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Cross-layer Design and Optimization Techniques in Wireless Multimedia Sensor Networks for Smart Cities ⋆

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Abstract. The future smart cities vision can be developed through leveraging the potentials of Internet of Things (IoT) and wireless sensor network (WSN) technologies. WSN is a resource constrained network where network nodes are tiny devices that are run on battery power. Diverse types of applications such as environmental and habitual monitoring, detection, and tracking, use WSNs. The invention of new network protocols, the establishment of new models for communications, and testing the available solutions in real world environment are some of the current research issues in WSNs. Main challenges in such networks include energy conservation in an efficient way, dealing with variable channel capacity, and the resource constrained nature of such networks. The design of architecture for such networks has a vital role in solving the issues to some extent, i.e., the cross layer design approach is an architectural technique that offers the interaction of different layers together to enhance the performance, minimize the energy consumption, enhance the network life time, and provide Quality of Service (QoS) in real time communications. These are some of the current areas where cross-layer design approaches are being used. This paper presents different types of cross-layer design techniques in wireless multimedia sensor networks. Using such architectural techniques, different state of the art cross-layer optimization approaches are discussed while giving the reader an insight on prominent challenges and issues along with future directions.

Keywords: Optimization, Multimedia, Wireless Sensor Networks, Smart Cities, Internet of Things.

1. Introduction

Wireless Sensor Networks (WSNs) include a large number of low-power devices normally known as sensor nodes. Sensor devices are resource-constraint nodes with respect to computational power, storage capacity, energy, bandwidth, and communication range [26]. Depending on the application scenario, sensor nodes are either precisely placed in the area of interest (e.g., structure monitoring of a building) or randomly deployed in the

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⋆ Corresponding Author: Muhammad Khurram Khan (mkhurram@ksu.edu.sa) field (e.g., environmental monitoring). Furthermore, these nodes are responsible for the sensing parameter of interest and/or detect an event from their environment and report it to a base station that is often called sink node or gateway node. The sink is more resourceful node compared to other nodes in the WSN.

Recent advancement in the sensor technology and micro-miniaturization has enabled the emergence of a more specialized field of WSN that is known as Wireless Multimedia Sensor Network (WMSN), which has applications in various domains in futuristic smart cities such as health-care monitoring [27], home automation [16], transportation & vehicular networks [18,11]. In WMSN, sensor nodes are equipped with audio and video capturing devices, such as microphones and inexpensive CMOS cameras. Sensor nodes are also responsible for capturing and delivering multimedia content, such as (a) audio, (b) video, and (c) still images to the gateway node [2]. Some applications of the WMSN are surveillance [10,16], traffic management [29,36], health-care services [2,19], environmental monitoring [35], and industrial process management [41], as shown in Fig. 1.

The rapid and persistent evolution in tools and technologies along with the explosive growth in the market proliferation of IoT devices has made WSN a ubiquitous medium towards the realization of smart cities [12,13]. WSNs have presented various applications and have given space for developing several services to benefit smart city infrastructures. There have been several issues and challenges which hinder the full scale deployment of the future generation of IoT enabled smart cities [14].

In resource constraint IoT based network infrastructures, for example, WMSN, achieving (a) low frame loss, (b) reduced delay, and (c) better end-to-end video quality are a challenging task. In order to ensure higher quality of service with constrained resources, one has to think out of the box. Traditional smart city design approaches might not be suitable and efficient for taking full benefit from the WMSN. One such approach is the cross-layer design for cross layer optimization, being an optimal approach, which is used not only to improve but also optimize the overall network performance. The cross layer optimization has made it possible for the smart cities research community.

”Cross-layer design techniques with regards to the reference layered model is the design of protocols, architectures, or algorithms, that not only exploit but also offer a set of inter-layer interaction which is a super set of the standard interfaces provided by the overall reference layered architecture” [20]. According to [38], the cross-layer design is a back-and-forth information flow that merges different layers and couples those layers that have no common interface. In contrast to the layered reference model, there are explicit interfaces among layers and some time the concept of shared database. In a layered structure, protocols communicate with adjacent layers via function calls, while a cross-layer design violates such limitations of communications [6].

The focus of this paper is to explore cross-layer optimization techniques in the context of WMSN for future smart cities. The rest of the paper is organized into the following sections: Section 2 covers the basic concepts of cross-layer design techniques. State of the art cross-layer design approaches in WMSNs are discussed in Section 3, and Challenges of cross-layer designs in WMSNs are discussed in Section 4. At the end, we finalize the paper with the concluding remarks and future directions presented in Section 5.

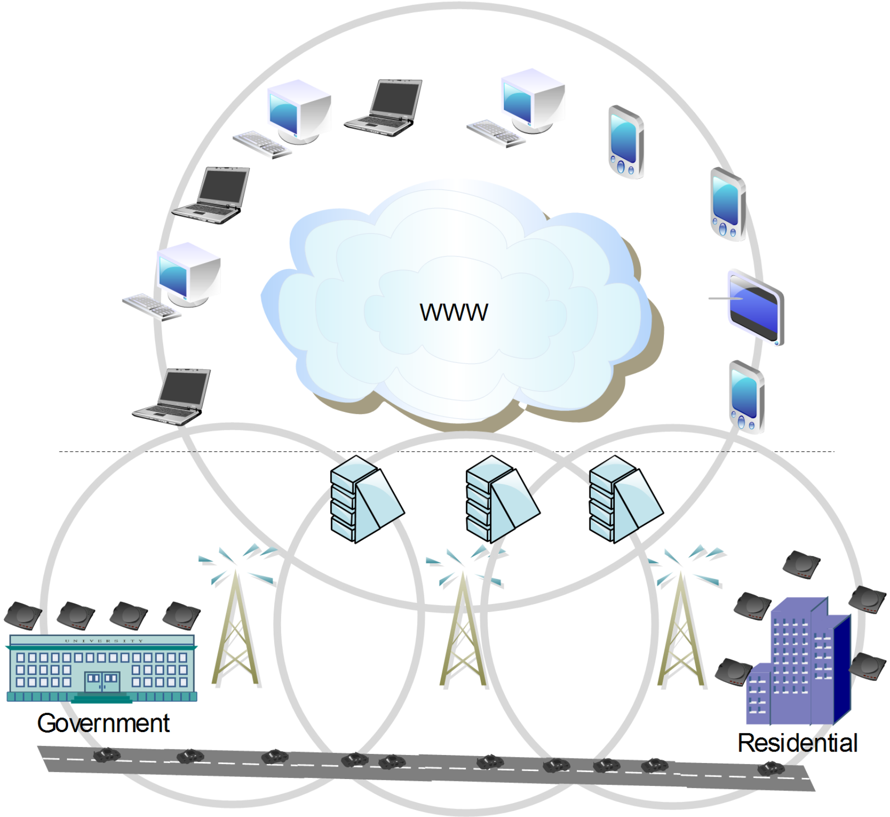

Fig. 1. Smart City Applications Home Automation, Building Monitoring, Health-care monitoring, and Vehicular Networks to name a few.

2. Cross Layer Design

A great deal of research is being carried out since last few years in the field of wireless technology to come up with better architectural approaches. Most of these efforts are focused towards reducing strong inter-dependency among layers, which is a typical characteristic of the layered architecture. The cross-layer design is an emerging technique for both wireless and wired networks. The theme behind this approach is optimizing the flow of data in such a way that any two or more layers can be crossed for upgrading the complete performance of the network [49]. The ultimate goal is to enhance the performance of WMSNs in terms of energy usage, routing, delivery of multimedia contents, and network management.

Depending on the user requirements, two, three, or four layers of the layered architecture can be crossed. For example, in order to accomplish in-network processing and better multi-path selection, the application layer and routing layer are combined. Service level differentiation, priority scheduling, and efficient routing techniques are achieved when the routing and MAC layers work together. Moreover, achieving QoS and reliability of multimedia content when multiple routing paths scheme is used, the routing and transport layer contribute in achieving these enhancements [3].

The cross-layer design approach is one of the preposition in this regard that enables the designers to develop protocols which enable communications across layers (in contrast to the layered architecture approach) [15].

3. Cross Layer Design Techniques

Every layer contributes different functionalities in the protocol stack of WSNs and WMSNs. Crossing these layers can achieve 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 WMSN is resource constrained with respect to energy. The ultimate focus of every alike contribution is energy preservation of such networks. Other areas such as QoS and communication reliability along with security are also discussed later in this section.

3.1. Energy Efficiency

Energy efficient communication is always the most important and critical aspect while conceiving WMSNs. Researchers and developers come up with new frameworks, new architectures, and new protocols whose main goal is achieving the energy efficiency. Generally, every layer is responsible for something like protocols at network layer construct routes and do resource reservations. While considering multi-hop communications, the MAC layer is responsible for efficient channel utilization. The combination of both Network and MAC layer achieves to provide bounded delay in the communication via multi-hop paths. Another example is the use of routing information at the network layer that can maximize the sleep duration of each network node [40], the information taken from network layer that the network layer is busy, the MAC layer differs the channel access for nodes, and thus the nodes remain in sleep mode for a longer time. Hence, in the long run, the energy efficiency is provided for the whole network when the sleep duration is increased. Following are related works from the literature that contribute energy efficiency with the use of cross-layer design approaches.

The cross-layer technique, discussed in [48], deals with the life time optimization of WMSNs, where the correlation between sensing data and the redundancy due to overlap regions consume more energy and degrade the life time of the network. Three layers are contributing in the optimization in such a way that the application layer is sharing the global variables, the transport layer is controlling the source rate, and the responsibility of the network layer is to adjust the flow rates on links.

Similarly, Lee *et al.* [21] address the problem of end to end video delivery in resource constrained sensor networks and life time enhancement. Routing and power allocation are optimized by the cross layer optimization. This is a three step procedure, i.e., first, the physical layer does the energy management by announcing power allocations to upper layers. Second, the network layer performs optimal routing on the basis of channel state and hop count. Third, the MAC layer performs power allocation by finding the optimum power allocation matrix with regards to information from other layers. The data rate and network life time are increased that achieve better end to end video delivery.

Collision Aware Routing Protocol (CARP) [45] uses two parameters, i.e., collision degree and energy level, for routing and rout adjustment rather than traditional hop count. High collision in the network consumes more energy, while the cross layer design avoids high collisions. The energy level is calculated with the help of residual and initial energies. A logical control unit over the network layer attains parameters from the physical and link layers. The more residual energy nodes are chosen based on the parameter value from the physical layer as relay nodes to save the energy. The CARP's routing metric needs physical layer functions characteristics such as data rate, number of collisions, and state parameters so as to set up an autonomous logical control unit in the network layer that fetches the physical and link layer parameters, and computes the degrees of collision and energy for routing. The control overhead is avoided by using the route metric in the RREP and RREQ packet header.

The cross-layer technique presented in [8] optimizes the energy usage by balancing the traffic flow across multiple paths, thus, the life time of the network is increased. The contributions presented in this work for different layers are as follows: At the routing layer, the multiple paths are used for data transmissions. In addition, when the retry limit of transmissions is over, the MAC layer is controlled for each channel.

The cross-layer optimization design presented in [30] increases the life time of WMSNs in two stages. In the first one, the number of connected sensor nodes is increased while in the second case, the network life time is increased by controlling the connection of low priority nodes in the network. All layers are involved in this optimization design technique.

3.2. Quality of Service

Quality of Service (QoS) is a very generic term used in computer networks domain. The term QoS refers to the end-to-end data transmission without much delay. The term is more specific for real time communications where the basic requirement is on time delivery and reception. A few of cross-layer design techniques are discussed in the following sections.

Table 1. State of the art in Cross Layer Energy Optimization Techniques

Ref.	Layered Crossed	Research problem	Performance Matrix
[40]	MAC and Network Layers	Information of routing at the network layer is used for the MAC layer, thus, it can maximize the sleep duration of all nodes, which ultimately increase the energy efficiency.	Data rate
[48]	Application, Transport and Networks	Densely deployed WMSNs have redundancy and correlation in multimedia data; allocating source rate and flow rate can enhance the life time.	Data rate
[21]	MAC, Network and PHY Layers	Efficient power management can enhance the network life time based on optimal routing from the network layer.	End to end delay.
[45]	MAC, Network and PHY Layers	Control overhead create the energy of WMSNs nodes depletes more rapidly, controlling the unwanted traffic can increase the life time of WMSNs.	Hop count, /collision degree/energy level.
[8]	MAC and Network Layers	Balancing the traffic flow across multiple paths can enhance the energy preservations.	data rate/ retry limit
[30]	All Layers	The network life time is maximized by controlling the admission of low priority nodes in the network	Data rate.

Well-known areas like QoS achievement are discussed, e.g., QoS in terms of resource reservation, video quality, and packet loss etc.

QoS in terms of resource Reservations A model based channel capacity prediction scheme is presented in [50] for providing statistical QoS. The scheme perceives the state of a link from the MAC re-transmission information where statistical channel capacity is calculated when the traffic load is saturated. Based on the proposed model, the QoS routing optimization and resource reservations are carried out. The proposed scheme assigns network resources and forwards packet taking into consideration the interference among flows and state of a link.

The path reservation technique, VSN-Module, is presented in [9]. This protocol is based on UltraWideBand (UWB). The VSN-Module provides the QoS support while the path reservation is done in a distributed manner in the network.

Multi-hop routes are set from source to sink and different parameters such as jitter, end-to-end delay, and bandwidth are satisfied based on flow requirements. The physical layer is integrated with the upper layer functionalities, for example, MAC, network and transport layers. The UWB technology is set at the physical layer while the channel access and transmission parameters are coupled.

QoS in terms of communication protocols function optimization The framework presented in [34] provides the QoS imposed on each stream. The tasks of communication protocols are optimized in this framework through maximizing video stream requests.

The increase in video sources in WMSNs along with the QoS is hard to achieve. Thus, frames are classified by the traffic classifier module and the rout classifier module of the framework selects the appropriate path for each frame delivery. The MAC layer maps frames in access controllers (ACs) according to the priorities and the appropriate transmission mode is then chosen by the network layer.

QoS in terms of prioritization of streams The new framework introduced in [15] provides QoS for each stream by prioritizing them. The traffic in WMSNs is classified into six classes. The network is partitioned into hexagonal cells to minimize the interference. A shared database is used for the cross layer design.

A single node supports multiple applications in this framework via reserving some area in the memory. Each application requests for its protocol parameters and a middleware is used for the interaction of shared database and applications. The middleware sets suitable parameters at different layers on the basis of network conditions and application requirements from physical channel conditions and MAC layer feedback. Then the application is informed by the middleware about the status of the network so that its behaviors can be adapted by the applications accordingly.

QoS in terms of application requirements The communication paradigm on the basis of time-hoping impulse radio ultra-wide band technology is presented in [25]. A control unit called cross-layer control unit (XLCU) controls and configures the networking functionalities at three layers, i.e., physical, MAC, and network layer. The QoS is provided on the basis of unified logic that takes decisions. These decisions depend on two conditions. First is the application requirements at application layer and second is the status of the functional blocks that implement the networking functionalities. Reliability and flexibility are achieved when delivering contents to different types of applications.

QoS in terms of streaming video quality The cross-layer framework in [39] aims to deliver only the summaries of video instead of the video file over wireless channels. Three layers, i.e., physical, data link, and application are combined in a cross-layer fashion that provide the best quality of video across the WMSN. Each layer optimizes the parameters like coding scheme, adaptive modulation, source coding, and retransmission. Source coding is optimized at the application layer. Similarly, ARQ at the data link layer and other parameters, e.g., adaptive modulation and encoding schemes at the physical layer.

An integrated cross-layer optimization algorithm is presented in [4] for video streaming across multi-hop networks [4]. It optimizes different control parameters across the application layer, network layer, MAC layer, and physical layer to provide QoS in multipath transmission networks using IEEE 802.11a/e. At routing layer, the end-to-end optimization is done for path choosing. At MAC layer, the maximum retry limit is set and the modulation scheme is chosen at physical layer.

The proposed system presented in [23] consists of a video encoder module, MAC layer cognitive module, modulation and coding module, and cross-layer module. The cross-layer module adjusts all network functions by an appropriate selection of system parameters, hence, the network functions are jointly optimized in order to obtain best user perceived video quality using cognitive radio. The dynamic channel coding MAC (DCC-MAC) technique is used in this system to allow the concurrent transmissions of distinct pairs of source and destination that reduce the interference among nodes.

A new architecture, called QoS MAC is presented in [46], where different contention windows for application specific QoS requirements are set thereby the traffic is categorized on the basis of delay requirements. The proposed MAC scheme efficiently shares channel and contention windows are updated dynamically to set it for different types of categories of traffic in the WMSN.

QoS in terms of packet loss A novel transport layer protocol, i.e., User Datagram Dispatcher Protocol (UDDP), minimizes packet loss ratio in WMSNs [1]. Information is taken from MAC and Application layers which send number of packets and frame types to the transport layer. Similarly, the MAC layer sends MTU to the transport layer for fragmenting a video frame into a corresponding number of packets.

3.3. Reliable communication

The technique presents two geographic forwarding schemes [17]. These schemes are based on the cross-layer design. The first scheme is called Load Balanced Reliable Forwarding (LBRF). The LBRF integrates network and MAC layers for efficient and reliable data delivery in WMSNs. The idea behind this scheme is considering the buffer occupancy level information of those sensor nodes that are used as relay nodes. Every sensor reports buffer occupancy conditions of relay sensors by passively monitoring and storing this information.

A sensor is simply piggybacking information to the MAC layer and neighbors store this information for future use by overhearing. Stored buffer occupancy information of candidate nodes is used for dynamic load balancing.

To enhance the video quality of every video stream in WMSNs and maintaining the balance in video quality among video streams, a new rate control strategy is introduced [31]. The end-to-end data rate is controlled through the cross-layer optimization control algorithm, while the strength of the channel coding and video quality at the physical layer. The SNR is calculated along the forward path at the physical layer and the lowest SNR value is recorded in the packet. This information is sent back to the sender after extracting from the packet at the network layer. Thus, the most recent forward path SNR value is used. Congestion is avoided by computing the end-to-end data rate.

The interaction of physical, network, and transport layers is a cross-layer design that dynamically adjusts the transmission radius and data generation rate for energy efficiency [44]. The optimum transmission radius of sensing devices is chosen at the physical layer. Multiple routing paths are discovered at the network layer. The qualified multiple paths are selected at the transport layer and the information creation rate adjustment is carried out at the Physical layer.

The cross-layer design that cumulatively regulates the video encoding rate, the channel coding rate, and the transmission rate is proposed in [32]. First, the sensed video is encoded to be transmitted over the channels. Second, a rate controller is used which balances the videos streams and maximizes the video quality. Third, the compressed video

Table 2. Cross Layer Optimization for Quality of Service

Author	**Layers Crossed**	**Research Problem**	**Performance Matrix**
[6]	MAC and Network Layers	Resource reservation and routing optimization decreases delay and improves the delivery ratio.	Packet delivery ratio.
[9]	Physical, MAC and Transport Layers	The video traffic is reached from source to destination across multiple path; single path creates delay; multiple path minimizes delay and achieves QoS for video traffic.	Delay / jitter / power consumption.
[34]	Application, Network and MAC	QoS can be achieved in WMSNs by improving the functionalities of communication protocols as the nature of WNS and WMSN is different due to heavy traffic in WMSNs.	Data rate/ SNR/ delay
[15]	Application, Network, MAC, and PHY layers	Traffic in WMSNs is affected by high interference level; minimizing the interference level achieves QoS in WMSNs by classifying the traffic classes.	Delay/ throughput
[25]	Application, Network, MAC, and PHY layers	QoS to heterogeneous applications	Bit error rate/ delay/ throughput
[39]	Physical, Data Link, and Application layers.	Transmissions consume more energy than computations; delivering only meta data can achieve better quality and minimize the end-to-end delay.	Video quality/ End-to-end delay.
[4]	Application, Network, MAC, and Physical Layers	The video streaming consumes more time; improving the video streaming achieve better QoS with respect to video quality.	Data rate/ delay
[24]	Application, Network, MAC, and PHY layers	Adjustment of all network functions by selecting appropriate system parameters so that the network functions are jointly optimized to obtain the best user perceived video quality of cognitive radio	Data rate.
[1]	Application, MAC, and Transport layers	The packet loss rate degrades the QoS in WMSNs; minimizing the packet loss rate improves the QoS.	Frame rate/ delay/ throughput

coding is controlled at the application layer. Last, the adaptive parity at the physical layer and the rate is controlled at the transport layer.

A technique [28] where all layers perform some controlling, for example, on the application layer, optimal routing is achieved by controlling video bit stream and adaptive FEC. The MAC utilization is controlled with the help of congestion aware scheme on the Network layer. The adaptive channel allocation on MAC layer controls channel information.

Some cross-layer techniques [42] combine all layers into a single one for energy efficiency. The objective of this model is the development of a highly reliable communication, avoiding congestion locally, and adaptability in communication decisions. The design principle is a completely unified cross-layered such that both functionalities and information of legacy communication layers are encapsulated in one particular protocol.

Congestion is always caused by the communications waste and the minimization in energy efficiency. Sensor fUzzy-based Image Transmission (SUIT) is a cross-layer based image transport protocol [37]. Congestion estimation is done based on fuzzy logic that

Table 3. Cross Layer Optimization for Communication Reliability

Ref.	**Layered Crossed**	**Problem and Contribution**	**Performance Metrics**
[17]	MAC and Network Layers	Load balancing locally improves the reliability of video across the network. The node dynamically selects the next hope to send data to the sink.	Frame rate/ delay/ latency
[31]	Physical and Transport layer	Controlling the data rate in the network achieves better end-to-end delay and video quality.	Packet error rate/ video rate/ distortion loss
[44]	Transport, Network, and PHY Layers	Reliable video Transmission	Data rate/ delay
[32]	Application, Transport, Physical	Encoding the video can achieve better video quality and minimize the congestion.	End-to-end delay/ video quality.
[28]	Application, Network, MAC, and PHY layers	Reliable video Transmission	MAC utilization is controlled with the help of congestion aware scheme on the network layer; adaptive channel allocation on the MAC layer controls channel information
[37]	Application, MAC, Transport, Network Layers.	Congestion Control	Application layers get the congestion level from the Transport layer for deciding the frame rate.
[42]	All Layers	Efficient and reliable communication	Completely unified cross-layer design in which both functionalities and information of legacy communication layers are encapsulated into a single unified mechanism

decreases the image quality on the fly, which can mitigate the congestion. The idea behind this is to drop some packets of frames that lower the quality but with acceptability. The application layer receives the congestion level from the transport layer while determining the frame rate. A table is generated by the MAC layer that caches the neighbors' buffer occupancy by piggybacking the completeness of the transport layer's buffer into every outgoing packet. The transport layer uses the elements of this table during the fuzzy logic-based congestion estimation. Moreover, at the time of congestion estimation, the transport layer invites the ID of the next hop sensing device from the network layer.

3.4. Security

Security is always the main concern of WSNs and WMSNs. For securing the communication among wireless sensor nodes, the algorithm is based on the information taken from the application layer wherein this information will trigger the algorithm of the provided solution [5], which is a routing algorithm at the network layer. Event notification message is broadcasted by a node that would probably be under attack in some time. The closer nodes will receive a lot of messages, which means that the node is closer with which the incident is going to happen. The counter for that event messages will be used to locate the node in the neighborhood of any node. The algorithm running on the network layer is based on an assumption that there is one or more backup receivers associated with the sink. In this case, the distance is calculated by Euclidean distance formula. Once it is detected that a receiver is under attack, information from the application layer is forwarded and the secondary sink is selected as a receiver. The proposed cross-layer optimization approach [43] is to secure the delivery of images via wireless channels. The parameters– BER, ARQ retry limit, and transmission rate are optimized across the three layers (i.e., PHY, MAC, and APP).

An Efficient Dynamic Selective Encryption Framework (EDES) to ensure security of multimedia traffic in WMSNs is proposed in [33]. Among three security levels, the selection depends upon the energy and QoS parameters, and for the EDES, a cross-layer approach is used to take different parameters from 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 assessed by combining the QoS parameters and residual energy to capacity function CAP. This needs parameters from the MAC, network, and upper layers. The second step selects the security level based on CAP.

3.5. Error Correction

The work in [47] presents the forward error control (FEC) scheme based on cross layering of physical layer, transport layer, and application layer. Three approaches which are based on FEC are jointly considered. RVLCs at the application layer and RSC codes at the physical layer are exploited. Redundant packets are generated at the transport layer for the FEC. Strong bit error correction is offered which also overcomes packet loss in multi-hop wireless communications. A cross layered scheme is proposed in [22] that joins the functionalities at different layers (i.e., network, link, and application layers). The scheme avoids the video quality degradation when burst error occurs in the communication. The scheduling mechanism is jointly exploited on these layers.

3.6. Network Resource Management

A cross-layer optimization across three layers, i.e., physical, link, and application layer, manages network resources [7]. This new approach is adapted for the Direct Sequence Code Division Multiple Access (DS-CDMA) using visual sensor networks. Source coding rate, channel coding rate, and power level are also assigned simultaneously to all nodes in the network. The network resources can be optimally allocated to nodes based on two criteria that maximize the video quality of the network as follows:

- Minimize the average end-to-end distortion among nodes.
- Minimize the maximum distortion of the network.

Based on the node density and video quality, the capacity of the WMSNs can be determined to allocate resources.

4. Challenges of Cross-layer Design

Cross-layer design approaches though present much needed improvements to the network and improve the overall Qos. However, some studies have suggested that these techniques

Table 4. Cross Layer Optimization for Security Provision

Ref.	Layers Crossed	Research Problem	Performance Metrics
[5]	Application and Network Layers	Event notification message is broadcast by a node that would probably be under attack in some time. The more closer nodes will receive a lot of messages which means that the node is closer on which the incident is going to happen	Radio range
[43]	Physical, MAC, and Application layer	The images traveling across the network need to be secured.	Retry limit/ transmission rate/ frame length
[33]	MAC, Network, Transport, and Application	Defining the security level for different scenarios can enhance the energy efficiency as well as QoS.	Residual energy/ capacity function

Table 5. Cross Layer Optimization for Error Corrections

Ref.	Layers Crossed	Problem and Contribution	Working of technique
[47]	Application, Transport, and PHY Layers	Strong bit error correction	3 FEC approaches are jointly utilized in the ISCFC, i.e., the RSC codes at the physical layer and the RVLCs at the application layer while generating redundant packets by different random interleaves corresponding to the FEC method of the transport layer.
[22]	Application, Network and Link layer	The burst error in the communication degrades the video quality.	Packet loss rate/ PSNR

violate strong dependencies in layered approaches. Such dependencies have significant role to play once we consider the abstraction and seamless integration they provide. Thus, there are several inherited challenges of wireless technology for multimedia sensor networks.The new challenges for cross-layer approaches make it a difficult task for the designers and developers alike.

While achieving the cross-layer design in order to optimize the overall interactions, the TCP/IP layered architecture is dismantled. This not only disturbs the encapsulation mechanism of a well structured model but also makes it rather difficult to make further improvements in the well structured and planned TCP/IP reference model. In the event of a modification, we must consider almost all layers that are interacting. This might be the most significant issue with the cross-layer design.

One of the prominent challenges is the unavailability of a uniform cross-layer design. There have been many designs proposed but what lacks is a unified approach. This is due to the fact that these designs are normally modelled for specific problems and therefore not easy to have two different designs which can achieve the desired goals. One solution for this problem is to minimize the interactions between cross-layers as much as possible. This way, multiple cross-layer designs may co-exist through a proper standardization.

Generally, cross-layer design tends to resolve a specific issue or target a particular scenario such as video surveillance or vehicular infotainment system. Rather than providing a uniform approach for all situations, it improves only specific aspects of the communication. For example, in vehicular networks, infotainment system requires a lower TCP retry value but in case of text based transmission regarding vehicle's situations, we may require a longer TCP retry value to cope with fragmented or bad networks. Developing a universal cross-layer design is also a significant open research issue. One approach with finding common schemes in various designs can be a good approach towards modeling a uniform design. In case of vehicular networks, we may need to find common grounds in video streaming designs and finally come up with a design which has advantages of each of these designs.

5. Conclusion and Future Directions

Future smart urban spaces are realized through a lot of IoT and WSN applications requiring millions of sensors to work together. These sensor nodes generate a large amount of data. Among these applications, a prominent one is where sensors are deployed for capturing multimedia data such as for video surveillance, patient health monitoring, and traffic management to name a few. In order to have an optimal network throughput, cross-layer design techniques have posed promising results.

Table 6. Cross Layer Optimization for Network Resource Management

Ref.	Layers Crossed	Problem and Contribution	Working of technique
[7]	Application, Link, and Physical Layers	Proper resource management in WMSNs can receive a better video quality.	Source coding rate/ channel coding rate/ transmission power level

In this paper, we have discussed in detail various cross-layer optimization techniques for Multimedia Wireless Sensor Networks (WMSN) on different layers. WMSNs present one of the promising applications for the IoT in Smart Cities. Though similar to generic WSN applications, WMSN leverages the underlying infrastructure to communicate audio visual feedback from a certain environment. Thus, enabling various applications and services in smart cities such as high definition surveillance, traffic control and management, health-care diagnosis and efficient drug delivery, industrial and building automation, surveillance and monitoring to name a few.

Multimedia applications tend to put a considerable burden over the WMSN. This kind of network load can be optimized through several cross-layer optimization techniques. In this paper, we have put forward several such techniques which not only improve the overall interactions but also improve the Quality of Service (QoS). Similarly, we consider that along with the cross-layer optimization, WMSNs also require raw data in-network processing. In future work, we intend to extend the work by developing a test-bed using state of the art Technologies. One of the important future directions would be to fully test the cross-layer optimization techniques through proper testing it under controlled experiments.

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