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An adaptive cross-layer error control protocol for wireless multimedia sensor networks

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ABSTRACT

In this paper, we introduce a new adaptive cross-layer error control protocol (NAC) for reliable and efficient real-time multimedia streaming in Wireless Sensor Networks (WSN). The proposed protocol uses an adaptive Forward Error Correction (FEC) algorithm in the application layer, a dynamic hybrid FEC/ARQ method, and an Unequal Error Protection (UEP) mechanism in the wireless link layer. Moreover, it dynamically tunes the amount of erasure codes per group of packets based on mean absolute deviation of recently measured average round-trip times, and cross-layer information such as arrival of acknowledgment packets, network traffic load, and wireless channel state. In fact, by dynamically determining suitable redundancy for the source packet based on the packet loss rate in the hybrid FEC/ARQ error control algorithm in the wireless link layer, we achieve significant improvements over the existing error control schemes, while decreasing the number of retransmissions in ARQ mechanism. Our comprehensive simulations show that the proposed NAC protocol achieves better performance compared to the popular error control schemes in terms of energy efficiency, frame loss rate, frame Peak Signal-to-Noise Ratio (PSNR), and delay-constrained PSNR for real-time multimedia streaming over sensor networks.

1. Introduction

Quality of Service (QoS) requirements of multimedia communications and energy constraints of battery-powered sensor nodes, necessitate the design of reliable and energy-efficient communication protocols for Wireless Multimedia Sensor Networks (WMSNs) [1,2]. Transmission of video over multimedia sensor networks is a challenging task due to limited bandwidth and high propagation Bit Error Rates (BER) of wireless channels. In WMSNs, high video compression ratios make multimedia streams suitable for low bit-rate wireless channels. However, the compressed multimedia streams become more vulnerable to transmission errors due to predictive nature of the coding standards. Moreover, the low power communication constraints of sensor nodes worsen the effects of wireless channel errors, leading to more error rates.

In order to provide high quality multimedia communication despite the aforementioned challenges, WMSNs need to employ energy efficient and reliable error control mechanisms. Intelligent Forward Error Correction (FEC) packet adjustment, Unequal Error Protection (UEP), hybrid scheme, and utilizing the cross-layer information are among the most important techniques that should be considered in design of such error control schemes [3,4]. Although more FEC packets provide greater opportunity to recover erroneous packets, they may overload and congest WMSNs when the traffic load is high. On the other hand, fewer FEC packets may fail to recover erroneous packets when wireless channel condition is being degraded. As a result, an intelligent FEC packet utilization method can provide better network performance and higher video quality at the sink node. Moreover, the UEP mechanism considers different protection levels for multimedia streams according to their importance. Hence, the important packets can be protected with more powerful schemes to improve the quality of perceived video. Furthermore, the hybrid FEC/ARQ approaches in [5,6] and [7] combine the best features of the Automatic Repeat Request (ARQ) and FEC mechanisms to achieve better performance. Finally, utilizing cross-layer information from the protocol stack can increase the efficiency of the overall system, enhance the video quality, maximize the usage of network resources, and save energy in WMSNs [8].

In this paper, an adaptive cross-layer error control protocol for WMSNs is proposed that incorporates the effect of application and link layer FEC strength, maximum number of retransmissions, net-

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work traffic load, wireless channel condition and energy consumption, simultaneously. This cross-layer protocol uses an adaptive forward error correction algorithm in the application layer and a dynamic hybrid FEC/ARQ error control algorithm in the wireless link-layer to provide the desired performance. More specifically, to improve the static FEC performance over variable wireless channel conditions and avoid network congestion, the number of redundant FEC packets in the application layer are dynamically adjusted per group of video packets by using the cross-layer information such as mean absolute deviation of recently measured average queuing delay times, the arrival of acknowledgment packets, and network traffic load. The proposed protocol expedites upward and downward transitions to the higher and lower levels of erasure coding strength. By dynamically determining the redundancy of FEC bytes in the hybrid FEC/ARQ error control algorithm, we could adapt the protection level of link layer to increase the efficiency of WMSN. In addition, the UEP strategy is applied on video packets to improve the packet loss resiliency, and to reduce the energy consumption.

The advantages of the proposed protocol are:

- It provides adaptive error resiliency for bit error and packet erasure, simultaneously.
- The cross-layer adaptive erasure coding scheme combats the packet erasure and avoids congestion and contention in the multi-hop path by gradually tuning the FEC packets.
- It uses dynamic redundancy in the FEC bytes of the link layer.
- It minimizes the energy consumption with a reliability constraint.
- It utilizes an UEP strategy on video packets to improve the error resiliency and quality of the perceived video at the sink node.

It is important to note that WMSNs require the performance and energy constraints of WSNs as well as the QoS requirements of multimedia communications. Hence, compared to the state of the art error protocols in wireless communications and WSNs, our New Adaptive Cross-layer error control protocol (NAC), captures the multi-hop communications effects and the energy consumption constraint of WSNs by using erasure coding and UEP techniques on multimedia data and communications, to provide reliable protection in WMSNs.

The rest of the paper is organized as follows. Section 2 summarizes the recent related works on adaptive, hybrid, cross-layer, and optimized error control protocols. Section 3 presents elements of the proposed system. Sections 4–6, provide the detailed design of NAC; Section 4 describes the design of adaptive cross-layer erasure coding error control scheme, Section 5 presents the dynamic hybrid FEC/ARQ scheme, and Section 6, introduces the complete NAC protocol. The simulation results are provided in Section 7. Finally, Section 8 concludes the paper.

2. Related works

Despite the existence of many works on reliable and robust error control schemes in various networks, previous studies have not focused on error control protocols for WMSNs. In particular [9] and [10] are the only specific error control protocols which have been proposed for multimedia sensor networks. Moreover, in [3] and [4] the authors have provided comprehensive simulations to evaluate the performance of different error control mechanisms in WMSN. Many researchers have focused on adaptive, cross-layer, hybrid, and optimized error control schemes for sensor, Internet, and wireless networks in recent years. The most related works to the scope of this paper are described below.

The authors in [3] present a comprehensive study to evaluate the performance of different error control mechanisms in WMSN. This study provides a comparison between ARQ, FEC and hybrid ARQ/FEC error control mechanisms in terms of frame loss rate, frame peak signal-to-noise ratio (PSNR), and energy efficiency. It is shown that although Reed–Solomon (RS) is energy efficient, it cannot provide acceptable video quality in higher error rates at the receiver. Moreover, it has been shown that the ARQ scheme has the worst performance in terms of PSNR. Furthermore, the authors showed that while the hybrid ARQ/RS scheme outperforms other schemes based on perceived video quality and frame loss rate, it cannot provide the best energy-efficient results.

In [4], a comprehensive performance evaluation of ARQ, FEC, Erasure Coding (EC), link-layer hybrid FEC/ARQ, and cross-layer hybrid error control schemes over WMSNs is presented. In this study, performance metrics such as energy efficiency, frame PSNR, frame loss rate, cumulative jitter, and delay-constrained PSNR are investigated. Table 1 presents the most efficient and worst schemes for each metric. The results reveal that link-layer hybrid and cross-layer hybrid schemes improve the quality of perceived video at the sink node in comparison with simple schemes. More specifically, this improvement can be utilized by using cross-layer scheme in low bit error rates, and link-layer hybrid schemes in high bit error rates.

In [9], a cross-layer FEC scheme on variable length coded data for WMSNs is presented. It employs a novel fountain code to exploit the physical layer, transport layer and the application layer FEC approaches. Although the reliability as the probability of correctly decoded blocks at the receiver side is evaluated, this work has not investigated the most important performance metrics of WMSNs such as energy efficiency and quality of perceived multimedia data. Moreover, [10] introduces an adaptive error control mechanism by scheduling the optimal error control scheme based on the importance of link-layer frames. Indeed, it uses an UEP mechanism for MPEG-4 video streams, however it does not consider the delay-constraint and QoS performance metrics.

In [11], the authors have proposed an Enhanced Adaptive FEC (EAFEC) mechanism for video delivery over a wireless network. The number of redundant data is determined by Access Point (AP), based on the network traffic load and wireless channel status. Moreover, it used the queue length to indicate the traffic load and packet transmission time to indicate wireless channel status, by defining four thresholds. The results of simulations showed that the EAFEC improves system performance by dynamically adding FEC redundancy packets based on the current amount of wireless channel loss. However, this mechanism does not provide any optimum threshold values, and QoS performance metrics have not been considered.

In [12], the authors proposed an Adaptive Hybrid Error Correction Model (AHECM) to improve the Hybrid ARQ (HARQ) mechanism. The AHECM algorithm can limit the packet retransmission delay to the most tolerable end-to-end delay. Besides, the AHECM can find the appropriate FEC parameter to avoid network congestion and reduce the number of FEC redundant packets by predicting the effective packet loss rate. Meanwhile, when the end-to-end delay requirement can be met, the AHECM will only retransmit the necessary number of redundant FEC packets to the receiver in comparison with the legacy HARQ mechanisms. Furthermore, the AHECM can use an unequal error protection mechanism to protect important multimedia frames against channel errors of wireless networks. Besides, the AHECM uses a Markov model to estimate the burst bit error condition over wireless networks. The AHECM is evaluated by several metrics such as effective packet loss rate, error recovery efficiency, decodable frame rate, and PSNR to verify its efficiency in delivering video streams over wireless networks. However, QoS performance metrics and sensor energy efficiency have not been mentioned in [12].

In [5], a link-level hybrid FEC/ARQ based on an adaptive FEC algorithm for wireless media streaming is proposed to decrease