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Video Coding and Routing in Wireless Video Sensor Networks

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Abstract

Video represents a form of data that needs large storage space. In addition, and due to the complexity of video coding (encoding/decoding) techniques, they usually involve computationally intensive operations. This imposes heavy burdens upon sending and receiving entities that are required to have high processing power and abundant storage capacity, as well as the network infrastructure transporting video content that is required to have sufficient transmission bandwidth. Therefore, it is important to tailor video coding techniques to resource-constrained wireless sensors. Moreover, the intensive computations needed by video codecs consume substantial power, which is a scarce resource of wireless sensor nodes as they are usually battery powered. Therefore, it is of paramount importance to design power-aware coding, streaming, and routing schemes for the emerging wireless video sensor networks (WVSNs), that also achieve high levels of QoS and QoE. This paper introduces a brief survey of the recently published research on some important topics about WVSNs including video coding and routing and point to possible venues for future research.

Keywords: Wireless Video Sensor Networks; Video Coding; Routing.

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1. Introduction

An emerging type of networks called wireless sensor network (WSN), Yick et al. 2008 is comprised of a number of smart sensor nodes working together to sense and monitor an inside or an outside environment. Each sensor node consists of one or more sensors, a processor, memory, a power supply (typically a battery), a radio, and an actuator. Depending on the application, sensors could be mechanical, thermal, biological, chemical, optical, or magnetic. The wireless sensor node is constrained in terms of energy, communication range, transmission link capacity, and processing and storage capabilities. To design a WSN effectively, the application and environment in which they will be used should be carefully considered.

An important class of WSNs is the wireless multimedia sensor network (WMSN), Akyildiz et al. 2007 that allow retrieving different types of multimedia content like video, audio, graphics, and scalar data. The development of WMSN has been triggered by the availability of inexpensive off-the-shelf cameras and microphones. WMSNs can be employed for multimedia surveillance in a wide range of applications covering various aspects of human life in both civilian and military aspects. Some of the most popular applications include industrial control, patient monitoring, habitat and environmental monitoring, battlefield and border monitoring, household management, disaster and rescue, and target detection and tracking. In addition to capturing multimedia content, WMSN are also used to perform in-network non-real time processing as well as real time processing, storage, correlation, and fusion of the sensed multimedia content. Mobile multimedia sensor networks (MMSNs) can be used to provide better event description, Chen et al. 2011. WVSN is a special type of WMSNs consisting of miniature video cameras for surveillance missions, Wu et al. 2011, Cho et al. 2010, and Durmus et al. 2012.

Coverage percentage in WMSNs is the perception area of the environment being monitored. Chen et al. (to appear in IEEE Sensors Journal) proposed a coverage-enhancing algorithm based on overlap-sense ratio (OSRCEA) to increase coverage and prolong WMSN lifetime by to shutting off redundant sensors. The proposed algorithm finds the rotation angle of a sensor node using the overlap-sense ratio (OSR), while the centroid of overlapping regions is adopted to determine the rotating direction. The issue of finding the optimal camera placement to provide angular coverage in WVSNs has also been addresses by Yildiz et al. (to appear in IEEE transactions on computers).

To compare between the different image quality evaluation techniques in WMSNs, Sarisaray-Boluk 2012 evaluated the impact of packet size, link and node correlation effect, and loss areas on the performance of image quality assessment (IQA) metrics like PSNR, WSNR, SSIM, and VIF. The author found that packet size and link and node correlation do not affect PSNR. He also found that as larger packets are used WSNR decreases, while SSIM and VIF increase. Moreover, the author proposed and evaluated the block-based weighted peak signal-to-noise ratio (WBBSNR) method to evaluate image qualities on the fly and made several suggestions like combining IQA metrics using weights.

There are several other issues and challenges facing WVSNs including for example node architectures Seema and Reisslein 2011, the design of low-power distributed video sensors, Chien et al. 2013, security in terms of encrypting video streams in WVSNs, Wang et al. 2010 and watermarking, Harjito et al. 2012, and efficient communication protocols and algorithms that address the unique challenges posed by WMSN requirements in order to realize various WMSN applications, Gisirses and Akan 2005. However, we focus in this paper on two important subjects: video coding and routing in WVSNs. Remaining sections of this paper are as follows: in Sections 2 and 3, we survey recent research papers about video coding and routing in WVSNs, respectively. Then in Section 4, we point to some open issues for future research. The conclusion of this paper can be found in Section 5.

2. Video Coding in Wireless Video Sensor Networks

The H.264/MPEG4 AVC is the most recent coding standard of video streams. This protocol suite has been introduced by both ISO/IEC MPEG and ITU-T VCEG. Compared to previous video coding methods, the H.264/MPEG4 AVC impressively provided efficient video coding, achieved better error robustness, and maximized applicability. Therefore, H.264/MPEG4 AVC has been applied in many video compression applications including mobile video services, videoconferencing, IPTV, HDTV, as well as HD video storage. The coding in H.264/MPEG4 AVC has been built on the conventional block-based motion estimation and compensation but with many improved features and services like the enhanced entropy coding and scalable video coding (SVC) techniques. Entropy coding can provide reductions in bit rate while maintaining similar perceptual video quality. SVC methods can reconstruct video at lower quality, Marpe et al. 2006.

The conventional MPEG and H.26x video codecs are based on complex encoders and simple decoders. The encoder performs intra-frame coding and exploits statistical dependence between frames in the source video signal to perform inter-frame coding. The decoder is on the contrary much simpler. This configuration seems suitable for many applications like video broadcasting, where encoding is needed to be performed just once while decoding is performed multiple times by several decoders. In many other applications like in WVSNs, the requirements are typically different, where devices have limited energy and computational capabilities. The distributed video coding (DVC) – reader is advised to see Girod et al. 2005 – is built on principles of the information theory of 1970s. Theoretically, DVC employs Slepian/Wolf (which is a lossless coding) and Wyner/Ziv (which is a lossy coding) to produce video codecs that exploit statistics gathered by source at the decoder and thus provides a complex decoder and a less-complex encoder. Practically, one can find implementations of DVC in the literatures utilizing several methods like pixel-domain encoding, joint decoding and motion estimation, transform-domain encoding, in addition to rate control. These practical implementations were able to achieve 10X to 100X reduction in the computational complexity of compression performed by the encoder relative to conventional encoders. Moreover, these practical implementations outperform conventional intra-frame coding considerably. However, it is not expected that these schemes will reach the conventional inter-frame codecs in terms of rate-distortion but at least come close to them.

Compressed sensing (or compressive sampling) has been proposed as an alternative to conventional video codecs aiming at building encoders with very low computational complexity. Pudlewski et al. 2012 proposed the C-DMRC algorithm based on compressed sensing for streaming video over wireless multimedia sensor networks. The proposed system is comprised of a distributed rate controller, video encoder, in addition to a channel encoding scheme with adaptive parity using low-complexity video sensor nodes.

To reduce traffic volume on video sensor nodes and to maximize the bandwidth at hand, Politis et al. 2008 proposed packet scheduling scheme to selectively drop combinations of video packets before transmission, where less important video packets.

Tsai and Lin 2012 proposed an approach for VSNs to increase coding efficiency and decrease coding complexity. The proposed coding exploits the existing redundancy related to foreground and background objects in the image. The macroblock having distinguished context will be classified and then the encoder compresses MBs.

3. Video Routing in WVSNs

Multimedia routing in WMSNs demands certain requirements and is faced by several challenges. The successful routing protocol is therefore highly application and circumstances dependent. The most dominant requirements encompass QoS requirements and energy efficiency, Ehsan and Hamdaoui 2012. QoS requirements include latency (the maximum allowable delay of multimedia content to reach the sink node), reliability (an upper bound on the tolerated packet loss ratio), jitter (the maximum allowable variation of delay in between the reception of video packets), and bandwidth (the minimum amount of bandwidth in bits per second that should be supported). The energy efficiency requirement is vital in WMSNs because the high required data rates and the extreme processing needs cause fast depletion of sensors power. Some of the most challenges that face routing protocols in WMSNs include architectural issues and hole detection and bypassing. The points the routing protocol designers should consider in terms of the network architecture are the network dynamics like mobility issues, data delivery models addressing the periodicity of data delivery and dissemination (continuous, event-driven, or query-driven), architectural configuration addressing homogeneity or heterogeneity among sensor nodes in terms of purpose and capabilities, and channel capacity.

Most energy-aware routing protocols used for routing in WVSNs employ shortest path routing or multipath routing approaches to address bandwidth, end-to-end delay, or both requirements, Ehsan and Hamdaoui 2012. Here, we mention some examples of protocols specifically designed for routing video streams over WVSNs. A modified version of LEACH is a hierarchical protocol to reduce video distortion and address bandwidth constraints. The fully distributed OEDSR is a protocol that addresses end-to-end timing constraint. Directional Geographical Routing (DGR) protocol streams real-time video over WVSNs. Therefore, it considers both bandwidth and delay constraints, Ehsan and Hamdaoui 2012.

The routing scheme proposed by Kandris et al., 2011 combines an energy efficient routing protocol with a scheduling algorithm of video packets. The proposed hierarchical routing protocol selects routes and manages network load based on residual energy of sensor nodes. The authors also adopt analytical distortion prediction model in their video packet scheduling algorithm to minimize distortion. The authors also extend their work to include scalable video coding, where the base video layer streams can be routed over high-transmission-quality routes, while lower-quality routes can be used to transport enhancement layers video streams.

It is possible to achieve lower energy consumption or lower communication cost if the data being sensed are correlated by applying the information theory using network combinatorics by applying network coding (NC) as well as distributed source coding (DSC). Li et al. 2011 proposed a coding and routing mechanism by applying an analytic power-rate-distortion (P-R-D) model for distributed video coding (DVC) to reduce distortion of video and prolong the lifetime of network. Dai et al. 2012 proposed CAQR scheme in order to minimize the energy consumed by wireless video sensor nodes under delay and reliability QoS constraints through the utilization of correlation inherent in the perceived scene information. The correlation-aware compression/decompression employed by CAQR uses differential coding, Dai and Akyildiz 2009 between intra coded frames to reduce the size of the generated traffic. CAQR then performs correlation-aware load balancing. Dai et al. 2012 then integrate these two correlation-aware schemes into a distributed optimization QoS routing framework targeting reduced energy of nodes.

Video is typically of large size. The transmission requirements therefore exceed the bandwidth available for video sensor nodes. To achieve better transmission performance, the multi-path transmission lends itself as a viable solution. TPGF, Shu et al. 2007 is a hole-bypassing multi-path routing protocol for WMSNs that reduces the end to end transmission delay as well as path length. Another multipath transmission scheme was adopted by Politis et al. 2008 and Zou et al. 2011. It can also be observed that in multimedia applications video and audio streams are of varying importance levels. For instance, one can notice that video has higher importance than audio in the forest fire monitoring application while audio has higher importance than video in the monitoring of deep ocean application. MPMPS, Zhang et al. 2008 routing protocol is built on TPGF and assigns two priority levels to audio and video streams according to their importance in the specific application and selects routing paths that have high priority level for more important video/audio stream. The CAMS, Shu et al. 2010 was proposed to increase the possibility of gathering valuable (comprehensive) information by video sensor nodes in order to send to the sink node based on brightness level and noise level.

4. Open Research Issues

There are several issues in WVSNs that can be addressed by researchers in the future. In this section, we point to some important future research issues. Researchers should consider that the routing protocol used in WVSNs must achieve high QoS and saves energy. It is also important to consider joint compression, aggregation, and routing of video under QoS constraints with an objective to minimize the amount of energy consumed by wireless video sensor nodes. Congestion-aware routing algorithms is another important subject.

To reduce redundancy, wireless sensor cameras must be made awake when they sense something in the sensing range, which leads to a need for optimal placement of sensor cameras for the best coverage and to avoid redundancy. We should also remember that mobility of either sensor nodes or object being tracked can impose additional challenges to video-sensing applications. Moreover, if the WMSN is used to collect various multimedia data, then robust protocols are needed for data aggregation and fusion.

5. Conclusions

Wireless video sensor networks represent a promising solution in many human life areas. In this paper, we have surveyed recent research papers in topics addressing various issues of WVSNs with a focus on video coding and routing in WVSNs. We have also outlined future research directions and open research issues in this active area of research.

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