different situations. The traditional layered

architecture might not be suitable and efficient in the wireless environment due to the basic features of wireless communication [3]. In this point of view, cross-layer design for cross-layer optimization being an optimal approach, that is not only to improve but also optimize the overall network performance. Different cross-layer interaction and optimization techniques used by the WSN designer and developers to provide QoS in WSNs. The major contribution of this paper is consequently that of supplying researchers with a summarized comparison of existing CLD approaches by the different techniques in WSN. As Jurdak defines it “Cross-layer design techniques with respect to the reference layered model are the design of protocols, architectures, or algorithms, that not only exploit but also offer a set of inter-layer interaction which is a superset of the standard interfaces provided by the overall reference layered architecture” [4].

The focus of this paper is to explore the cross-layer optimization techniques in the context of wireless sensor networks. The remaining portion of the paper is organized in the following sections: Section 1 describes the brief overview of CLD and its objective and significance. It also explains the need for cross-layer design in WSN. Section 2 presents the research gap. Section 3 briefs the cross-layer design framework in WSN. Section 4 describes the cross-layer design implementation method. Section 5 covers different cross-layer design techniques. Section 6 briefs

*Corresponding Author: Sultana Parween, New Delhi, India | Email: sultana.tech@gmail.com

the categorization of recent cross-layer design by a different technique. The challenges of cross-layer design in wireless sensor networks are discussed in section 7. Finally, Section 8 gives the conclusion of this paper.

1.1. A brief explanation of Cross-Layer Design

The OSI layered architecture comprised of basically seven layers and these layering structures brings many benefits: it breaks the complex task of networking into separate parts simplifies design; it makes protocols easier to optimize, manage, and maintain; the lower layers can be changed without affecting the upper layers [5]. Although the traditional layering structure is beneficial for wired networks because it provides modularity, transparency, standardization, and abstract functionality. It means that this structure is not suitable for a wireless network. The main purpose behind this is that, there are strict boundaries in the OSI model, all the protocol is proposed for a single layer and each layer cannot communicate directly with the non-adjacent layer. And this characteristic is opposite to energy limitation, node mobility, and the dynamic nature of wireless sensor networks [6]. An approach that could exchange information across many layers is needed to solve this problem. Therefore, the cross-layer technique has affected increased attention. The basic idea of a cross-layer is to use the close interaction between different layers for improving the performance of the entire network. For many domains, this technique has been widely used.

1.2. The objective of Cross-Layer Design in WSN

The major goals that needs to be considered while designing a cross layer architecture are mentioned below.

Table 1: Objective of CLD

Goals	Explanation
1.Network lifetime maximization	It is significant in the context of enhancing the flawless operation of battery-constrained WSNs.
2.Energy-efficient routing	The CLD is responsible for creating a perfect routing algorithm to calculate the best routing path, which could not only consume minimum power but also maintain the network connectivity.
3.Reliable event detection and transfer	The main request for an event-based sensor network is to detect an event and transport the data accurately.
4.Optimization among multiple, conflicting objectives	To find the optimal scheme, which concerning the conflicting goals, to accomplish the best performance of the sensor network
5.Bringing flexibility into the application-specific design of WSNs	The CLD should be flexible enough to satisfy the dynamic requirement of different application.

1.3. Why do we need a Cross-Layer Design?

The traditional layered method avoids communication among non-adjacent layers in the protocol stack, which limits its use in

wireless sensor networks (WSN) [7]. CLD method helps in breaking the traditional waterfall idea that was considered in traditional network protocols. CLD doesn't destroy the traditional layered structure of the networks [8]. It additionally presents the inter-layer communication between non-adjacent layers. With the help of CLD, the internal status and parameters of every layer can be revealed to the different layers ensuing in the removal of redundancy. CLD also helps in figuring out the behaviour of different layers by way of retrieving and receiving the facts from them [9]. CLD helps in increasing the functionality of the wireless network, quality of service, mobility, and security in sharing information amongst all layers. To get the maximum energy consumption in WSNs, a cross-layer can be useful.

1.4. Significance of Cross-Layer Design

The motivating points that trigger to apply the cross-layer design approach were numbered as follows.

- It improves network efficiency and satisfy the quality of service requirements of various applications [10].
- It increases network performance and optimizes network throughput [11].
- It is used to enhance the performance of sensor nodes.
- It allows communication among various non-adjacent layers and the exchange of information amongst them.
- It helps to reduce the transfer load through exchanging information across different layers.
- It maintains the features and functions related to the layers, but to allow for coordination, communication, and optimization of protocols across various layers.
- It is an appropriate technology for overcoming some of the current TCP/IP stack limitations, particularly for wireless networks.

1.5. Assessment among Conventional layered approach and CLD approach

After a review of existing work, we find Comparisons between CLD Approach and the Conventional layered approach [11].

Table 2: Comparison table of Conventional Layered approach and CLD approach

CLD Approach	Conventional Layered Approach
CLD approach minimizes the communication traffic efficiently.	Communication traffic is more in a conventional layered approach.
Nodes ingest less energy.	Energy consumption by the nodes is more likely to be in this approach.
Appropriate for both wired as well as wireless networks.	More appropriate for a wired network.
We can interact with one layer to any other non-adjacent layer in a cross-layered approach.	We cannot interact with one layer to the other non-adjacent layer in the conventional layered approach.

2. Research Gap

After a review of several works the gaps in existing work are mentioned below:-

- It is not clear how when and where the cross-layer proposals should be implemented in CLD.
- It is hard to review and redesign because changes in subsystem may cause changes in other parts of the system [12].
- There is a lack of standardization in cross-layer design that leads to many problems. The network performance should be decreased due to this reason.
- Parameters that are similar across all layers need to be identified.

3. Cross-Layer Design Framework

3.1. TinyCubus

The architecture of TinyCubus provides a new conventional model that can satisfy many different application specifications. It is flexible and adaptive by nature and applied to the top of TinyOS with the help of the necessary programming language [13]. It has many components like a Data management framework (DMF), a Cross-Layer Framework (CLF), and a Configuration Engine (CE). Tiny DMF as stated in [14]. It offers a set of data management as well as the system components that are selected dynamically. It is also responsible for selecting the proper implementation based on system information. The cube of fig 1 named ‘Cubus’ integrates all the optimization parameters like energy, communication latency, etc.

CLF helps in cross-layer information sharing & management. E.g. if some of the application and the link-layer component requires information regarding the actual network neighbourhood, then one of its components in the framework collected that information and provide it to all others. A tiny cross-layer framework is not sufficient to give proper parameterization for most of the cases. This problem is solved by the Tiny Configuration Engine. It enables reliable and efficient code delivery, by taking into consideration sensor topology and its assigned functionality [15]. Figure 1 shows the key components in TinyCubus.

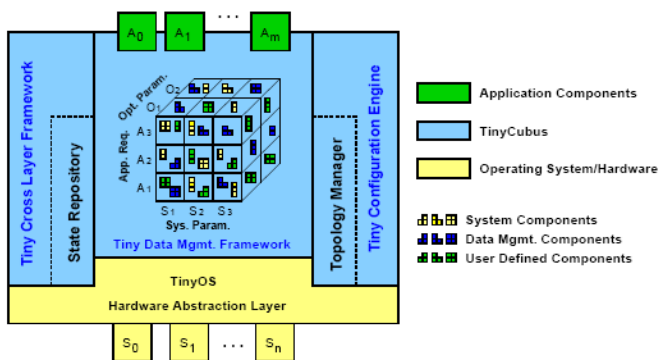


Figure 1: The architecture of TinyCubus [15]

3.2. DMA-CLD Framework

DMA-CLD refers to the Dynamic Multi-Attribute Cross-Layer Design framework [16]. In this framework, various objectives are met. The main purpose of DMA-CLD is to enable cross-layer connections with wireless ad hoc networks & WSN to achieve various as well as probably overlapping goals (networking, nodal, single layer, and cross-layer). DMA-CLD framework recognizes a

set of routes chosen to maximize the network performance according to given parameters like "residual battery," "reliable packet transmission", etc. as input [17]. Figure 2 showing the main idea for DMA-CLD.

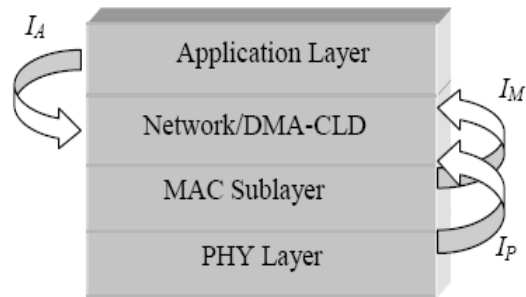


Figure 2: The architecture of DMA-CLD [16]

3.3. Optimization Agent-Based Framework

The main aim of this framework is to emphasize wireless channel & physical layer properties. It is an extended version of DMA_CLD [17]. It utilizes an optimizing agent to transmit the significant changes in the physical layer as well as a wireless channel to other layers. The basic interactions among different layers are intra-layer interaction or inter-layer interaction. The directions of interaction were maybe bottom-up or top-down. Figure 3 shows the OA based framework.

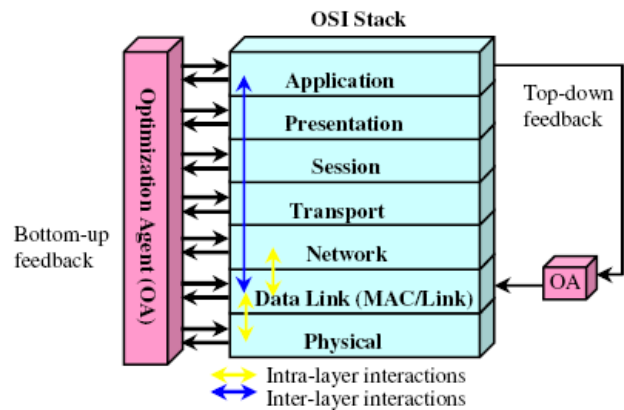


Figure 3: The architecture of the OA based framework [17]

3.4. Horizontal Framework

This framework comprises of the basic entities: cross-layer management entity, application, and protocol stack as shown in figure 4. The main reason for using the Horizontal model rather than a vertical model framework is to optimize the protocol stack height and to reduce resource use [17]. The CLM provides a shared data structure and needs to take care of different features of the sensor network, such as topology control and energy savings whereas APS is accountable for the data transmission of only application-specific. It also includes several extra features for the application and other layers that can be used in the protocol stack. The main concept for using this framework is just to streamline the

protocol stack and isolate such activities like CLM entity modules, thereby enabling application programming easier [14].

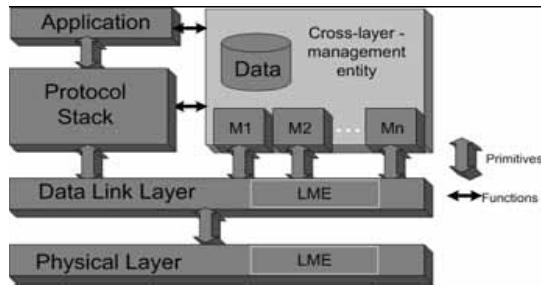


Figure 4: The architecture of Horizontal framework[14]

3.5. XLM Framework

XLM is a unified cross-layer framework that was created to achieve reliable and effective communication in WSN with minimal energy costs. It incorporates the protocol layer's most essential feature into a single cross-layer system that is used to provide all the requirements for effective communication [14]. XLM's architecture is built upon an initiative concept that gives full authority to each and every sensor node to determine, when and how to take part in the process of communication [18].

4. Cross-Layer Design Implementation Method

After an analysis of existing work, three Implementation strategies for the cross-layer design approach are identified:

4.1. Straightforward communication between layers

In straightforward communication among the layers, allow the variables at one layer are accessible to all the other layers during runtime. Straightforward communication among layers is the easiest way of exchange information among layers in runtime. It allows direct interaction among layers [19]. It is shown in Figure 5:

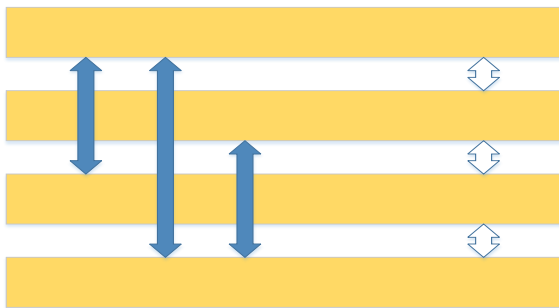


Figure 5: straightforward communication between different layers[19]

4.2. A Common database between the layers

As shown in Figure 6, there is a common database among the layers, which can be shared by all the layers. Just like a new layer, it provides a resource-share service to each and every layer [20]. The common database method is ideal for common resource sharing. The common database can connect to different layers at once by an optimization program [21].

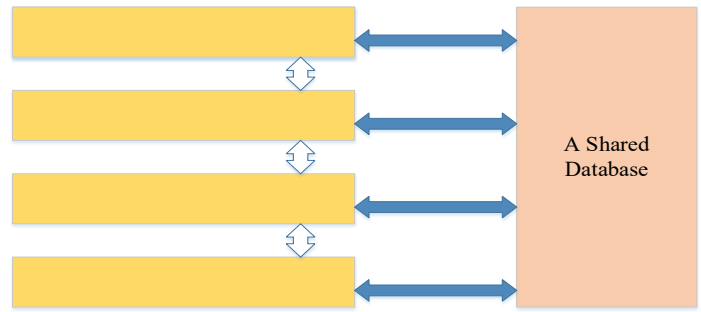


Figure 6: A Common Database across layers [19]

4.3. Completely new abstractions

Each layer can communicate from each and every other layer in a completely new abstraction. A completely new abstraction approach allows strong communications between different layers and it provides more flexibility during runtime [21]. It is shown in Figure 7.

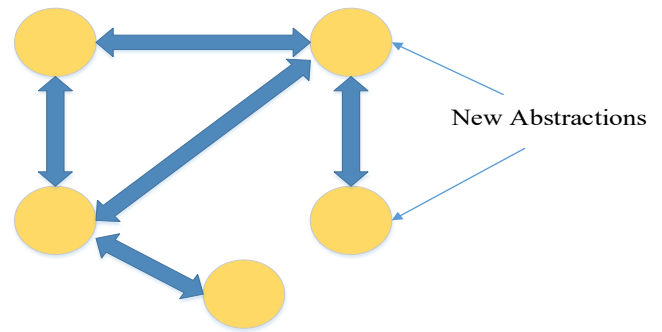


Figure 7: Completely new abstractions [21]

5. Cross-Layer Design Optimization Techniques

Each layer contributes to different functionalities in the protocol stack of WSNs. Crossing these layers can accomplish performance gain in different scenarios. The most common of these performance enhancements are discussed in this section. Energy efficiency is a broad category as the nature of WSN is resource-constrained with respect to energy [22]. The key focus of each similar contribution is the energy preservation of such networks. Other areas such as QoS and communication, reliability, error correction, network resource management along with security are also discussed. Cross-Layer approach is one of the most significant emerging technique that communicates across layers for upgrading the complete performance of the network, increases energy efficiency, reduces power consumption, and deliver real-time communications for achieving quality of service (QoS) [23].

5.1. Energy Efficiency

An energy-efficient usage is one of the main and critical constraints in the WSN. For prolonging the lifespan of the network, it is essential to save energy at every node. The major challenges of WSN are to design an energy-efficient algorithm that significantly reduces the usage of energy during the transmission

of data. Many researchers are working to improve energy efficiency through a different technique [24].

Cross-layer methods proved that it is better than layered equivalent and it offers much better optimization outcomes. Though, the overall performance of WSNs is greatly enhanced by layer cooperation in cross-layer based systems [25].

The following are several other works that make a significant contribution to energy efficiency by using cross-layer design approaches.

The authors in [7] proposed different modulation techniques to extend network lifetime and use the energy of WSNs in the best possible way. They suggested that when the sensor nodes within a diameter of 35 to 40 meters be run on BPSK or 8PSK modulation technique. When the sensor nodes and their CH (cluster head) and border nodes above 40 meters be run on 16 PSK or 4 QAM modulation technique.

The authors in [26] presented a very popular technique to solve energy consumption issues i.e. LEACH (Low-energy adaptive clustering hierarchy). It is appropriate for large-scale networks and problems of the wireless channel are identified throughout the packet forwarding. They are taking into consideration the residual power and SNR rate. LEACH has significantly improved with multi-hop communications by determining the right possible route from the source cluster head to the destination cluster head. The simulation outcome clearly indicates that it outperforms the traditional LEACH in terms of several parameters like network lifespan, power consumption & PDR.

In a typical LEACH algorithm, it is difficult to share information among each layer, so the communication overhead increased. But the authors in [27] proposed a novel technique to improve energy efficiency and reduce overhead. The algorithm of routing for Leach-CLO (Cross-Layer Optimization) is built upon the typical Leach algorithm along with a cross-layer optimization model. The WSN should also communicate with the bottom three layers to save energy. Routes are determined by the network layer through residual energy information, thereby, reducing energy usage. The experimental findings indicate that this algorithm can balance energy usage in wireless sensing networks effectively & efficiently in comparison to other related algorithms.

In [28], the authors proposed a cross-layer optimization technique that considers both the routing layer and the MAC layer. The routing layer balances the traffic flow through multiple paths that can enhance energy conservation. The MAC layer controls the retry limit of retransmissions for each wireless link, further energy conservation can be achieved, thus improving the network lifetime.

The authors in [29] proposed a cross-layer optimization technique that improves Dynamic Source Routing (DSR) to reduce the frequency of recomputed paths. It enables DSR to initiate route discovery when link failure is occurring. This technique can improve the DSR's routing energy efficiency.

In [30], the authors proposed an energy-aware routing technique based on a cross-layer approach for WSNs. A cross-layer routing algorithm uses the information from different layers to help the routing protocol in deciding the next hop. A fuzzy logic-based approach used to prolong the sensor node's lifetime.

The authors in [31] presented a cross-layer technique HECMAC. The technique was based on the integrated procedure of a duty cycling MAC protocol and a reconfigurable beam-steering antenna. The authors have used information from MAC and network layers to handle the scheduling process of MAC to reduce power consumption. Although the proposed technique has improved the performance but, achieving an accurate antenna adaptive approach is an extremely challenging task.

On the other hand, the author in [1] proposed an energy-efficient technique i.e. EECL (Energy-efficient cross layer) approach. The EECL approach utilizes X-MAC protocol to maintain an asynchronous duty cycle process as they consume less energy. It provides short preliminary instructions which shift to get up/sensing mode just for the routing node whereas the other nodes are in sleeping mode. Therefore, X-MAC protocol overcomes the issues of low power listening: overhearing, unnecessary preamble, and mismatch with packetizing wireless channels.

The authors in [32] suggested a new technique named CLEEP designed for the improvement of energy efficiency through WSN. It utilizes the cross-layer method by taking into consideration only three layers. Throughout the physical layer, it handles the transmission power among the nodes and periodically maintains the neighbour's table. By using the neighbour's table, each node makes a routing table in the network layer. Eventually, the MAC layer uses the information of the routing table to find the duty-cycle of the node. The findings of simulation reveal that the new protocol is more energy-efficient and leads to achieving better performance enhancement.

Based on the above method, the authors in [33] suggested another technique for the improvement of energy efficiency i.e. EECP. It is a type of CLEEP protocol and used essentially to improve and optimized the performance of the network. It utilizes those data that are produced by the layers. It is mainly designed to facilitate effective data communication by reducing energy consumption. In this protocol data routes towards the node that has the highest energy rate and that is also nearest to the sink. But on the other hand, it takes into account the MAC layer information to calculate the node's service cycle and to increase the sleep' state. A comparative analysis reveals that EECP may boost system performance when compared with CLEEP.

The authors in [34] developed a hybrid technique named ATEER. They proposed a WSN adaptive threshold routing protocol for the energy-efficient cross-layer network. In this paper, the algorithm presents the initialization, deployment, selection of CH, the formation of a cluster, and the transmission of gathered information to the base station. The simulation results show that

ATEER has enhanced network lifetime as compared to old techniques

In [35], the authors applied a metaheuristic technique like SA (simulated annealing) for cross-layer energy-aware topology control problem. They suggested optimizing problems to reduce energy consumption through energy control, packet transfer via ECC, and topology regulation in WSNs with power-aware. SA algorithm should be useful in the evaluation of the modified topology. When they compared their results it indicates the SA provides a much better solution than the random sampling.

The authors in [36] presented an energy-efficient transmission technique named EAP-CMAC. This protocol employed physical layer network coding (PNC) that could minimize transmission time slots and achieving better performance and power efficiency than conventional network coding. Direct communication, conventional communication, and PNC-based communication are selected by the EAP-CMAC based on correct communication mode and taking into account the target queue as well as the link quality of the source-destination. However, a combined relay function and energy algorithm were measured in the context with position and residual energy node that not only increases the network lifespan but also saving power. The simulation results demonstrate that EAP-CMAC's performance in terms of network

life is better than IEEE 802.11 and CoopMAC. Besides, the suggested optimal level of power allocation tends to increase the performance of EAP-CMAC by 7 % particularly in comparison with the same power allocation for network lifespan.

In [37], the authors implemented a cross-layer architecture with a different timescale technique that included constraints such as congestion and power control, and processing delay. A primary aim is just to develop a cross-layer architecture that improves overall efficiency as well as reduces the overall communication latency and energy usage.

The authors in [38] presented a solution for 6LoWPAN Wireless Sensor Network to boosts the efficiency of mobility handover via different extents. Such approaches emphasize the convergence of the two separate processes i.e. Layer 2 & Layer 3 handover. It provides an effective combination of these handovers to improve the overall handover performance.

In [39], the authors have proposed a framework trying to find the optimal packet size for transmission with decreased energy consumption. And based on the calculation the authors find the packet size and energy consumption are related to three parameters, that are the condition of channel, medium access and routing.

Table 3: Comparative analysis of different CLD approaches for WSN by energy efficiency

Reference Paper	CLD approach	Layers contributed in CLD approach	Result of CLD approach	Future scope
[1]	Proposed CLD approach for energy-efficient communication i.e. EECL for cloud wireless green communications	Network, MAC and Physical layer	The short preamble implemented in X-MAC only with target node address and minimizes delay and overhearing issues.	Future work would be to implement the suggested EECL approach with various network characteristics.
[7]	The CLD approach for the optimization of layers and framework for WSN has been proposed.	Network, DLL and Physical layer	Uniform clustering can be applied to minimize interference, path loss, and preserve energy.	Future work may include testing of the hardware analysis and evaluating the findings.
[26]	Proposed cross-layer approach for deriving analytical expression of the energy consumption along with the small and large scale channel fading.	Physical layer, Network layer	Improving the existing cross-layer clustering approach concerning network lifespan and power efficiency, without penalties for the PDR.	Evaluate the optimum residual energy values as well as the SNR thresholds allowing for PDR energy minimization and delay constraints.
[27]	A ring cross-layer optimization model is suggested to improve energy efficiency	Network, DLL and Physical layer	LEACH cross-layer optimization is used for energy saving.	-----
[34]	Energy efficient CLD approach which is based on adaptive threshold sensitive distributed routing protocol	Transport layer, MAC layer, Physical layer	ATEER is tested and simulated by previously established routing protocols. It has increased the lifespan of the network in contrast with the old techniques.	-----

[35]	Adopted Cross-layer method for energy-aware optimization of power control and technique of topology control using Simulated Annealing	Physical, Data link, and Network layer	Simulated Annealing leads to better solutions as compared to Random Sampling.	To derive conclusions on energy consumption and topology control comparing Customized Metaheuristic Probabilistic to SA.
[33]	Proposed a novel protocol named EECP for routing in WSN	Network layer, MAC layer, and Physical layer	EECP reduces power consumption and increases the lifespan of the wireless network	Plan to extend the work by enhancing the protocol in terms of the selection of the next-hop and allowing the case of equal costs and eliminating loops.
[36]	Proposed CLD approach for new cooperative communication protocol	Physical and Network layer	EAP-CMAC performs better than the existing protocol and improves energy efficiency.	Performance of EAP-CMAC will be considered in vehicular networks in terms of high mobility.
[38]	Cross-layer mobility support scheme	Network layer and link layer	Evaluated and analyzed the protocol's performance parameters such as latency handover, cost of handover, and packet loss rate.	-----
[39]	CLD approach to get the optimum size of data packets in WSN	MAC and Physical layer	The packet length is optimized to lower energy usage per bit and enhance the network lifespan.	-----
[40]	Proposed CLD for magnetic induction based WUSNs	Transport layer, Network layer, MAC layer	DEAP provides high system throughput and extremely low power consumption within just an obligatory delay.	-----
[41]	CLD approach for energy-efficient and reliable routing to be achieved in WSN	MAC, Network and PHY layer	DRPC can save more energy when compared with DPC and ETX-based routing.	-----
[42]	CLD approach to improve energy efficiency	Network layer, Physical layer, MAC layer	To improve interactions in CLD, the interface among the various layers needs to be updated.	Introduce the new protocol for energy conservation.

5.2. Quality of Service

A CLD has now become a better way to increase Quality-of-Service in WSN. Implementation of QoS techniques in WSNs is considerably challenging because WSNs were originally developed for non-real-time applications with low data-rate. WSN designers and developers, therefore, lead to various cross-layer communication and optimization techniques to provide QoS in WSNs. A few cross-layer design techniques are described in the following section.

The authors in [43] presented the cross-layer QoS techniques as delay-aware and reliability-aware techniques. They highlighted the main QoS challenges in WSNs that are related to delay and reliability-aware applications.

The authors discussed a cross-layer technique in [44] are IQOS that optimizes the quality of service factors of the sensor nodes at the bottom three layers of the wireless protocol stack because QOS factors exist in these layers. Another cross-layer technique presented in [45] is XLCP (cross-layer-communication protocol) based on QOMOS architecture. It is capable to offer soft and scalable service differentiation in QOMOS architecture.

A cross-layer approach is an important technique to optimize the QoS requirement of different types of data. In [46], the authors utilized a cross-layer design between the physical layer and MAC layers. Analyze and compare the performance of the QoS control scheme and standard scheme. The results show that the proposed scheme performed better than the standard scheme.

The authors in [47] proposed a novel cross-layer framework for QoS support in WMSNs. The objective is to maximize the capacity of the deployed network to enhance the number of video sources given that the QoS constraint of each source is also preserved. It is accomplished by implementing Wyner-Ziv lossy distributed source coding at the sensor node with a variable group of pictures (GOP) size.

5.3. Reliable Communication

The cross-layered framework performs better than the layered solution. Many experimental simulations show that the average transmission reliability of the cross-layered design has an improvement when compared with the layered counterpart. Congestion is always caused by communications waste and minimization in energy efficiency. The authors in [49] presented a cross-layer approach that takes the benefit of communication

among MAC and network layer to detect and control congestion. The MAC layer detects congestion by querying the network layer before transmitting any packet. When congestion is observed, the MAC layer begins its priority scheduling function using priority-based packet dispatching and packet drop policy to manage congestion, thus increasing real-time transmission in WSN. A Novel congestion mitigation technique is used in [50]. This

technique works well in the application, MAC, and network layer. SUIT (Sensor Fuzzy-based Image Transmission) is a new cross-layer transport protocol that provides a fuzzy logic method for estimating and mitigating the congestion efficiently. It uses two different techniques that are adapting video frame rate at the source node and new congestion mitigation technique which can adapt the quality of the image on the fly.

Table 4: Comparative analysis of different CLD approaches for WSN by QoS.

Reference Paper	CLD approach	Layers contributed in CLD approach	Result of CLD approach	Future scope
[43]	CLD approach to QoS in WSNs to meet the optimum latency and reliability	MAC layer and Physical layer	Qos challenges in WSN that are associated to delay and reliability-aware applications.	-----
[44]	CLD approach for IQOS control scheme in WSN.	Network, DLL and Physical layer	IQOS improve energy effectiveness, quality of service and system throughput in WSN.	-----
[45]	CLD approach for QoS in WSNs	Network layer and Data link layer	XLCP helps to provide and distinguish QoS to various levels of service class.	Evaluate the performance of the current protocol in terms of node mobility and loss.
[46]	CLD approach for QoS in WBAN	Physical layer and MAC layer	Performance Analysis and optimization of the quality of service (QoS) control system in WBANs.	Evaluate and analyse the other error control schemes and access protocols.
[47]	A framework for CLD in support of QoS under WMNs	Application, Network, and DLL	QoS constraint can be achieved by implementing Wyner-Ziv lossy distributed video coding.	-----
[48]	CLD approach for QoS in WSNs	Network and MAC layer	Clustered multipath routing in WSNs as well as QoS aware scheduling for various traffic classes.	Emphasis on maximizing threshold values based on Network specification in mathematical representation and Simulation.

Table 5: Comparative analysis of different CLD approaches for WSN by reliable communication

Reference Paper	CLD approach	Layers contributed in CLD approach	Result of CLD approach	Future scope
[49]	A framework of Cross-Layer to improve transmission reliability	Network layer and MAC layer	Congestion detection and congestion control to accomplish real-time transmission in WSN.	Plans for more network parameters to be tested.
[50]	SUIT is a cross layer-based image transport protocol	Application, Transport, MAC and Network layer	The fuzzy-logic method is used for evaluating and minimizing the congestion effectively.	Plan to apply prioritization of packets based on fuzzy-logic technique.
[51]	CLD scheme to enhance video quality in WSNs	Physical and Transport layer	Compressed sensing video transmission to provide high-quality video to the receiver.	Measure the system performance and complexity with other video encoders and channel encoding.
[52]	Forwarding scheme based on CLD for video sensor network(VSN)	MAC and Network layer	LBRF and DLBS introduce significant improvement as regards to the reliable data delivery in VSN	-----
[53]	CLD approach for reliable video transmission	Transport, Network and Physical layer	RRA method is used to improve data gathering performance in WSNs.	-----

5.4. Security

Security is always the main concern of WSNs. The idea of cross layering has improved the efficiency of WSN communication. It also reduces modularity by the exchange of parameters between layers that enhance wireless sensor network communication capacity, reliability, and efficiency. Notwithstanding these many successes, there have been security threats in a cross-layering model.

The authors in [54] suggested a new cross-layer technique i.e. T-XLM, which considers a comprehensive solution to securing a sensor-based network. This model uses the trusted method to initiate and coordinate interactions between entities in an intimidating routing process. A cross layering framework of T-XLM builds on the XLM. They also introduced TruFiX, a T-XLM inspired protocol of configurable cross-layer. The security efficiency of TruFiX was compared with RBSS protocols through comprehensive simulation experiments. The results indicate that the TruFiX performs better than the RBSS-based protocols to packet delivery.

XLM security features are not strong in [54], so another authors in [55] suggested the fuzzy logic calculation method which is used to provide defence against attacks. It is mostly based on trust and used to calculate the reputation of nodes to allow safe data

transmission and accurate data delivery through a cross-layer architecture. It shares interlayer information by using different parameters to reduce security attacks on WSN.

In [57], the authors have proposed a cross-layer optimization technique to secure the delivery of images through wireless channels. The desirable parameters–BER, ARQ retry limit, and transmission rate are optimized across the three layers (i.e. PHY, MAC, and APP) with respect to image distortion reduction required and energy-efficient communication.

In [58] the authors have presented an Efficient Dynamic Selective Encryption Framework (EDES) to ensure the security of multimedia traffic in WMSNs. EDES proposed three security levels and the selection depends upon the energy and QoS parameters. A cross-layer approach is used for EDES to take different parameters from the physical, MAC, and upper layers. The capacity metric is used for the evaluation to increase or decrease the level of security. The EDES is a two-step framework wherein in the first step, network performance parameters are determined by combining the QoS parameters and residual energy to capacity function CAP. This requires parameters from the MAC, network, and upper layers. The second step selects the security level based on CAP.

Table 6: Comparative analysis of different CLD approaches for WSN by Security

Reference Paper	CLD approach	Layers contributed in CLD approach	Result of CLD approach	Future scope
[54]	CLD framework introduces TruFiX mechanism	Physical and Network layer	T-XLM specific protocol TruFiX performs better than RBSS(resource bound security solution) based protocols with regard to security performance.	Both SVM and MCDA are being used to evaluate the effectiveness and efficiency of each routing estimation technique.
[56]	CLD Based security Framework	The Network layer, MAC and Physical layer	CLBCSF(cross-layer based comprehensive security framework) is an appropriate model used for the hierarchical clustering.	CLBCSF gives a new direction towards protecting the communication links and extending the lifespan of the whole network.
[57]	Cross-layer resource allocation technique	Application layer, MAC layer, and Physical layer	The images that are moving across the network must be protected.	-----
[58]	EDES- based on a cross-layer approach	Application layer, Network, and MAC layer	Defining the security level for the various scenario can improve energy efficiency and QoS.	Plan to extend the study to dynamic MWSNs by using mobility.

5.5. Error Control

An efficient cross-layer erasure coding technique in [59] determines the redundancy rate of erasure coding. It keeps trying to adapt the channel condition with the traffic load in the application layer. Another technique to detect redundancy in the wireless link layer is the hybrid FEC/ARQ method. Afterward, the objective function is proposed for FEC/ARQ approach. It controls the parameters through packet loss Information. At last, the UEP approach was used to improve the efficiency and consistency of the transmission of video packets. The result of the simulation verified the performance of the cross-layer error control method in contrast to other approaches with respect to different parameters like energy efficiency, PSNR, and delayed-restricted PSNR.

5.6. Network Resource Management

The authors in [63] represented a new cross-layer technique namely cross-layer collaborative communication (CL-CC). The sensor nodes must be adjusted to the changes in their environment to achieve successful network management. At any time, CL-CC uses temporal correlation to correctly estimate the node’s sleeping time. It assists the node is transmitting data of higher quality and also reducing redundancy of data and energy usage. Spatial correlation is also used by sensor nodes to change their sensing activities. The simulation result indicates that the performance of CL-CC is better than the CC-MAC, LSWCC & Anycast to improve network performance.

Table 7: CLD approaches for WSN by error control

Reference Paper	CLD approach	Layers contributed in CLD approach	Result of CLD approach	Future scope
[59]	Novel adaptive cross-layer protocol intended for error control across WMSN	Application layer and Link layer	NAC offers improved performance as a contrast to the other error control methods in real-time multimedia streaming across networks.	-----
[60]	CLD approach for error control scheme in 3-D UWSNs	Network, MAC and Physical layer	HARQ-I and FEC block codes have high error correction feature and a small n/k ratio is the most appropriate for error control schemes.	Initial tests with an underwater research platform, and assessment and comparison of results by using Fountain Codes.
[61]	CLD approach for error control in WMSNs	Application layer, Transport layer, and Physical layer	FEC approach capable to deliver strong bit error correction to solve packet loss in multi-hop transfer.	-----
[62]	Cross-layer method for error control mechanism in WSN	Network, MAC and Physical layer	Hybrid ARQ and FEC methods significantly enhance error resilience Communication in contrast to ARQ.	FEC scheme can be used in multimedia applications.

Table 8: CLD approaches for WSN by Network Resource Management

Reference Paper	CLD approach	Layers contributed in CLD approach	Result of CLD approach	Future scope
[63]	Correlation among nodes to improve the effectiveness of the network by CLD approach	MAC layer	CL-CC determines the node's sleep time to transfer high - quality information while reducing data redundancy and power consumption.	Aim to expand the current work on mobile WSN.
[64]	CLD for network lifetime optimization	Network and MAC layer	Optimize the network life of WNSs by evaluating the impact of both the physical layer parameters and SPP.	-----

Table 9: Abbreviations used in this work

Abbreviations	Description	Abbreviations	Description
CLD	Cross-Layer Design	WMSNs	Wireless Multimedia Sensor Networks
WSN	Wireless Sensor Networks	SUIT	Sensor Fuzzy-based Image Transmission
DMF	Data Management Framework	LBRF	Load Balanced Reliable Forwarding
CLF	Cross-Layer Framework	DLBS	Directional Load Balanced Spreading
CE	Configuration Engine	RRA	Radius and data generation Rate Adjustment
CLM	Cross-Layer Management	T-XLM	Trust-based Cross-Layer Framework
QoS	Quality of Service	CLBCSF	Cross-Layer Based Comprehensive Security Framework
LEACH	Low-Energy Adaptive Clustering Hierarchy	SVM	Support Vector Machine
PDR	Packet Delay Ratio	MCDA	Multi-Criteria Decision System
BPSK	Binary Phase-Shift Keying	RBSS	Resource Bound Security Solution
CH	Cluster Head	NAC	New Adaptive Cross-layer Error Control Protocol
DEAP	Distributed-Environment-Aware Protocol	UEP	Unequal Error Protection
EECP	Energy Efficient Cross-layer Protocol	ARQ	Automatic Repeat Request
EAP-CMAC	Energy-Aware-Physical-layer Network Coding Cooperative MAC	HARQ	Hybrid ARQ
DRPC	Distributed Routing Algorithm with Transmission Power Control	FEC	Forward Error Correction
DPC	Distributed Power Control	PSNR	Peak Signal-to-Noise Ratio
WUSNs	Wireless Underground Sensor Networks	CL-CC	Cross-Layer Collaborative Communication
IQOS	Improved Quality of Service	MAC	Media Access Control
XLCP	Cross-Layer Communication Protocol	CC-MAC	Correlation-based Collaborative MAC
WBANs	Wireless Body Area Networks	LSWCC	Localised Slepian-Wolf Coding-based Correlation approach

6. Categorization of Recent Cross-Layer Design by different techniques

Except for the classification based on the number of layers participate in the optimization. Another categorization for cross-layer design in WSN could be technique. I summarize the table 10 according to the recent work of CLD in the WSN.

Table 10: Categorization of CLD by different techniques

Author et. al./Year	Energy efficiency	Reliable communication	Quality of service	Security	Error correction	Network resource
Zhang et al. (2018)	√					
Babber et al. (2017)	√					
Saini et al. (2017)	√		√			
Sarvi et al. (2017)					√	
Umar et al. (2017)				√		
Sadiq et al. (2017)	√					
Singh et al. (2017)	√					
Xenakis et al. (2016)	√					
Ammar et al. (2016)	√					
Yan et al. (2016)	√					
Anbagi et al. (2016)			√			
Ranga et al. (2013)		√				
Das et al. (2015)	√					√
Lin et al. (2015)	√					
Fouzi et al. (2015)	√					
Demir et al. (2014)			√			
Gawdan et al. (2011)				√		

7. Cross-Layer Design Challenges

Although there are many advantages of implementing the cross-layer architecture, there are still some new challenges faced by the system. Some of them are discussed in table 11.

Table 11: Challenges of CLD

Challenges of CLD	Main Reason	Possible Solution
Coexistence problem in CLD[3]	Each CLD has its individual standard for the interaction among different layers.	The coexistence of CLD is determined by the standardization of interfaces.
Signalling problem in CLD	There is also no standardized format or way of exchange of cross-layer information in the wireless network.	To make use of ICMP Messages and packet headers to avoid implementing a signalling protocol.
Extra workload induced through cross-layer signalling	It results in an additional burden while sharing information among the nodes.	The layered abstraction method and distributed mechanism may be used for reducing overhead.
The nonexistence of universal CLD	CLD for any particular application might not be appropriate for any other application.	Universal CLD is unlikely to exist for all of the purposes.
Destruction of layered architecture[65]	Cross-layer may disrupt the very well-organized layered design into a disorganized design.	TCP/IP model is used to enhance the features and performance of the layer without destroying its layered design.

8. Conclusion

In this paper, we have presented the goals and significance of CLD and its implementation method in WSN. It demonstrates the several frameworks for cross-layer design within the WSN. We have discussed in detail various cross-layer optimization techniques for wireless sensor networks. To bring wireless sensor networks more secure, energy-efficient, and optimized, the different aspects of the cross-layer design approach have been discussed.

In this paper, we have put forward many such techniques that not only improve the overall interactions but also improve the Quality-of-service(QoS). Furthermore, the challenges of cross-layer design have been highlighted and identified their possible solutions. This could be a reason for the future improvement in cross-layer design to overcome existing work limitations.

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