A Survey on the Cross-Layer Design for Wireless Multimedia Sensor Networks

Honggang Wang[1], Wei Wang[2], Shaoen Wu, and Kun Hua

[1] University of Massachusetts, Dartmouth, MA, USA
hwang1@umassd.edu
[2] South Dakota State University, Brookings, SD, USA
wei.wang@sdstate.edu

Abstract. Small low-cost multimedia sensors ubiquitously capture and transmit multimedia information from fields to central stations in support of applications. However, Multimedia sensors in Wireless Multimedia Sensor Networks (WMSNs), have limited resources in terms of their computational capability, memory capability, bandwidth, and battery power, which hinder a wide application of WMSNs. The challenges, issues and solutions in WMSNs regarding QoS, energy efficiency and security have been recently studied. It is highly desirable to incorporate the characteristics of multimedia and information security at the application layer into adaptation and optimization at lower layers in a cross-layer approach. In this paper, we conducted a survey on the recent development of the cross-layer design in WMSNs. Based on our studies, we concluded that that cross-layer approaches are promising solutions and can efficiently support future multimedia application in WMSNs.

Keywords: Cross-layer design, Wireless Multimedia Sensor Network.

1 Introduction

Small low-cost multimedia sensors ubiquitously capture and transmit multimedia information from fields to central stations in support of applications such as instance multimedia surveillance networks, target tracking, environmental monitoring, and multimedia-aided navigation systems. These multimedia sensors are wirelessly connected to retrieve still image, video, audio and scalar data in Wireless Multimedia Sensor Networks (WMSNs). Multimedia sensors in WMSNs, have limited resources in terms of their computational capability, memory capability, bandwidth, and battery power, which hinder a wide application of WMSNs. They generate a large volume of data and consume a great deal of energy in data processing and transmission. With limited bandwidth and resource constraints in sensors and relay nodes, network bottlenecks in WMSNs likely occur and thus degrade network performance.

Multimedia Quality of Service (QoS) is another major concern in WMSNs. The error prone wireless channel causes packet loss and then degrades the multimedia quality. It is challenging to efficiently utilize limited network resources in order to protect the quality of multimedia transmissions. Multimedia

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sensor nodes are vulnerable to a variety of malicious attacks and compromises when they are deployed in a hostile environment. Therefore, security methods must be designed judiciously in sensor network environments to enhance error resilience, and provide security and perceptual integrity under limited power, memory, and computational constraints. A dynamically varying network topology and resource configuration becomes one of the major challenges to security protection efforts.

In response to these challenges and issues regarding QoS, energy efficiency and security, it is highly desirable to incorporate the characteristics of multimedia and information security at the application layer into adaptation and optimization at lower layers. Multimedia applications require secure, effective and efficient communication, as well as in-network processing platforms, where the entire multimedia system performance can be optimized as a whole. The error-prone and shared nature of dynamic wireless channel in WSNs allows us to break the traditional layer architecture for pursuing optimized network performance of multimedia delivery in a cross-layer manner. Given fundamental resource constraints, secure quality-driven energy-efficient cross-layer architecture for multimedia delivery must be developed carefully in WSNs to enhance error resilience, gain energy efficiency, and provide security protection. The joint design and control of multimedia source coding, resource allocation and information security creates a new perspective from which to explore the interaction among multiple equivalent layers, and fill the gaps among networking, cryptography and signal processing.

However, traditional cross-layer optimization and architecture [1-4] limit themselves in real practices due to their associated complexity. These challenges are even more critical for multimedia data delivery in WSNs due to the nature of multimedia data. The major focus of this survey is to investigate the current cross-layer design research development in addressing the QoS, security and energy efficiency issues in WMSNs.

1.1 Wireless Multimedia Sensor Hardware Structure

A basic multimedia sensor hardware structure can process multimedia data and be capable of networking. In the multimedia processing part, different types of physical sensors such as cameras, audio and scalar sensors acquire environment information in the form of multimedia. The Central Processing Unit (CPU) and memory implement algorithms to manipulate multimedia data such as data compression. The communication system handles the multimedia transmission over wireless environments, which includes the system software module and network interface as well as the wireless transceiver. The motor part is controlled to offer a platform for mobile multimedia sensor applications. The localization system provides information on the location of sensors in mobile application environments. Typical multimedia sensors include Cyclops image sensor (CMOS camera + MICA) with low resolution, medium-resolution imaging motes based on the Stargate platform , and the Imote 2 developed by Crossbow and Intel. The wirelessly-connected multimedia sensor nodes enable the interplay between multimedia processing and networking. To achieve overall quality network performance, the communication system protocol design and network resource management must provide an efficient support for multimedia processing techniques (e.g., compression); inversely, the processing techniques must be adaptive to the networking and communication capabilities.

1.2 Wireless Multimedia Sensor Networks Communication Structure

In WMSNs, heterogeneous multimedia sensors (audio sensors, scalar sensors, high- and low-end image sensors) have different capabilities in data processing and transmission. In WMSNs, a set of multimedia processing gateways formulates the distributed multimedia processing architecture. The multimedia contents are delivered and relayed through multimedia processing gateways. These multimedia processing gateways fuse and process multimedia data locally. A multi-tiered structure allows sensors to handle different levels of processing according to their memory, CPU computation and bandwidth capability. Wireless gateway functions as a sink node to collect multimedia data, which are ultimately delivered to users through the Internet or through satellite networks. In practice, this multimedia network of heterogeneous sensors has advantages over networks with homogeneous sensors, especially for multimedia processing and transmission. For example, more complex hardware and extra batteries can be selectively embedded in a few gateways such as cluster heads or high-end nodes rather than in all sensors for comprehensive multimedia processing, thereby reducing the hardware cost of the network.

1.3 WMSNs Applications

WMSNs support multimedia information retrieval and delivery over wireless environments, which enable new potential applications and enhance many existing network applications. These major WMSNs applications include:

- Target tracking applications
- Home automations
- Multimedia surveillance
- Environmental monitoring
- Multimedia-aided navigation systems and traffic avoidance
- Healthcare monitoring and delivery applications
- Environmental monitoring in the form of acoustic and video
- Manufacturing process controls for semiconductor chip, food or pharmaceutical products

A typical application, for example, is a secure multimedia surveillance over image/video sensor networks. the video sensor monitors the secure military area. Suddenly, an enemy robot is coming and trying to attack the secure area. The video sensor captures this scene and transmits the emergency multimedia information to the monitoring office through wireless links. However, the intruders can access and modify the image content so that the enemy robot is hidden or scratched in transmitted images. In this scenario, the monitoring office receives this faked image and cannot detect this incoming enemy robot. An authentication solution for recognizing this malicious activity is studied by utilizing watermarking techniques in this work, which allows the monitoring office to detect the modified image.

Many of the above applications require new mechanisms to deliver multimedia content with a certain level of quality of service (QoS), energy efficiency and security. These mechanisms should not only include energy efficient communications, but also the interplay between multimedia processing techniques and the communication process. In this paper, intelligent cross-layer architecture is studied to offer such new mechanisms to efficiently support WMSNs applications.

2 Research Challenges for WMSNs

Many WMSNs' applications as mentioned above require sensor networks to deliver multimedia content with a certain level of quality of service (QoS) and security protections as well as resource efficiency. To ensure multimedia deliveries are secure, energy-efficient, and high-quality, the following four issues are major challenges:

2.1 Resource Constraints and QoS Requirements

Sensor devices are constrained in terms of CPU computation and memory capability, bandwidth and battery support. These resource constraints make it difficult for Wireless Sensor Networks (WSNs) to provide a required QoS (e.g., multimedia quality, real-time performance) in many applications.

2.2 Layer Interactions and Complexity

The variable and shared nature of a wireless channel and uniqueness of multimedia in WSNs provide an opportunity to break the traditional layer structure and allow the interactions among different equivalent layers to optimize WMSNs system performance as a whole. This requires a secure energy-efficient cross-layer architecture that can couple several layer functionalities. However, only a few studies on cross-layer design have been conducted for multimedia delivery in WSNs, while much research focuses on image/video delivery over general wireless networks. As cross-layer design violates the layer structure, an optimization framework is needed to concurrently model multiple parameters from equivalent layers. The design complexity is thus intensified and needs to be addressed along with overheads.

2.3 Interplay between Multimedia Processing and Networking

Networked multimedia sensors can conduct in-network multimedia processing. In traditional designs, multimedia processing is independent of delivery of multimedia contents, while in WMSNs their interplay has a significant impact on the levels of QoS. The multimedia contents and source coding techniques cannot be designed without wireless network conditions and resource support. Inversely, the network protocol and resource management must consider multimedia contents and source coding techniques when multimedia sensors acquire and transmit multimedia data.

2.4 Resource Constrained Multimedia Security

Multimedia sensor nodes and data transmission among this nodes are vulnerable to a variety of malicious attacks and compromises when they are deployed in a hostile wireless environment. Security protection methods must be provided to guarantee multimedia content security and integrity in such environments. Given the fundamental issues (i.e., resource constraints and source coding) related to information security, they must be judiciously designed and implemented for secure multimedia delivery over WSNs.

Typical challenges include reliable secure resource-efficient multimedia processing and communication in WMSNs, such as multimedia quality definition with heterogeneous sensors, security protection, and tight QoS expectations. They boost developing feasible solutions to design and deploy wireless networked multimedia sensor systems. Comprehensive cross-layer architecture should be proposed to achieve the goal of resource efficiency, certain level multimedia QoS and high security. In this architecture, it is essential to jointly control efficient source coding, intelligent resource allocation and information security in a cross-layer manner.

The optimization problem for cross-layer multimedia delivery over WSNs is formulated as follows:

$$\begin{aligned}&\{(APP_1,\, APP_2, ...APP_q), (NET_1,\, NET_2...NET_n),\\&(MAC_1,\, MAC_2, ...MAC_m), (PHY_1,\, PHY_2, ...PHY_p\\&)\} = \arg\max(Target)\ \mathit{or}\\&\ \arg\min(Target),\end{aligned}$$

$$s.t.\quad \{Con_1, Con_2...Con_i\},$$

where we either maximize or minimize the target. This target function is defined as any metric related to QoS requirements, energy efficiency or security performance of multimedia transmissions. The four sets, $(APP_1,\, APP_2, ...APP_q)$, $(NET_1, NET_2...NET_n)$, $(MAC_1, MAC_2, ...MAC_m), (PHY_1, PHY_2, ...PHY_p)$ denote the cross-layer parameters at equivalent application layer, network layer, MAC layer and physical layer, respectively. $\{Con_1, Con_2...Con_i\}$ represents the constraints at equivalent layers with low or high bound.

3 Current Research Development of the Cross-Layer Design for WMSN

In WSNs, it is necessary to break Open Systems Interconnection (OSI) architecture, as there is a tradeoff between QoS gain and resource cost in optimizing multimedia delivery performance. The cross-layered design for multimedia delivery in WSNs has more advantages than traditional layered approaches in transmissions. First, the traditional layered architecture is hierarchical and layer-independent, which forbids direct communication between nonadjacent layers. The layers in the cross-layer design are dependent, and can communicate directly or share variables between nonadjacent layers. Second, although traditional architecture performs well in wired networks, it does not function well in wireless networks. Supporting multimedia applications and services over wireless networks is challenging due to constraints and heterogeneities such as limited battery power, limited bandwidth, random time-varying fading effect, and stringent quality of service (QoS) requirements. These challenges cannot be solved via traditional layered architecture. The cross-layer design, instead, provides a new venue to enable optimal communication over wireless links and multimedia data processing at the application layer. Third, in WMSNs, new patterns of communication (e.g., channel broadcast nature, variance channel) through wireless medium allow new interfaces, merging of adjacent layers, and vertical calibration across layers. The adaptive strategy at each individual layer in traditional layer architecture is always suboptimal as the dependence of these layers is ignored and the optimization is localized at each layer. In a cross-layer approach, the layers share systematic information and can achieve global or systematic optimization of the multimedia network performance. Finally, the application-specific and energy-resource limitations of WMSNs pose challenges for cross-layer architecture design. To address these issues and challenges, optimal solutions need to be proposed to explore the benefits of this cross-layer approach.

There are three primary approaches to cross-layer architecture design [17]. The first approach allows direct communication between layers, where the information is shared in real time through visible variables (e.g., protocol headers). The second approach enables several layers to share a common database that is used for service storage and information retrieval. This approach is suitable for vertical calibration across layers. The third approach is to provide a complete new abstraction to organize protocols with flexibility. These cross-layer approaches in WSNs have been studied in two main contexts. One is focused on cross-layer interactions, where each layer has the information about other layers while the traditional layered structure has information at each layer. The second context reconsiders the mechanism of network layers in a unified way to provide a single communication module for efficient communication.

In WSNs, the cross-layer optimization considers the fundamental tradeoff between application-specific QoS gain and resource cost. Sensornet Protocol [1] uses the link layer abstraction and allows cooperation between the link layer and network layer, where limited resources can be utilized efficiently. EYES MAC [2] models the interaction between the MAC and routing protocol. It can improve traffic routing performance with consideration of network topologies, power duty cycling and node failure. In [3], the authors studied an energy consumption minimization problem by developing a joint design of MAC, Link and routing schemes. The link adaptation, optimal routing and scheduling are modeled for calculating the energy consumption. [4] proposed a unified cross-layer protocol to achieve energy-efficient and reliable event communication, which integrates the transport, network and MAC functionalities into one single module called XLM. In [5], the end-to-end congestion control at the transport layer and the power control at the physical layer are optimized through the JOCP algorithm. In [6], the authors form a network lifetime optimization problem under the constraints of transmission rates, energy budget and communication range. The optimal solution suggests an optimal rate control and link scheduling. In [7], the authors proposed a Low Energy Self-Organizing Protocol (LESOP) specifically for target tracking applications in dense WSNs. The LESOP can achieve high protocol efficiency through direct interactions between the application layer and MAC layer. In [8][9], we studied the cross-layer design for distributed source coding (DSC) in sensor networks by a joint design of the routing, link assignment and coding rate allocation at the application layer. However, these approaches are not easy to apply to in the multimedia transmission over WSNs, as their resource management, adaptation, and protection strategies at lower layers (PHY, MAC, Network/Transport) are suboptimal without considering characteristics of multimedia applications. In [10], we studied the joint design of the resource allocation at the Link-PHY layer with the rate distributions at the application layer for collaborative multimedia transmission. In [11], the single hop scenario for wavelet-based image transmissions in WSNs was also studied. The key idea is to differentiate the importance of digital images and allocate extra network resources to protect position values (P values).

More general cross-layer studies for multimedia delivery in wireless networks (not limited to sensor networks) have been conducted extensively in recent years. In [12], the authors proposed an adaptive cross-layer strategy to enhance the robustness and efficiency of scalable video transmission by optimizing MAC retransmission strategy, application-layer forward error correction, bandwidth-adaptive compression and adaptive packetization strategies. The research in [13] describes a cross-layer framework that selects and adapts different strategies available at the various OSI layers in terms of multimedia quality, consumed power, and spectrum utilization. In [14], the authors investigated how several APP (application layer) and MAC strategies can be jointly optimized to improve multimedia quality. Specifically, the experimental results show that the decoded video quality can be maximized by optimizing the MAC retry limit along with the application layer rate adaptation and prioritized scheduling strategies. In [15], an application-centric cross-layer approach is studied, where the APP layer selects the optimal MAC and PHY parameters. Incorporating the APP layer information into the cross-layer optimization, this approach offsets the disadvantages of the suboptimal multimedia delivery performance of the single MAC-PHY cross-layer approach. In [16], the source coding, allowable retransmissions, adaptive modulation and channel coding have been jointly optimized within a rate-distortion theoretical framework. Through the joint selection of parameters at physical, data link and application layers, the transmitted video quality over wireless networks can be improved.

Table 1. Existing Research and Cross-Layer Architecture

Cross-Layer Design Application	**Cross-Layer Architecture** (PHY—physical layer; APP- transportation layer; MAC/LINK- MAC and Link layer; Equivalent)	**Detail Methodologies**
For general data transmission in Wireless Sensor Network	MAC+PHY	[1]-energy consumption analysis for Physical and MAC layers is performed for three different MAC protocols [6]- Network lifetime maximization
	MAC+Transport+Routing	[4]- single XLM module for energy efficiency and reliable event communication
	MAC+Routing	[2]-traffic routing with the consideration of network topologies, power duty cycling and node failure
	Routing+MAC/LINK	[3]- form an energy consumption minimization LP problem
	Transport+PHY	[5]-an cross-layer optimization solution for power control and congestion control
	APP+MAC layer	[7]-Low energy self-organizing protocol(LESOP) for target tracking applications
	APP+Routing+MAC/LINK	[8]-joint the rate allocation, link assignment and rate-oriented routing for distributed source coding based applications
	APP+PHY+MAC/LINK	[9]-Join the resource allocation at LINK-PHY with the source coding adaptation
For multimedia transmission over Wireless Networks	APP+Routing+ MAC/LINK+PHY (In WSNs)	[10]-the rate-oriented routing, unequal resource allocation (PHY+LINK) and rate distribution for collaborative image transmissions.
	APP+MAC/LINK+PHY	[11]-joint optimizations of the resource allocation at LINK-PHY, and Position-Value based wavelet coding at APP layer(In WSNs) [15]-application-centric approach incorporating APP parameters into MAC-PHY optimization (General Wireless Networks) [16]-within rate-distortion frameworks, joint source coding, retransmission, adaptive modulation and channel coding
	OSI equivalent Layers	[13]-the adaptive strategy from various OSI layers for multimedia quality, power and spectrum utilization
	MAC+APP	[12]-joint the MAC retransmission, APP forward error correction and adaptive compression [14]-joint retransmission limit at MAC and rate adaptation at APP

These cross-layer approaches have difficulty in WMSN applications. First, generic wireless networks are more concerned with throughput, rather than energy efficiency, while in WSNs, the throughput is not critical as other metrics such as energy consumption and network life time. Energy efficiency is one of major goals for the cross-layer optimization of multimedia delivery in WSNs. Second, the existing cross-layer design for the general form of data transmission in sensor networks does not consider multimedia characteristics or content. Without incorporating multimedia information from the application layer, the cross-layer optimization at other lower layers is always sub-optimal. Therefore, the multimedia compression and streaming algorithms at the application layer should consider the mechanisms provided by the lower layers for error protection, scheduling, resource management, and so on. In addition, security is another major concern in WSNs. The security protection of transmitted multimedia requires both communication and computational resources. There is always a tradeoff between resource cost and security protection. The multimedia data protected by either encryption or authentication methods usually contain major information, and extra network resources should be provided to guarantee its transmission quality. Therefore, a joint design of the security and other cross-layer parameters such as resource allocation is necessary.

The current research is lack of an efficient cross-layer platform that can interplay among the multimedia processing, crytopography, and sensor networking to optimize overall WSNs performance. With the new development of multimedia applications over WSNs, the large volume of multimedia data transmission, strict QoS and security requirements need new efficient cross-layer architecture to support them under limited resource constraints in WSNs. Table 1 summarizes the current related research works in this field.

4 Case Study: Cross-Layer Based Collaborative Transmissions

An image sensor array deployed in the field with the same field views can provide distributed imaging of many applications. However, transmitting and processing a large volume of image data often causes bottlenecks in WSNs due to their limited resources (e.g. battery, and bandwidth). In many sensor network applications, they can drastically decrease the network performance and lifetime. One solution is to exploit the inter-image correlation among multiple sensors and remove inter-image redundancies. Many previous studies include cooperative methods [19]-[23] or predictive methods [24]-[28] to take advantage of sensor correlations. However, the former cannot be easily applied in image sensor applications due to heavy inter-sensor image communication overheads. Utilizing the sensor correlation model for efficient image transmissions should not only consider source image sensors themselves, but also take into account the network parameters such as the routing patterns and MAC/Link design. In our previous work [10], a cross-layer approach is proposed to distribute and protect the transmission of the overlap image regions shared by multiple sensors in a collaborative manner. We studies cross-layer architecture to support collaborative transmission by utilizing inter-sensor correlations. The maximum energy consumption saving bounds for collaborative transmissions are analyzed in this section. Let L denote the size of overlap regions, S be the size of the captured image, and N be the number of correlated sensors in a cluster group. In a two-sensor scenario for target monitoring, let sensor S_1 be at (x_1, y_1, z_1) position, and S_2 be at (x_2, y_2, z_2). d_1 is the distance between the target and S_1, and d_2 represents the distance between the target and S_2. To determine the overlap regions for these two sensors, several reference points in the target can be selected. For example, if the reference point i is at location $(x_i,\ y_i,\ z_i)$ and f is the focal length of the sensor, the coordinates of the projection point on the image plane (p, q) can be derived as:

$$p = \frac{x_i - x_1}{z_i - z_1} \times f,\ q = \frac{y_i - y_1}{z_i - z_1} \times f.$$

The errors in each dimension of the reference points are assumed to be normally distributed,N $\sim (0,\ \sigma^2)$, with zero mean and the variance of σ^2. The error term (e) is added to $\{p, q\}$,

$$p' = \frac{x_i - x_1}{z_i - z_1} \times f + e_p;\ q' = \frac{y_i - y_1}{z_i - z_1} \times f + e_q,$$

To determine if the two image sensors overlap, the intersection of these captured image shapes constructed by the reference points need to be determined. Thus, the size of overlap regions (L) can be represented as a Δ function of $\{p', q'\}$, which is denoted as

$$\Delta(\frac{x_i - x_s}{z_i - z_s} \times f + e_p,\ \frac{y_i - y_s}{z_i - z_s} \times f + e_q) \quad ,$$

where $\{x_s, y_s, z_s\}$ represents a sensor camera location. In non-collaborative multimedia transmission approaches, the total amount of transmitted image data Ψ_{no} is expressed as $(S + H_c) \times N$, where H_c denotes the communication protocol overheads. In collaborative image transmission, the overlap regions are transmitted to the base station collaboratively, and the total amount of communication load Ψ_{co} is expressed as:

$$N \times (S + H) - (N - 1) \cdot \Delta(\frac{x_i - x_s}{z_i - z_s} \times f + e_p, \frac{y_i - y_s}{z_i - z_s} \times f + e_q)$$

When the proposed secret sharing scheme (see Chapter 4) is applied, the amount of transmitted data is increased due to the redundancies of secret shares. In this proposed $(r,\ n)$ threshold image secret sharing scheme for overlap regions, the size of each image secret is L/r . Then the total amount of communication load is

$$\Psi_{se} = N \times (S + H) - \Delta(\frac{x_i - x_s}{z_i - z_s} \times f + e_p, \frac{y_i - y_s}{z_i - z_s} \times f + e_q) \times (N - \frac{n}{r})$$

The relationship $\Psi_{co} <= \Psi_{se} <= \Psi_{no}$ is always true when there are overlap regions. Due to this ordered relationship among Ψ_{co}, Ψ_{se} and Ψ_{no},this collaborative approach can achieve the minimal communication loads for any overlap regions.

Table 2. Analytical PMES Results for Collaborative Transmissions

Number of sensors	PMES (Collaborative; no energy minimization)	PMES (Collaborative; energy minimization)
5	30%	86.72%
6	32%	87.10%
7	33.33%	87.35%

Let $\rho_{\min}$ denote the minimum energy consumption per transmitted bit, and $\rho_{\max}$ represent the energy maximum energy consumption per transmitted bit. Compared with non-collaborative approaches, the Percentage of Maximum Energy Saving (PMES) without the low layer energy minimization is $[(\Psi_{no} - \Psi_{co})/\Psi_{no}]\%$ for the collaborative transmissions. The PMES with the energy minimization mechanism for the collaborative approach is

$$[\frac{(\Psi_{no} \times e_{\max} - \Psi_{co} \times e_{\min})}{(\Psi_{no} \times e_{\max})}]\%$$

In this case study, the image size is 10k bytes, and the total overlap regions are 4K bytes. $\rho_{\max}$ is 6.324 e-4 joules/bit , and $\rho_{\min}$ is 1.2e-4 joules/bit. The (r=6, n=10) secret sharing scheme is applied in this case. When the number of participated image sensors varies, the percentage of maximum ES is shown in Table II.

Table 2 shows a theoretical bound for energy savings with determined multimedia sensor network configuration. It is observed that the energy savings are increased with the number of correlated sensors. The values of PMES with energy minimization (see Table 2) indicate that the collaborative approach in the proposed architecture can achieve up to 87% maximum energy savings compared with the non-collaborative multimedia transmission approaches.

5 Conclusions and Future Directions

The main goal of this paper is to investigate the current development of cross-layer design research in WMSNs and provide research directions in these fields. Current research mainly focuses on three objectives: The first objective is to improve resource efficiency. Multimedia sensor has limited resources in terms of CPU computational capability, memory and bandwidth as well as battery support capability. These resources must be utilized efficiently or be optimized for applications. Among them, energy efficiency is the major objective. The second objective is to improve multimedia transmission quality over WSNs. The error-prone wireless channel causes packet loss and degrades multimedia transmission quality. The cross-layer adaptive strategy of multimedia delivery must be designed to prevent packet loss through efficient resource allocation. The third objective is to enhance security. There is a critical need to provide privacy and security assurances for distributed multimedia sensor networking in applications such as military surveillance and healthcare monitoring. In order to achieve these three objectives, we believe that the cross-layer design provides a promising solution by incorporating the characteristics of multimedia and information security at the application layer into adaptation and optimization at lower layers.

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