A Survey on Cross-Layer Optimization in Wireless Networks

Bindeshwar Singh Kushwaha, Pramod Kumar Mishra

***Abstract*—TCP/IP model is a dominant layered stack for wired networks but from the evolution of wireless technologies such as WiFi, WiMax, 3G/4G, ZigBee, sensor networks and satellites communication systems, these systems have posed specific challenges to support Quality of Service (QoS), mobility and handover, link adaptation, energy constraint performance, and security. To solve these problems TCP/IP model should be enforced. Cross-layer architectures have shown great performance improvement and it may shape the future of wireless networks. In this paper, we list several cross-layer models and parameter to design and address important issues and challenges to develop cross-layer stack. Moreover, we discuss standardization, complex architecture, solicitous design, and implementation issues to build cross-layer architectures.**

***Index Terms*—wireless networks, cross-layer optimization, energy consumption, network security, throughput optimization, Quality of Service (QoS).**

I. INTRODUCTION

The categories of wireless networks depend upon transmission range, geographical area it covers, maximum data rate it supports, media they use for transmission of signals and the purpose they are being used. Furthermore, from the proliferation of wireless technologies [Fig. 1] many wireless network architectures have come into existence, such as, sensor network, PAN (Personal Area Network), BAN (Body Area Network), infrastructure network, mobile ad hoc networks, wireless MAN (Metropolitan Area Network) and (Wide Wireless Network). Moreover, each network poses specific problems for protocol designers and also requires specific solutions, however, one of the common things that they can be solved by cross-layer optimization techniques.

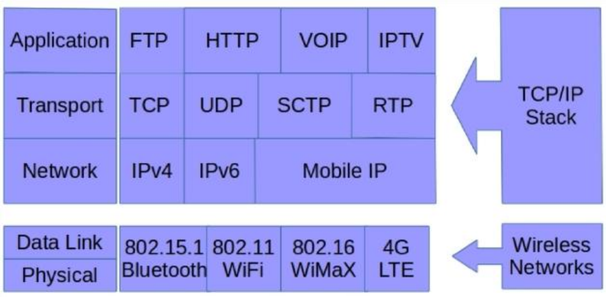

Fig. 1. TCP/IP over wireless networks

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TABLE 1: NETWORKS AND THEIR ISSUES

Network	**Cross Layer Issues**
WLAN	QoS, Mobility, Security
MANET	QoS, Mobility, Energy, Transmit Power Management
Sensor Networks	Energy Constraints Nodes
Cellular Network	Location and Handoff Management

A. Sensor Networks

A sensor network [1] [Fig. 2] contains distributed sensors and a sensor network has wide range of applications in monitoring systems, for instance, air pollution in the environment, industrial monitoring, health monitoring and wild life monitoring. Usually, sensors are deployed where human do not reach frequently. The energy efficiency becomes paramount issue and introduces the characteristics of energy constraints nodes, low data rate and small transmission range.

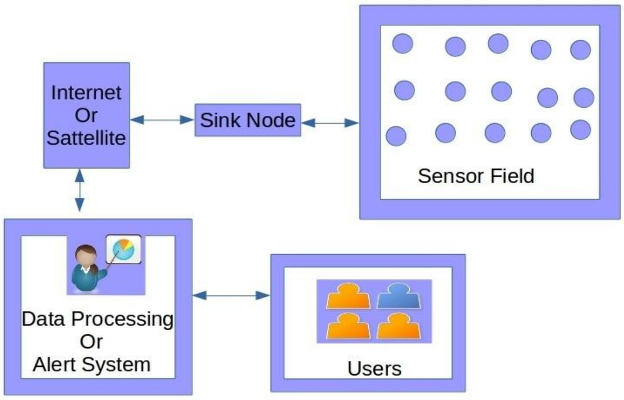

Fig. 2. Sensor network

These types of networks characterized by low transmission power and short-range such as 10 meters to 15 meters. The IEEE 802.15/Zig Bee standard [2] specifies the PHY and MAC of the protocol stack for underlying wireless technology. Further, it uses the ISM band 2.4 GHz frequency band. IEEE 802.15 specification for PHY layer and MAC layer is defined for low data rate and transmission power. In addition, the challenges in sensor networks are energy consumption and interference due to high transmit power that devices can introduce interference, if they operate at the same frequency band.

B. Wireless Local Area Networks

Basically, there are two types of wireless area networks, the first is the infrastructure network [Fig. 3] and the second is wireless ad hoc network. Furthermore, in infrastructure network end users are connected to a central device that

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coordinates the function of medium access called access point or base station, and the base station is usually connected to a router or another switch which are Integrated to the Internet. Moreover, when a node needs to communicate with another node on the Internet it can do only through the base station and base station sees all communication-related tasks, such as time allocation, bandwidth allocation, security, and authentication. In addition, the problems related to the infrastructure network that can be solved by cross-layer optimization are TCP deployment, error control, interference mitigation, and security.

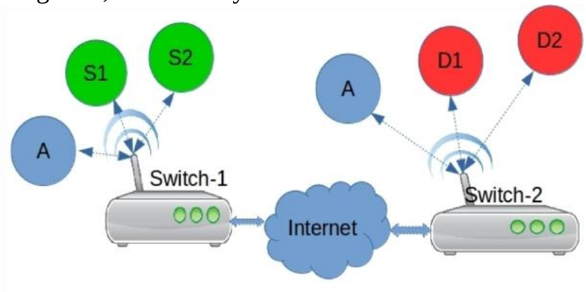

Fig. 3. Infrastructure network

Moreover, the second type of WLAN architecture is ad hoc network [3] [Fig. 4] is a decentralized network in which a node works as host as well as router. There is no central control on nodes and they autonomously form network topology. This type of network is used for a specific purpose like a military operation, disaster situation, and areas where building infrastructure is costly or infeasible.

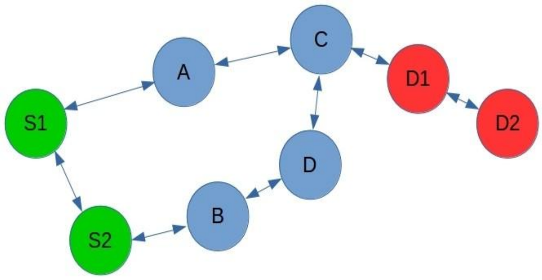

Fig. 4. Ad hoc network

Additionally, traditional routing solutions, such as RIP (Routing Information protocol) and LSR impose hierarchal structure and cannot address new network architecture issues, for instance, mobility, frequent link broken, energy optimization, transmit power control and security. To address these problems, many routing solutions have been proposed in the literature, such as AODV [4], DSR [5], and OLSR [6] and these protocols address issues like routing loop and distributed solutions. However, they do not address energy optimization, high mobility, topology control, and security issues. In addition, for both types of networks IEEE standardized as 802.11 specifications [7] popularly known as WiFi and it has generally transmission range from 150 meters to 250 meters. Furthermore, 802.11 specification defines PHY and MAC layers and the MAC layer uses CSMA (Carrier Sense Multiple Access) with collision avoidance to access the medium. Here CSMA means to listen to the medium before transmit and to void collision it uses RTS (Request To Send) and CTS (Clear To Send). Further, it defines two coordination functions DCF (Distributed Coordination Function) and an optional PCF (Point Coordination Function). Moreover, there to increase data rate many physical layers that use different modulation techniques have come, and still are coming. Additionally, 802.11a physical layer standard uses OFDM (Orthogonal Frequency Division Multiplexing) modulation technique over 5 GHz bandwidth and supports data rates 6, 9, 12, 18, 24, 36, 48 and 54 megabits per second this standard came in 1999. 802.11b supports data rates 1, 2, 5 and 11 Mbps and as physical layer modulation DSSS (Direct Sequence Spread Spectrum) 802.11g also uses OFDM technique but it uses 2.4 GHz band instead of 5 GHz and supports data rates as the 802.11a does, 802.11n standard uses MIMO-OFDM with 4 antennas and it uses both 2.4 GHz and 5 GHz frequency bands. 802.11 technologies is a standard for WLANs, although to deploy mobile ad hoc network on 802.11 BSS (Basic Service Set) is changed in IBSS (Independent Basic Service Set) which supports ad hoc network architecture.

C. Cellular Networks

Cellular network [Fig. 5] is a wide area network and the last access link of the network is wireless. The fact that the cellular network uses hexagonal cells. These networks have name cellular and it is now fast-growing wireless technology which provides voice and data services. The evolution of cellular technologies is categorized into generations based on the technologies they use. The first generation of cellular networks was based on analogue radio signal AMPS (Advanced Mobile Phone Systems) [8] and the technology it used was FDMA (Frequency Division Multiple Access). In this technology whole channel is divided into small frequency slots and when a user made a call a slot was allocated to him and the slot would be busy until the user released the connection. In the limited frequency, this technology was not scalable and supported a very limited number of users. Moreover, from 2G to onwards generations 3GPP (3rd Generation Partnership Project) [9] specifies cellular network architectures. Further, the second generation was the first digitized cellular network and GSM (Global System for Mobile) which was based on TDMA (Time Division Multiple Access), CDMA (Code Division Multiple Access) and GPRS (General Packet Radio Services) were the major technologies in this generation. The third generation was also based on 2G technologies but IMT-2000(International Mobile Telecommunications) compatible. Fourth-generation cellular network standard uses OFDM (Orthogonal Frequency Division Multiplexing) with MIMO (Multiple Input Multiple Output) to support high data rates LTE (Long Term Evolution) and LTE-Advanced is two standards for 4G. The fifth generation cellular network is in evolving phase and it uses OFDM with Massive MIMO and millimeter-wave frequency (frequency more than 30 GHz or wavelength in millimeter) this standard is characterized by a large array of antennas (64-256 antennas).

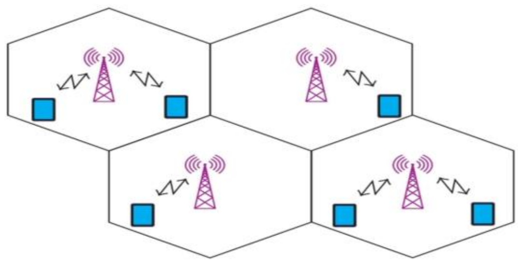

Fig. 5. Cellular network

In cellular networks, major problems are location and hand off management, security, energy optimization and transmit power control which can be solved by cross layer optimization techniques [11]. In addition, the next major sections are described as follows. [Section-2] discusses related work. Further, in [section-3], we will discuss the cross-layer design. In section-4, we explain cross-layer interactions, challenges to design models. In [section-6] NS-2 based MIRACLE for cross-layer architectures is explained.

TABLE II: LITERATURE REVIEW

Ref.	Pub. Yr.	Advantage(s) of The Model	Disadvantage(s) of The Model	Layers Interact
[24]	2019	Optimizes Bandwidth and Delay for TDMA based MANET	Specific Cross-Layer Architecture	NET-MAC
[25]	2019	Solves the Problem of Blockage, Deafness and Hidden Node for Visible Light Ad Hoc Network (VL-NET)	Specific Cross-Layer Architecture	MAC-NET
[26]	2018	Provides Better Congestion and Power Control Mechanism in Cognitive Radio Ad Hoc Network	Theoretical Framework	PHY-Transport
[28]	2016	Improves Throughput in 5G Cellular Network	Need an Additional Module Centralized Controller	NET-PHY
[27]	2017	Saves Energy Consumption and Increases Network Lifetime in Body Area Network	Theoretical Framework and Analytical Solution	PHY-NET
[29]	2015	Optimizes Use of Energy in Sensor Network	Theoretical Framework and Analytical Solution	PHY-MAC
[30]	2014	Optimizes Flow Control, Routing, Relay Assignment and Scheduling for Fading Channel	Theoretical Framework and Needs Cooperation among Nodes	PHY-DLL-NET-Transport
[31]	2013	Optimizes Application Layer Objectives in IoT	Mathematical Framework not Practical	PHY-DLL-NET
[33]	2011	Optimizes Scalable Video Coding Over 802.11e Wireless LANS	Specific Architecture	APP-MAC
[34]	2010	Improves TCP Performance in Cognitive Radio Network	Theoretical Formulation of The Problem	PHY-DLL-Transport
[35]	2009	TCP Distinguishes Channel Error to Congestion and Improves Performance in WLANS	Theoretical Evaluation of The Model	MAC-Transport
[36]	2008	Improves Performance of TCP	Need An Additional Module	DLL-Transport
[37]	2008	Improves Performance of TCP	Need an Additional Module	DLL-PHY
[38]	2008	Performance Improvement of TCP	Need Two Additional Modules	DLL-Transport
[39]	2008	Performance Improvement of Video Streaming	Theoretical Formulation and Analytical Solution of The Model	PHY-MAC-NET-APP
[40]	2007	Improves TCP Performance over Wireless Network	Requires Additional Module in Protocol Stack	DLL-Transport
[41]	2006	Performance Improvement of Multimedia Communication	Requires Additional Module For Coordination Among Layers	APP-DLL-PHY
[42]	2006	Optimal Design of Link Layer Parameters For TCP Traffic	Theoretical Evaluation of The Cross Layer Model	Transport-DLL
[43]	2006	Improves Transmission Quality of Video over WLAN	Medium Sharing Predictor is Emulated Not Implemented in Real System	PHY-MAC-APP
[44]	2005	Controls Congestion in Wireless Multi-Hop Networks Using Cross Layer Model	Requires Additional Module Within Protocol Stack	MAC-Transport
[45]	2005	Improves Quality of Multimedia Services over WLAN	Specific Cross Layer Architecture	APP-MAC-PHY
[46]	2004	Increases Throughput and Reduces Power Consumption in Wireless Ad Hoc Networks	Theoretical Formulation of The Problem	PHY-MAC
[47]	2003	Increases Power Efficiency in 802.11 Network	Theoretical Formulation and Analytical Solution	PHY-MAC
[48]	2002	Provides QoS for Routing Protocols in Mobile Ad Hoc Networks for Multimedia Applications	Requires Cooperation Among Nodes	MAC-NET
[49]	2001	Distinguish Route Failure to Congestion	Too Much Assumptions	NET-Transport

II. Related Work

TCP/IP protocol suite [12] is designed for wired links, and they have characteristics of low bit error rate, constant delay, reliability, no mobility and transparency among layers. TCP/IP protocol suite has five layers and a layer can provide services to the layer just above it and can receive services from just below layer through the well-defined access point. This modular architecture provides protocol designers to develop their protocols without worrying about other layers. For instance, a network layer protocol designer is unaware of flow control of the data link layer. An application layer protocol designer is unaware of TCP retransmissions. Furthermore, TCP/IP is modular and this architecture provides clarity and separation of modules. However, many assumptions were made that are suitable for wired networks such as link is reliable and has fix capacity. However, for a wireless link where channel condition depends on time and space and the wireless link has a high bit error rate probability, unreliable link, and mobility of users. In this environment, the design philosophy may produce some unexpected results, for instance, a problem was found in TCP protocol in a wireless environment, when there is a loss of packet in the network TCP assumes this is due to congestion [13, 16, 17, 18, 19, 20]. However, this loss may cause by high noise of a link, or due to fading or by interference between two channels or due to hand-off of a device. Moreover, many performance issues come into existence when TCP/IP is deployed over wireless networks. For specific problems such as multimedia transmissions over a wireless link, transmission power allocation, security, and energy consumption. To implement these architectures signaling techniques play an important role, in [21] CLASS (Cross-Layer Signaling Shortcuts) is defined, in which four methods of signaling namely, packet headers, ICMP messages, network service, and local profiles. Two methods for cross-layer interactions which are direct communication among layers and signaling pipe mechanism that is similar to cross-layer plane [13] are defined. In addition, many researchers proposed their specific cross-layer architectures [14, 15, 47] to solve problems. However, a generic architecture should be developed so that it will be easy to port, modify, and enhance to solve further cross-layer problems. In [22], authors proposed ECLAIR generic cross-layer architecture for wireless networks. In which cross layer management is divided into two subsystems, the first is Tuning Layer and the second is OSS(Optimizing Subsystem). Moreover, in ECLAIR, TL provides an interface to access the protocol's variables. OSS contains POs(Protocol Optimizers) where the performance of algorithms can be enhanced. In [23], a model MobileMAN is proposed especially for ad hoc networks, in which a vertical layer NetSt(Network Status) handles the sharing of parameters among the horizontal layers. Further, NetSt has a database of parameters if a layer needs information about other layers it can simply access from the database. Furthermore, the lack of standardization, researchers proposes their own cross-layer architectures to optimize protocol or solve problems. A cross-layer feedback system from the network layer to TCP is proposed in [49] which distinguish route failure from congestion in mobile ad hoc network. [48] Designed a model that provides QoS at the routing layer with the help of physical and MAC layer interaction but it requires cooperation among nodes through advertising messages by each node. In [47], a cross-layer model was designed for power efficiency in 802.11 networks with the help of joint PHY and MAC layers. In [46], for power efficiency and throughput enhancement a model was proposed which transmits the power so that, interference at the physical layer and size of contention window can be minimized, in the model MAC layer schedules the transmit power of the physical layer. Further, an effort is also put to design cross-layer models for multimedia transmissions. In [45], the physical and the MAC layers optimize their parameters based on the application layer objectives. A summary of the literature review is listed in the Table-2 draw the tabular review of the literature.

In [44], TCP gathers capacity information, bandwidth and delay from the link layer and regulates data rate so that congestion can be avoided. [43] Proposed a cross-layer model for optimized video streaming in which codec at the application layer determines its data rate based on the information retrieved from the MAC layer.

In [42], a cross-layer model is designed in which ARQ at the link-layer interacts with TCP at the transport layer for channel efficiency and to improve TCP performance in a Rayleigh fading model. In [41], authors proposed a model for video streaming in which the physical layer, the data link layer and the application layer interact to optimize video streaming at the application layer. In [40], TCP exploits information from ARQ protocol of the data link layer and improves performance of TCP in a fixed wireless network. In [39], the physical, data link, network, and application layer interact with each other and improve video streaming in a wireless mesh network. For multi-hop wireless networks, [38] designed model that requires cross-layer communication between the MAC and TCP that improves congestion-window unnecessary reduction which impacts the throughput of TCP. In [37], ARQ of the MAC layer and HARQ of the physical layer interact with each other and improve throughput and delay of TCP protocol. [36] Proposed TCP-PRN that requires hand-off information from the data link layer and improves TCP throughput performance. In [35] a model for wireless LAN also improves TCP performance in which TCP interacts with 802.11 MAC. For cognitive radio network, a cross-layer model [34] is proposed that needs cooperation among the physical, the data link, and the transport layers to improve the performance of TCP. A model that uses packet prioritization and QoS mapping for SVC (Scalable Video Coding) and the model exploits the interaction between IEEE 802.11e MAC and the application layer [33]. In [32], at the application layer source data rate is determined by the physical layer's channel statistics to improve the quality of video streaming. Cross-layer optimization techniques can be used for any network, emerging architecture IoT(Internet of Things) has proposed many problems such as energy optimization and security issues that can be solved by cross-layer optimization techniques. In [31] cross-layer architecture is proposed for IoT that optimizes energy consumption and reduces end-to-end delay, the architecture needs cooperation among the physical, data link and network layers of the protocol stack. Moreover, [30] optimizes flow control, routing, relay assignment and scheduling for fading channel that requires interaction among, the physical, the data link, the network and transport layers of TCP/IP model. For a sensor network, a cross-layer technique is proposed [29] which optimize the use of energy for the sensor network. For cellular network, a model [28] is proposed that uses the interaction between physical and network layers and that improves the throughput of the network. For WBAN (Wireless Body Area Network) an architecture [27] is designed to improve network lifetime and use of energy. In [26], for cognitive radio ad hoc networks, a cross-layer framework is designed for congestion and transmit power that requires interaction between the physical and the transport layer. In [25] for Visible Light Ad Hoc Network (VLNET) a cross-layer model was proposed which solves the problem of blockage, deafness and hidden node. Moreover, in [24] TDMA-MAC layer based cross-layer model was proposed which optimizes delay and bandwidth for real-time applications.

In addition, choosing parameters which can result in performance improvement to find that parameters which require a lot of experiment and research.

TABLE III: LAYERS AND ASSOCIATED PARAMETERS

Layers	Parameter(s)
Application	Data Rate
Transport	Congestion Window
Network	Route Failure, Topology Information
Data Link	Contention Window
Physical	SNIR, Transmit Power

Moreover, to find out parameters which are sharable and which can improve the performance of the protocols are very important. Choosing the wrong parameters can lead to performance degradation of the overall stack. We investigated some parameters which are used to design in cross-layer models.

III. CROSS-LAYER DESIGN

In wireless networks, channel conditions vary by several factors, for example, fading, interference, and path loss and transmit power of the nodes and these factors can degrade network performance if variations are not utilized. Further, if higher layers can utilize these variations of channel variation and make network adaptive real-time system applications can be deployed which require stringent QoS [45], using traditional architecture these applications cannot work efficiently i.e. network should operate at its varying capacity, but in TCP/IP higher layers (Application, Transport, Network) are unaware of lower layers(Physical, MAC) parameters such as bit error rate, SINR (Signal to Noise Plus Interference Ratio). If this information is available to higher layers, the layers can make decisions provided by lower layers and the performance of protocol stack can be optimized, furthermore, higher layers can also share parameters to layers to gain high performance. In other words, violation of modular architecture [Fig. 1] of the reference model to gain performance is called cross layer model [Fig. 2] [50]. In addition, it allows communication among different layers, such as physical layer to the application layer, MAC to transport, physical to network, etc. exchange of information for better performance also falls in the category of cross-layer modeling, for instance, physical to MAC, MAC to network, etc. To design cross-layer models mainly two types of methods have been discussed in the literature [50, 51, and 52]. First, creation of new interfaces in which a direct path between two layers are created to share parameters, on the other hand, in cross-layer plans a database of parameters is created which can be shared by all the layers. The details are described in section 3.1 and section 3.2 respectively about the creation of new interfaces and cross-layer plans.

A. *Creation of New Interfaces*

Creation of new interfaces [Fig. 6] provides a path to share information from nonadjacent layers [50], the information can flow from downward to upward, in which, higher layers make a decision based on information provided by lower layers [40]. Further, information can also flow from upward to downward, and in this case lower layers set their parameters according to demand of higher layers [42] or information can flow back and forth. This method is also classified as non-manager in [51].

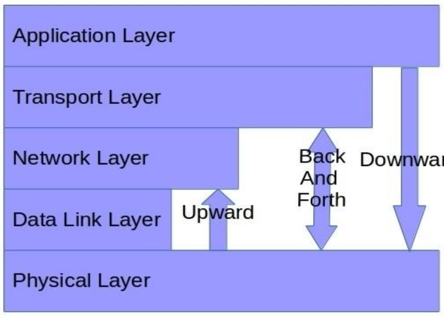

Fig. 6. Creation of new interfaces

B. *Cross-Layer Planes*

The disadvantage of creating new interfaces is that the two layers can only share information. To solve problem cross-layer plans [Fig. 7] [13] can be a solution.

Furthermore, in cross-layer plans, all five layers make a database of parameters that will be shared among all layers to optimize the performance of the protocol stack. Moreover, problems that belong to more than one layer, for instance, security, energy, mobility, QoS and transmit power control.

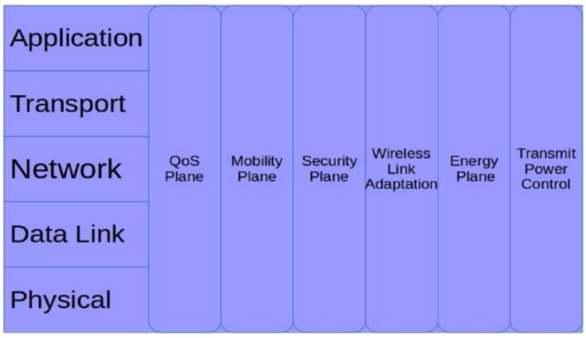

Fig. 7. Cross-layer plans

1) *Quality of service plane*

QoS indicates the ability of the network to provide the different requirement and resources demanded by the applications, for example, email requires high security, although, it can tolerate delay, live video streaming applications require low delay, on the other hand, they can tolerate loss BER (Bit Error Rate) in wireless links. It is very high and dynamic and to get better performance, higher layers must have adaptive algorithms to adapt to the environment. Moreover, for better coordination QoS plane [51] is necessary.

2) Mobility plane

The mobility problem cannot be solved by a single layer this requires coordination of lower layers to higher layers to reduce the effect of mobility and to provide smooth transmission of data of moving devices. Further, the IP level mobility management technique is not sufficient to mitigate packet loss and delay. To reduce the effect of mobility the network and the data link layers interaction can be a solution [11, 52], in which data link layer provides signal strength to the network layer and the network layer takes a decision.

3) Security plane

The purpose of the security plane is to ensure coordination among different layers to avoid multilayer attack, as well as, to eliminate multi-layer redundant security scheme to save energy consumption and avoid delay [13]. Further, in TCP/IP model layers are independent of each other and implement its own encryption methods [52], such as, IEEE 802.11 standard uses WEP, TKIP, and WAP2, at network layer IP security protocol, and at the transport layer SSL and TLS, security protocols require processing overhead, energy consumption, reduction in network performance. In addition, security plane can play an important role in the coordination of security protocols and mitigation of processing overhead, such as, if there is high processing overhead of security protocols the lower layers encryption algorithms should be stopped and higher-layer security algorithms should be preferred.

4) Wireless link adaptation plane

The high bit error rate of wireless link reduces the throughput and causes delay at higher layers, link adaptation plane provides coordination among higher and lower layers, such as, in [40] authors proposed a cross-layer model in which transport layer's TCP protocol congestion control algorithm adapts it according to link layer's ARQ protocol. Further, [43] designed a cross-layer architecture for video streaming that adapts 802.11 parameters.

5) Energy plane

Small devices such as sensor nodes are usually deployed where human do not reach frequently, such as landslide areas, tsunami, earthquake zones, woods. Moreover, to deploy them for a long time in such areas battery lifetime is very important and energy consumption depends on all the layers from the physical to the application layer and this reason enforces the concept of a vertical energy plane [51, 13] for cross-layer optimization for energy-efficient protocols.

6) Transmit power control plane

In ad hoc networks, due to mobility network topology changes frequently and fixed transmit power control cannot result in energy and throughput optimization. Furthermore, the physical's layer transmit power can impact both on the MAC layer and the network layer, if the transmit power is high then network layer hop count from source to destination will be low but at the MAC layer collisions will be high, it also impacts on congestion since high transmit power causes congestion in the network [53]. The mentioned issues almost need all layers to be involved, however, there is no discussion in the literature about transmit power control plane.

IV. Cross-Layer Interactions

To solve problems in wireless networks researchers are putting effort to design several specific cross-layer architectures [14, 15, 47]. It involves different layers and the different parameters to optimize communication protocols and solve problems, and this may involve two or more layers sometimes all layers (cross-layer optimization protocols for energy consumption). Moreover, scheduling of the link at the MAC layer can be scheduled based on transmission power and SINR parameters of physical layers, and the frame error rate can be reduced using channel state information from the physical layer. In mobile ad hoc networks breaking of links frequently occur the MAC layer can detect on the base of channel quality that link is about to break and MAC can schedule another link before breaking present link [54]. A cross-layer framework was proposed a for scheduling algorithm for QoS support at the MAC layer getting information from the physical layer and at PHY it adaptive modulation and coding scheme for delay and data rate guarantee [55] in WiMAX (IEEE 802.16) network. Further, MIMO based physical layers which have the capability to send parallel data with the help of multiple antennas posed challenges to exploit its capability by higher layers in [56] a model has proposed in which MAC layer exploits information from MIMO PHY in ad hoc network. In [57], the model uses adaptive modulation and coding at the physical layer and truncated ARQ mechanism at MAC layer to maximize spectral efficiency. In, [58] authors proposed a joint rate and scheduling mechanism in which MAC layer gets information from the physical layer and schedules data rate and packet on the channel condition. The transmission control protocol (TCP) cannot differentiate the cause of packet loss, whether it was due to congestion in the network or due to the noise of the link information provided by the MAC layer. In [35], authors propose a CLM in which MAC layer determines channel condition and provides TCP to distinguish the cause of transmission error to improve throughput, queuing delay and optimize average queue length. Moreover, retransmissions at the MAC layer indicates channel condition if the retransmissions are higher it means channel condition is poor and TCP should not decrease its sending rate. In [38] a CLM is proposed in which TCP utilizes information from the link layer and differentiate the cause of packet loss and significant performance improvement is gained. In [40], the link-layer estimates capacity information and provides to TCP such as delay and bandwidth for congestion control in multi-hop wireless networks. One of the problems that when a packet is lost on wireless link then both TCP at the transport layer and ARQ (Automatic Repeat Request) at the link layer compete for each other this problem can be solved by giving information from the link layer to the transport layer, and the transport layer congestion control mechanism should be stopped [13]. In [59], authors proposed a cross layer model that uses packetization at the application layer, at the MAC layer retransmission and prioritized strategy to improve rate-distortion of multimedia applications. In [60], for energy minimization a model was proposed for target tracking in the dense wireless sensor network. In this cross-layer feedback mechanism MAC layer (802.11e) isolates traffic of application layer and the MAC layer provides desired QoS level to the applications [61], and authors claimed that the cross-layer architecture mitigates mean packet loss and end to end delay.

V. Challenges to Design Cross-Layer Models

The trade-off is a part of optimization problems, at first seen cross-layer architectures improve performance. However, it introduces a complex model and dependency among several modules of the protocol stack. From the software engineering point of view, it is very coupled in nature and when a problem occurs it will be very difficult to solve. If multiple problems occur isolating them will be challenging before solving them. Further, it increases the execution time of the stack due to interaction among protocols of the stack. It is very hard to exist multiple cross-layer models in the same protocol stack because researchers develop their specific model for specific problems without caring about other protocols and when many cross-layer models come together they may influence each other and performance may be degraded. So, the standard mechanism should be developed for multiple existences of cross-layer models. Cross-layer models modify the protocol stack and protocols on different layers one of the challenges to ensure that protocols which are not modified are compatible to modified cross layer protocols, to overcome compatibility problems the models should be designed as software plugins so that it would be easy to remove and add in the protocol stack. Another a very important problem can be dependency among parameters, since in cross-layer architecture different protocols and their parameters interact each other and value of a parameter of a protocol can be important for another protocol pioneer paper [62] addressed this issue that dependency among parameters can create loops, so, before designing a cross-layer architecture dependency graph of parameters should be analyzed. In addition, many new network architectures such as IoT (Internet of Things), sensor networks and BAN (Body Area Network). These networks devices require energy-efficient protocols to operate longer. And cross-layer based architectures are very suitable for them. Usually, the above-mentioned networks use IEEE 802.15.4 standards. However, very less attention is paid for cross-layer Extension. The same is with IEEE 802.11 model which has also popular name Wi-Fi. New versions 802.11n, 802.11ac, and 802.11ad have come. Although, no attention has been paid that how to integrate cross-layer protocols. Additionally, the IEEE standards such as 802.11 and 802.14 should develop mechanisms to integrate cross-layer models within the standards at the time of development.

VI. Software Framework to Implement Cross-layer Models

In simulators, the TCP/IP model is not designed in the way that different layers can interact with each other or design cross-layer models. However, researchers have developed a framework that can be incorporated in the simulators and simulation models can be built. Furthermore, a framework NS-Miracle [63] in ns-2 is proposed that makes each layer as a module and any module can pass parameters to other modules. Using this framework cross-layer models can be implemented and tested.

VII. Mathematical Frameworks

A multi-hop wireless network can be modeled as graph G=(V, E) where $n_i \epsilon$ V represents wireless nodes in the network and $l_i \epsilon$E is the set of wireless links each having capacity of c_{li}. Moreover, [64] formulates a cross layer model of data rate flows at the network layer depends upon the channel capacity at the physical layer using Network Utility Maximization (NUM) technique. For instance, suppose x_s is the data rate of the source. NUM is the formulation of problem to maximize total utility $\sum_s U_s(x_s)$ over the data rate x_s subject to the flow constraints

$$\underset{x\geq 0}{maximize} \quad \sum_s U_s(x_s)$$

$$subject\ to \quad \sum_{s\epsilon l_i} x_s \leq c_l \quad \forall\ l_i \epsilon E \tag{1}$$

$$\textstyle\sum_{s\epsilon l_i} x_s \leq c_l \ \forall \ l_i \epsilon E.$$

i.e

Where $c_{li} = B\ log(1 + S/N)$ is Shannon's capacity limit. In which, B is bandwidth, S is signal power and N is noise power at the receiver. In the constraint, x_s data rate of a flow at the network layer depends upon signal and noise power received by the physical layer. The optimization problem can be solved and cross-layer model can be developed. That will utilize the full capacity of the network.

VIII. Research Directions

As wireless technologies are evolving and the traditional TCP/IP protocol stack is not able to solve problems such as energy constraint performance, multimedia transmission, and QoS. It becomes necessary to modify protocol stack for the requirement of solving problems related to wireless networks. However, modifying well-established modular communication architecture may result in performance degradation [62]. On the other hand, without modification in the protocol stack, optimal performance cannot be achieved. Before building cross-layer architecture one should consider all the effects and parameters. In modular architecture layers independently operate and there is no exchange of parameters. However, in cross-layer architecture, there is dependency among variables and procedures. Layers in TCP/IP stack can be seen as a module and software engineering principles can be applied for cross-layer model design. TCP/IP modular architecture has low coupling modules and high cohesion within modules. Cross-layer architectures increase coupling of modules and hence complexity. On the other hand, it increases communication between modules for optimization. Before designing a cross-layer model one should investigate these effects and trade-offs.

$$subject\ to \quad \sum_{s\epsilon l_i} x_s \leq B\ log(1 + S/N) \tag{2}$$

IX. Conclusion

To sum up, in this article we have discussed different types of wireless networks their issues. And how they solved problems using cross-layer optimization techniques. Moreover, we have discussed interactions among layers to solve cross-layer problems that may need specific architectures. Such as, optimization of multimedia streaming over wireless networks requires different architecture than optimum use of energy. Methods to design cross-layer models are very important we have explained two major techniques direct communication among layers and cross-layer planes. Cross-layer architecture introduces new challenges and needs very careful design and testing, otherwise, it can lead to the degradation of network performance. In addition, we have also prosed cross-layer model for transmit power control which exploits the interaction between the physical layer and the MAC layer. Which gives promising results for energy, throughput, hop count and collision optimization.

Conflict of Interest

Authors declare no conflict of interest.

Authors' Contribution

Bindeshwar S. Kushwaha performed research and wrote initial research paper, Pramod Kumar Mishra reviewed and edited the paper. Both authors approve final version of the article.

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