Cross Layer Design for Wireless Multimedia Networks: Issues and Solutions at Network Layer

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***Abstract* -- Computer networks have become a crucial element in the day-to-day life as world's scientific and technology level continues to rise. The computer networks not only increase the efficiency of communication systems, as well as minimize the commute time between people, and can also advance the global social and economic development, resulting in a favorable impact in the modernization. This modernization has brought out the new challenges in the design of the networks and architecture. The limited use of traditional layer has deemed and implemented a new architecture. Considering these parameters there is a need to develop a cross layer architecture to support the demands. This paper however describes the cross-layer design features and the challenges associated with the design and provides insights for those challenges.**

Keywords— Cross Layer Design, Data Privacy, Wireless Transmission, Local Area Network (LAN), Network Access, Wireless Fidelity (Wi-Fi), Network Models, Quality of Service (QoS), Virtual Private Network (VPN), Data Module, Reception Data, Routing, Scheduling.

I. Introduction

The cellular and the telecommunications technology has been in implementation since the mid-20th century [1]. Since then, its use has grown rapidly and the number of users of this technology has peaked enormously. The mobile phone technology has been implemented across all the countries around the globe [2]. These communications through the networks happen through the interconnection of networks. The most important components of the networks are Open System Interconnection (OSI) model and the TCP/IP model [3]. The primary focus of the OSI model or TCP/IP will be on the third most layer called Network Layer. The tracking of location feature is enabled in the Network layer and manages addressing. The network layer also has many applications like internetworking, routing, and addressing [4]. It also handles messages or packets from the top and bottom layer of Network Layer [4]. The critical packet loss is one of the demerits of this layer. Thus, a new model or cross layer architecture is required to overcome the demerits.

There are various problems and issues that must be addressed each differently. To achieve this, the designers of the cross-layer networks follows functional trade-offs mechanisms [5]. In today's generation the typical problem that the end user face is energy and power availability, routing and the Quality of Service (QoS) [5] where all the parameters work differently under different conditions. "Routing, one of the functions of the network layer, determines the path of the packet for the transmission and retransmission" [6]. The various parameters like packet length, queue length and time delays are lost during the transmission with the routing protocol.

In this paper the work is divided into seven sections. The section II gives an overview of network architecture, section III gives insights about cross layer architecture and section IV presents design goals respectively, section V gives the cross-layer design issues at network layer and section VI presents with possible challenges and solution followed by conclusion. The figure below represents the basic architecture of networks.

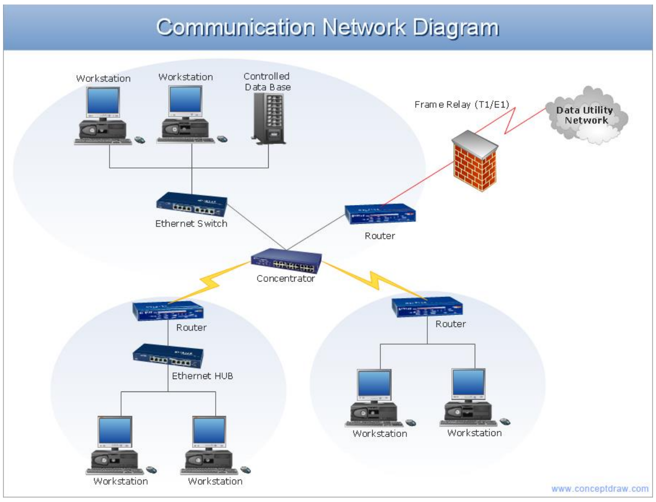

Fig 1. Basic network architecture

II. Network Architecture

The term Open system Interconnection (OSI) is coined by the International Standards Organization (ISO) during the mid-20th century and the standard definition describes that "it is a protocol which establishes the connection with different communication systems". These systems at each component are divided into the layers and the connections between these systems are formulated by grouping or combining the different layers of the systems [7]. These systems are maintained and developed by the ITU (International Telecommunications Unit), IEEE, and the ANSI standards organization. These organizations help in setting up different rules and functions of each layer for communication with other layers along with transmission and retransmission at proper times [8]. In other words, the standardization helps in establishing the connection between the communication systems by following the standard protocols. The OSI model has seven different layers and all of them communicate with other layers. These layers can also be coined as the stack and each layer has the layer number or descriptor [9]. The topmost layer is the application layer and bottom most is the physical layer where these layers are implemented by software and hardware respectively. The other layers in between the application and physical layers are mostly designed and implemented through software [9]. Each layer has its own function and protocol. The data or the message from the application layer is sent to the physical layer as bits and vice-versa. The data or message at the application layer is converted into the datagrams, frames, packets, and bits respectively while flowing from the topmost layer to the bottom and through hardware equipment.

The network layer is the most important of all the layers as the data requested to application layer is transported through the network layer. The network topology behaviour is unpredictable, and it changes from time to time. The values of the data will be different from before establishing the connection and after establishing. The theory of establishing the network connection is connecting with each networking nodes before the start of the data transmission. The wireless transmission of data is vulnerable to many threats at the physical and data link layer [10]. "Despite the widespread adoption of the computer network, some computer users are unaware of network security and do not pay attention to the installation and updating of anti-virus software and firewall systems, exposing personal information and jeopardizing network security".

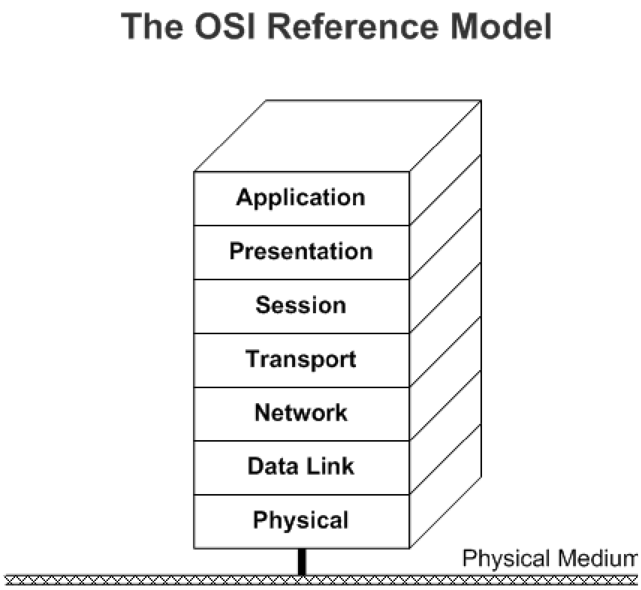

Fig 2. OSI Model Representation

The network layer is the most important of all the layers in the OSI model. A network is defined as an interconnection of many nodes through a medium where the data transmission takes place through these nodes through intermediate nodes. If the data or the packet length is too large, the packets are broken down into smaller packet length and sent over the channel, where it is rearranged at the destination end. Some of the protocols [11] that work at the network layer are TCP/IP, DHCP, ICMP, RIP, MARS etc. The operations performed at the network layer are described below.

a. Routing
b. Addressing
c. Packet-Switching
d. End-to-End Error detection
e. Error and Flow Control.

The functions [12] like *internetworking* will establish the logical connection between the nodes. The *addressing* function will identify the devices on the internet. The source and destination are identified during this function. The *routing* function will mainly try to identify the shortest and the best possible route for the packets from source to destination without the packet loss during the transmission. The crucial functions are depicted in the figure below for more clarity.

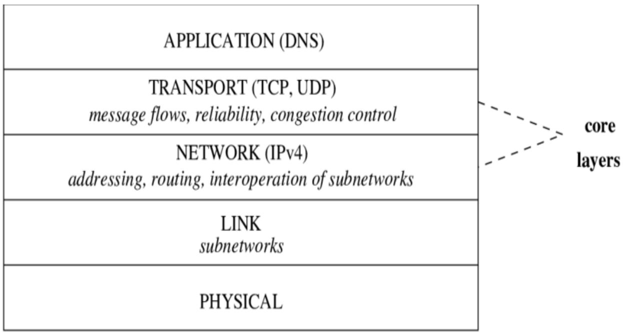

Fig 3. Network Layer operations

There are wide variety of services that Network layer offers. One such example of the service is the distribution of service which ensures timely delivery of the packets to their intended destinations. This also ensures that they are distributed in the order in which they are transmitted. This also guarantees the time interval [13] between two consecutive transmissions and reception. It also provides security and encrypts this data. This helps in maintaining the integrity of data and the authentication.

One of the crucial responsibilities of the network layer also includes the network addressing which is a software-based address. "The end system is referred to as a host and the computer has only one connection". The routers will have multiple connections, and which behaves as the link which receives the packet. The three most important protocols [14] at the network layers are:

1. ARP:

   This protocol mainly coordinates fixing the IP address to the MAC address and tends to know the IP address of the different host on the network. It also sends an ARQ request to packet containing the different IP address. Although the host receives the right packet, it will respond with the correct IP address. This results in establishing good links with the sender and receiver.

2. ICMP:

   This protocol is also referred to as the Internet Control Message Protocol. “This protocol is at Network Layer which are used by the hosts and routers to alert the senders and problems with IP datagrams”. Also, this protocol helps in finding out the destination of the packets. This protocol also detects the error and sends the acknowledgements [15].

3. PARP:

   This protocol is also known as Reverse Address Resolution protocol. This protocols message is almost identical to the ARP protocol.

III. Cross Layer Design Architecture

For the past few decades, the advancements in the technology have given rise to the new inventions in the technology. “These being the major inventions to the humans, the inventions in new technology in the cross-layer design for the wireless networks are new”.

To precisely understand this cross-layer design, we need to the functions and understand the design requirements [16]. In the OSI model, the services at each of these layers are provided and defined by the different and each layer of the layered structure, which prevents the miscommunications and is defined by the order of service by the following upper or lower layers and the communication between the top and the bottom layers are end-to-end [17] [18]and are limited. In order to design the structure, there has to be some standard set of guidelines that needs to be followed and the protocols must be defined taking into consideration for each layer.

To design the protocols at each layer we have multiple options with us. But in this paper, we define with two choices. We set it by defining as a standard that would give you a layered architecture where the bottom layers will be impacting by the top layers and the services provided by these layers will be irrelevant to each layer. The other option would be deviating the rules of each layer and defining the set of rules for each protocol layer.

To begin with, the layered architecture protocols, the protocols are designed with respect to the standard guidelines of layered architecture. This would allow us sharing of information among the layers. The layered architecture would allow and realize the functionality of the cross-layer design based on the other resources from the protocol layers [18]. Also, in this structure, the information sharing is allowed and facilitates the sharing of data to all other resources for the output and reliability [19]. This will also allow to increase the parameters such as throughput to different protocol layers and verifies the other information present in the different layers than the current ones.

The next choice for the design is by violating the standard defined rules in the layered architecture to design the cross-layer architecture. These can be defined as mentioned below.

i. The design goals and implementation should be different.

ii. The parameters for designing the architecture must be verified to give better performance.

iii. The integral parts of the architecture should be changed.

iv. Combining the adjacent layers to provide better service [19].

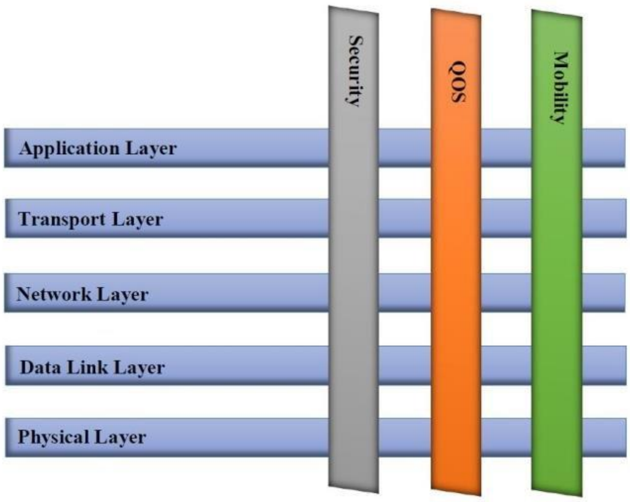

Fig. 4. Objectives of Cross-Layer Design

The various studies and experiments have confirmed the degraded performance of existing TCP/IP in wireless sensor networks without the implementations of the cross-layer designs. Furthermore, there are some difficulties and challenges while implementing the design goals of layered architecture during the setup procedures of cross-layer design. Since, the different applications have different set of goals and design, there is no ideal design of cross-layer networks [20]. The collaboration of different designs and merging into a single cross-layer design is the biggest challenge for all the designers, as it has different standards for the communication between each layer. The exploitation of the design destroys the encapsulation application [20] at the layers and changes the well-designed layer into the unwanted or undesired layer.

The cross-layer design is classified based on the information or data sharing techniques at the layer level. The design is classified as Manager and Non-Manager method [21]. The further classification based on organization of network is termed as Centralized and Distributed methods respectively.

A. *Manager Method*

“The manager method introduces one or more vertical planes for the layers in TCP/IP model”. This method does not necessarily change the structure of the model [21]. The main change in this method is the function of the protocol layers that allows data sharing in the vertical planes. This method is mainly proposed to solve the cross-layer design issues and improve the performance of wireless and link-terminals. The QoS [22], and the power saving requirements are the two main unpredictable factors that arises during the design of the networks. “The different layers of the protocol stack share the information in the vertical planes which helps in designing the enhanced version of the architecture”. The figure below represents the manager method abstraction.

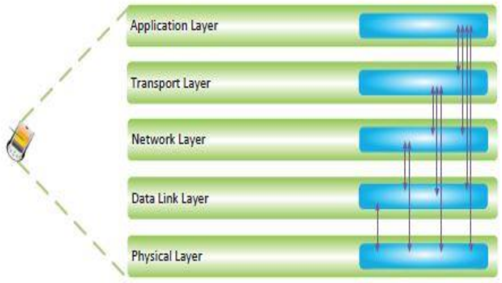

Fig. 5. Manager Method [17]

B. Non-Manager Method

"In this method, the communication will be allowed directly within the pair of layers of the protocol stack". The method does not change the five layers of the structure of the TCP/IP model [23]. In this method of design, the OFDM systems are used for the better performance and adapting the framework. In this type of design, a new Cognitive Network is developed as the new data network. The representation of Non-Manager method is depicted below.

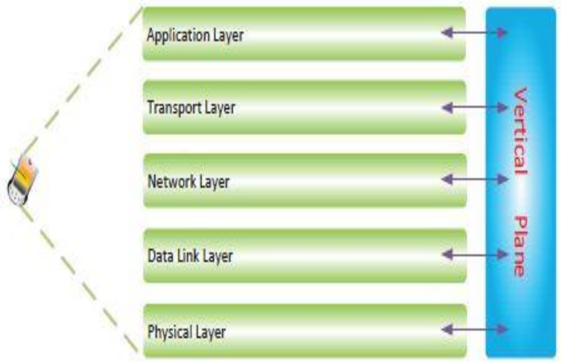

Fig. 6. Non-Manager Method representation [17]

C. Centralized Method

The centralized method introduces the base station in the cellular nodes and in the top-down model. This centralized node is introduced to manage the data sharing information in the TCP/IP layers between two nodes [24]. "This mechanism is developed by the UMTS"

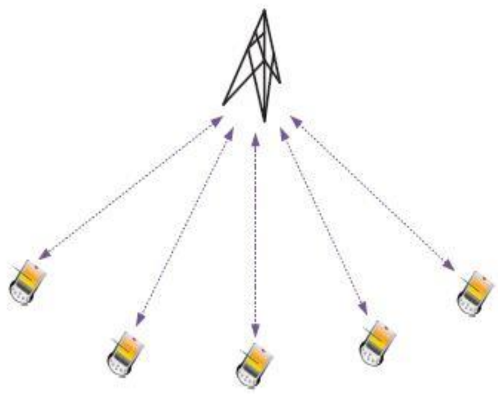

Fig. 7. Centralized Method Representation

D. Distributed Method

"In this method, the centralized node is not used or any base station". This method follows the multi-hop path, and the information is shared from node to node during the design of the cross-layer. The figure below gives an idea of the distributed method.

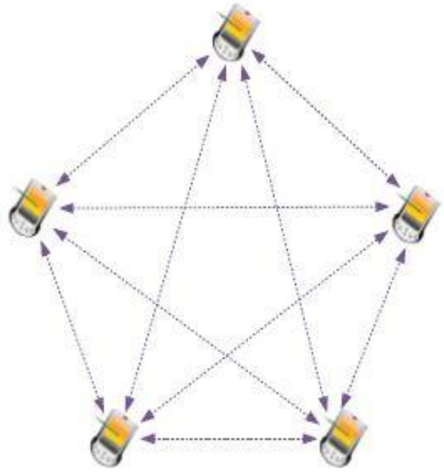

Fig. 8. Distributed Method [17]

IV. Cross Layer Design Goals

The goals of the cross-layer design are classified into three categories that describes the functionalities of the design. These are divided as Security [25], Quality-of-Service (QoS), Mobility.

A. Security

The Security coordination plane encapsulate the protocols about the security issues across the five TCP/IP layers [26]. For secure communication, the encryption methods may be implemented across the cross-layer design. These encryption methods like SSL particularly required at the application layer for end-to-end encryption. Other protocols like IPSec can be deployed at the network layer. The end-to-end encryption can also be applied at the other bottom layers such as the physical and the data link layer.

B. Quality-of-Service (QoS)

The QoS aims at providing the good quality of service in the wireless communication networks at all the five layers of the TCP/IP model. The topmost layers like application and the transport layers should have the information that is present with the physical and the data link layer [27] for the enhanced quality of service in any circumstances. This phenomenon is achieved by the coordination plane in the network model. One great example of QoS [28] is preventing the transmission error in wireless networks will improve the QoS.

C. Mobility

For the uninterrupted communication in the wireless networks, mobility plays a crucial role. It assures the smooth communications throughout the networks. Node movements are the common issues in the network [29]. The new routes and channel switches come into play for the enhanced handoffs and undisturbed performance [30].

S.No	Pros	Cons
1.	Upper Layers can reuse the functionalities of lower layers.	Performance issues due to layering
2.	Lower layers can be changed without disturbing the upper layers.	Application with hard QoS constraints
3.	Easier to optimize and maintain Protocols.	Information or data of one layer cannot be used with other layers
4.	Simplified Design	Introduces Redundancy

Fig. 9. Pros and Cons of Cross-Layer Design

a. Cross Layer Design in Wireless Local Area Networks

The cross-layer structure which is defined in five-layer structure and all the layers in the architecture are treated independently. The WLANs have the better performance when using the cross-layer design. To effectively utilize the design and efficiency, we use CDMA techniques [31] in parallel with the WLANs and this will enhance the performance of the design.

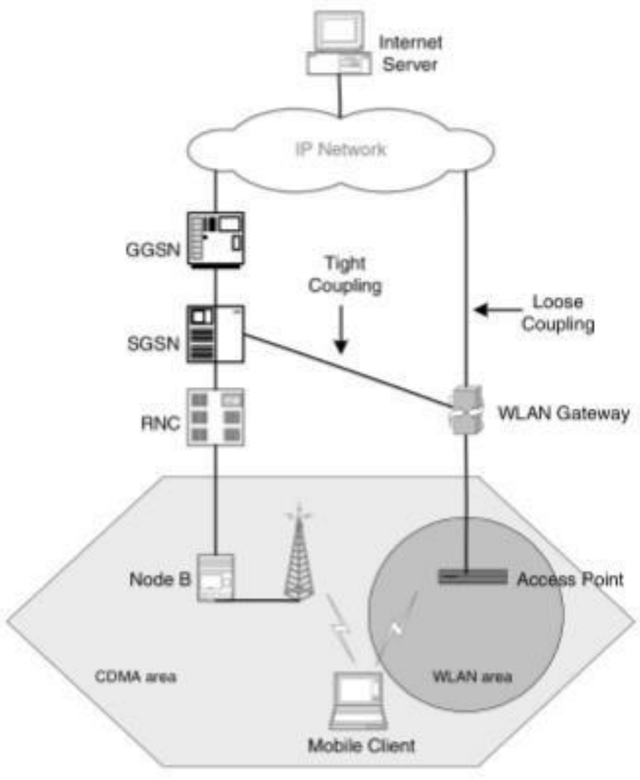

Fig. 10. CDMA and WLAN networks representation [32]

The two important aspects in developing the WLAN model are tight and loose coupling which is shown in the above representation where the UMTS [33] services are presented.

One of the core advantages is the improvement of the hight network transmission rates and this can also be improved further using the cross-layer design approach. This high transmission rate particularly important because, the large data size like high-quality video can be sent over the wireless channel. Due to the factors like availability, this large portion of the data can be sent, and the vast networks of wireless channels uses the WLANs preferably [34]. WLANs partially restricts the users from accessing the high data rates in smaller channel. “Contemporary mobile devices increasingly have smaller multiple networks allowing users to use the internet through the WLAN wherever possible”. Since there is a difficulty in having the transmission network handling the extremely huge content of data, Terahertz based network is proposed which supports extremely high bit rate.

b. Cross-Layer Design in the Cognitive Radio Networks

“CR or Cognitive Radio network is the technique that allows the unauthorized users to utilize the licensed spectrum”. The micros-signature schemes that is required to develop the CR networks are discussed in [35], which presents the characteristics like link adoption and cooperation.

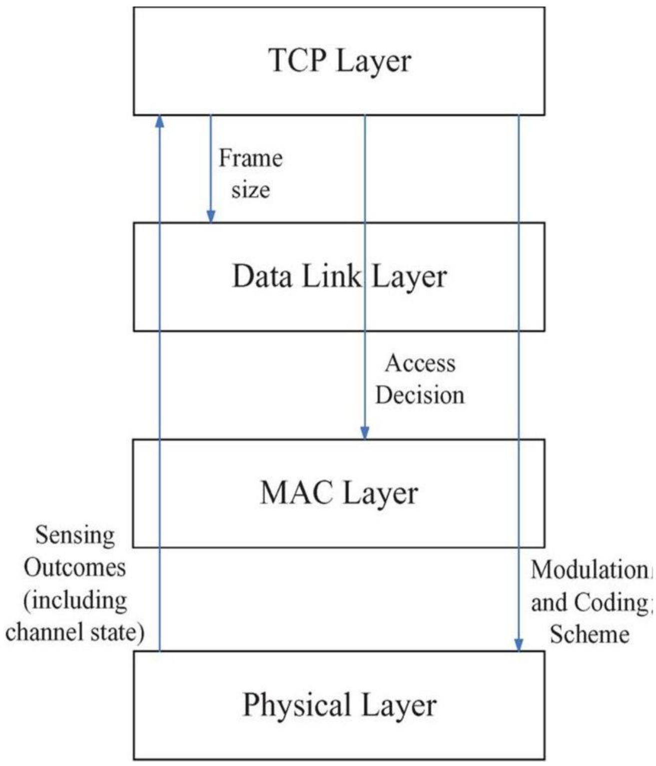

Fig. 11. Cross-Layer Design for TCP for Cognitive Radio Networks [35]

“The above figure represents the Cognitive Radio networks optimized version”. The sensor in the CR network captures and monitors the data resulting from the sensor activity. The output screened from the sensor network is sent to the TCP layers. To enhance the throughput of the TCP, we need to configure the channel and implement the coding scheme.

This method will prevent the interference problems and improves the accessibility to the spectrum, which identifies between CR MANETS to conventional MANETS [36].

V. Cross Layer Design at Network Layer

Network layer is one of the most crucial in the OSI model because of the communication between other layers through the packets exchange [37]. It also incorporates routing and selects the best possible route for the packets to reach to their destination. To enhance these functionalities, the introduction of cross-layer techniques will significantly improve the Quality-of-Service constraints along with the parameters like efficiency and the security. Cross-Layer also introduces some design issues. This research paper also presents some of the design issues of the cross-layer and gives you an overview of the solutions that can overcome these challenges [38].

Network coding is necessary for the cross-layer design since its principles are used in data processing techniques which helps in maximizing the data flow in the network. This technique also helps in improving the data broadcasting and communications. The number of retransmissions will be reduced by the help of network coding [39]. The network coding should be notified due to the reasons stated below.

i. The random loss and delays in the packet transmission.

ii. The inconsistent capacities caused due to the congestion.

iii. The status of broadcast capacity remains unknown.

Mobility Management Functions

There are important mobility management functions [35] that needs to consider while designing the cross-layer functions. The management is necessitated by the users covered by different radio cells.

A. Location Management

Location management helps the network to know its mobile's location so it can route the incoming calls to the correct destination. The messages sent by MS will indicate the point of access. There is a trade off between the location update cost and call delivery cost. There are also different management protocols for location management. The Visitor Location Register will keep track of the mobile base station and the Home Location Register [39] is a database for the user profile for mobile base stations. The HLR and VLR's exchange the signalling information through the SS7 signalling network [40].

B. Handoff Management

The handoff management will have the mobile node connection which keeps in the active state when moving from one location to the other. To maintain the connection throughout the network, handoff management [40] plays a crucial role. This is also termed as the soft handover process. The priority must be given to the handover process than handover dropping.

The cross-layer architecture has several applications in various fields like medical, satellite networks and other related research areas [40]. This research paper mainly gives an overview of how the cross-layer can improve their efficiency, performance and the QoS [41]. The wireless and the wired data networks support the data services due to the cross-layer infrastructure. Few challenges faced by the design are interference, multipath fading and the hidden node problem.

VI. Challenges and Possible Solutions

There are some challenges faced while designing the cross-layer networks. This research paper provides you with an over of challenges and presents possible solutions. Some of the challenges are mentioned below

A. Quality-of-Service

The Quality-of-Service is one of the important aspects while considering the cross-layer design. The QoS constraints [42] such as the throughput, delay and the jitter, packet transmissions etc are some of them that needs to be considered. QoS is considered while addressing the physical layer design implementation using the Signal to noise interference ratio [43]. The constraints such as the queue length is determined at the link layer or MAC layer, and SINR at the physical layer.

To efficiently maximize the throughput and power in the CR networks, channel allocation problems all of them uses the discrete channel methods. The secondary spectrum utilizes the operative spectrum in CR networks. The quality of video content for example is taken for QoS, where the quality is affected during the slow transmission. This tends the upper layer to communicate with the bottom layers.

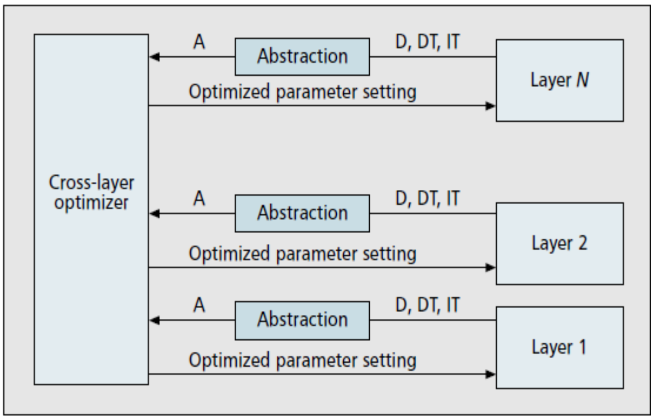

Fig. 12. Cross-Layer architecture for video-streaming [44]

B. Routing

In order to transmit packets from source to destination, the packets have to choose the best possible route. This process is called Routing in the networks. Routing is possible with the Internet Protocol (IP) [45] from source to the destination. This routing algorithm will generate a new route at the node of the network and checks for the quality-of-service constraints and forwards the packets.

The fastest route when decided, the node in the network always checks for the forwarding routes and makes sure no packet is lost during the transmission [45]. Due to this algorithm, there are high chances of enhanced throughput and the QoS improvement. On the other hand, this algorithm also uses the RSS to enhance the performance of the TCP and improves the QoS through each set of nodes throughout the network [46].

C. Throughput

Throughput is measures as the overall performance of the network or a particular network and this is one of the most important parameters for the cross-layer design. The total data that is measured or abstracted from the source to the destination is measured in terms of the throughput. The primary challenges where the designers face is modelling the throughput [46]. To overcome this challenge, designers are developing new models and one such model currently the cross-layer design has is the symbol mapping technique. The paper [47] briefs the multipath fading challenges and provides an overview of the solutions that can prevent the multipath fading and diversity issues. In this paper [48], the challenges and solutions related to the throughput problem has been discussed.

D. Latency

Latency is measured in terms of wireless networks as the data packets when transmitted is delivered to the destination and the source will acknowledge the delivery. The designers have addressed this issue in conjunction with the MAC layer protocols discussed in [48]. The aim is to reduce the total number of nodes present in the network and use the same nodes through which the packet has traversed. The algorithm used to improve latency will measure the total nodes or points which the help of the network layer and reduces the delay from reaching the destination. The current technology makes use of VANETS and SMDP algorithms [45] that helps improving the reception time and reduces the significant delays.

E. Traffic Optimization

Although there are too many channels and network nodes, the traffic that causes the inefficiencies in the networks are no less. This causes significantly poor reception at the receivers end and makes networks congested. These traffic in the networks are classified as elastic and the inelastic traffic [43]. The optimization techniques [49] are worked out among the radio access networks and the heterogeneous networks which leads to the channel allocation orthogonally [49]. These issues can be worked out by proper use of resource allocations to each channel, where only specific network packets use the channels.

F. Security

The security issues are deemed to be one of the major challenges in the wireless sensor networks. These security issues are identified mostly in the mobile and ad-hoc networks. This problem can be typically resolved my making use of new cross-layer techniques which can be worked on the physical, link and the network layers. The model proposed by the designers include the working on the monitors and the verifiers. The malicious activities on the network can be identified by these two elements [47]. The technologies such as authentication, firewalls and confidentiality can be implemented. One such type of security optimization technology is the Intrusion Detection System (IDS) and Intrusion Prevention System (IPS). The encryption technology will improve the message confidentiality and keeps the data end-to-end encrypted [48].

G. Packet Loss

Packet loss is the most common issue in the networks. To improve or prevent the packet losses, the new cross-layer designers approach includes Data Aggression DA-MAC layer [49], where this phenomenon can reduce the packet loss by tolerance. This technology uses the channel information from each node. The packets are sent over multiple nodes and the data is collected from each node individually. One of the current designs follows the synopsis model, where the robustness of the packet delivery enhanced significantly.

H. Network Lifetime

The network efficiency is measured in terms of the total time the wireless sensor networks currently have. This can be achieved by the routing schemes and developed in the bottom two layers, the physical and the MAC layers [51] respectively. The lifetime can be improved by reducing he latency at the link layer which reduces the burden on the network nodes. The routing scheme proposed in choses the alternate node for the energy efficient channel and uses scheduling algorithm. The inactive nodes will lead the energy efficiency issues [46]. The papers [47] [49] [50] [51] explains important algorithms and protocols that provides the solutions to the major challenges faced by the cross-layer design today.

VII. Conclusion

Considering the current cross-layer design the TCP/IP model layers were generally able to get access to the other layers and can communicate with each other [52]. To prevent the current challenges, the cross-layer design techniques must be applied on all the five layers of the model. To enhance the constraints like QoS, security and latency [53] [54], the design techniques should be usually applied across all other nodes in the network layer [55]. This research paper presents the current cross-layer architecture, network layer architecture, and presents the issues and possible solutions. To summarize, the design of cross-layer networks will have improved system functionality with efficiency, high QoS, mobility and security.

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