Journal of Network and Computer Applications 38 (2014) 54–64

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Low-cost prioritization of image blocks in wireless sensor networks for border surveillance

Kerem Irgan [a,*], Cem Ünsalan [b], Sebnem Baydere [a]

[a] Department of Computer Engineering, Yeditepe University, Kayisdagi, Istanbul 34755, Turkey
[b] Department of Electrical and Electronics Engineering, Yeditepe University, Kayisdagi, Istanbul 34755, Turkey

ARTICLE INFO

Article history:
Received 22 October 2012
Received in revised form
23 May 2013
Accepted 12 June 2013
Available online 29 July 2013

Keywords:
Wireless sensor networks
Border surveillance
Image transfer
Packet prioritization
Entropy
Edge detection
Reproducibility

ABSTRACT

Wireless Sensor Networks (WSNs) are becoming more imperative in monitoring and surveillance applications, such as border surveillance. For these applications, cameras attached on several sensor nodes are placed on preselected locations in the border region. In case of an intrusion event, these cameras capture images and transmit them to the sink node via other sensor nodes. WSNs operate with limited resources. Therefore, resource utilization is needed when processing and transporting images. In this study, we propose a cost-effective method for dynamic (on-the-fly) prioritization of image macro-blocks. Therefore, we employ a simple encoding scheme at the source node by labeling data blocks as "important" and "not-important" based on the information they contain. The network then transmits "important" data blocks from reliable paths. We established an experimental setup to assess the success of the proposed method using various prioritization measures for labeling and we compared the results with JPEG encoding. The results indicate the usefulness of the proposed prioritization based encoding scheme in terms of transferred image quality, delay and energy.

1. Introduction

A wide range of emerging wireless sensor network (WSN) applications benefit from multimedia capabilities (Akyildiz et al., 2007; Soro and Heinzelman, 2009). Border surveillance is such an application, where sensor nodes equipped with low-power cameras can be utilized in an intrusion detection scenario. In surveillance systems, it is crucial to get visual information about the event area. With the aid of this information, anomalies and threats can be realized. However, the quality of the gathered visual information is important to detect the event type and the perpetrators correctly, since it is the main input of recognition systems (Iqbal et al., 2012; Albano et al., 2012). In this study, we consider a WSN based border surveillance system consisting of camera nodes attached with motion detectors, a WSN formed by ordinary sensors nodes, and a sink as given in Fig. 1.

If intruders cross the border, a motion detector triggers the attached camera. The camera grabs the image and sends it to the sink via the WSN. Since the image to be transmitted requires a large bandwidth, we propose extracting the important parts of the image in the camera node and sending only these parts through reliable paths. Thus, at the sink node, the image parts containing these important information can be analyzed.

Although there are some works in the literature devoted to image compression for bandwidth utilization in WSN, these are still in their early stages (Lecuire et al., 2007). On the other hand, such complex encoding techniques that require processing of the full image data may not be suitable for tiny sensor nodes, due to memory and processing resource constraints. Even a 256×256 image cannot fit into the memory of commercial off-the-shelf (COTS) sensor devices. Besides, image data is extremely bigger than traditional scalar sensor data. We should find out proper image processing methods that suit such WSN constraints. In this respect, methods which do not need whole image data are mandatory. Therefore, in this study, we propose a simple encoding scheme that is applicable to image partitions rather than the full image. In our method, $N \times M$ 8-bit grayscale images captured by camera sensors are partitioned into $m \times m$ pixel macro-blocks. Here, m must be an exact divisor of N and M. The macro-blocks are serially passed to network layer for encoding. Here, a prioritization measure which is applicable to partial image data and suitable for resource poor environments is used to label macro-blocks as "important" or "not-important" based on the information they contain. Then, only "important" blocks are transmitted through reliable paths. We assume the existence of an accompanying priority based reliable routing protocol for the transmission. Image transmission terminates at the source node when all "important" macro-blocks of the image are sent to the sink.

In the border surveillance application, the quality of the image macro-blocks containing *objects* is essential, since they can lead to

* Corresponding author. Tel.: +90 5334191632.
E-mail address: kirgan@cse.yeditepe.edu.tr (K. Irgan).

1084-8045/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jnca.2013.06.005

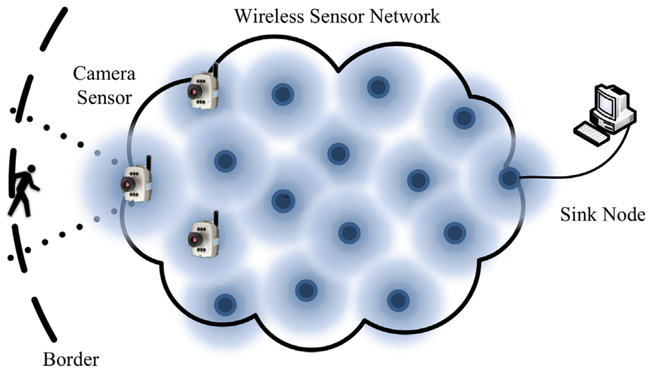

Fig. 1. WSN scenario for border surveillance.

security analysis at the sink node. Therefore, their successful transmission to the sink node is more important than transmitting the background image. The objective of the study is to decrease the amount of "to be transmitted" packets while preserving enough information required to detect the event and to identify its source. To this end, we analyzed three different packet prioritization measures in this study. These are *entropy*, *edge detection*, and *reproducibility*. We also analyzed hybrid usage of *entropy* and *edge* with *reproducibility*. We call these measures as *delta-entropy* and *delta-edge*. All these techniques are selected for their low computation cost and memory requirements.

To quantitatively compare the measures, we employed a new performance metric called as *Object Transmission Rate* (OTR). This metric reflects the quality of the objects in transmitted images. In the comparisons, we used transmissions over lossy paths without any encoding case as the baseline. We also evaluated the computational costs of the proposed measures on Telosb (Polastre et al., 2005) equivalent Tmote Sky sensor nodes.

In this paper, we extend our priority encoding scheme proposed in Irgan et al. (2010), with the hybrid usage of previously proposed priority measures and the additional results including energy and latency analysis and the comparisons with the traditional compression algorithm JPEG (Wallace, 1992).

The layout of the study is as follows. Section 2 introduces related work. Section 3 discusses prioritization measures. Section 4 presents the experimental setup. Section 5 includes performance analysis and experimental results. Finally, Section 6 concludes with discussion and future work.

2. Related work

Packet prioritization has been extensively studied in the literature. One of the pioneering works is by Albanese et al. (1996). Prioritization of network traffic is also used in differentiated service networks. However, in WSN the problem becomes more specific due to resource constraints and the dynamic nature of the environment. Therefore, static resource allocation methods are not convenient for WSN. Akyildiz et al. (2007) mention this issue in their literature survey paper. They indicate that multimedia packet prioritization at the link layer remains an open challenge. Yet in another survey paper on visual sensor networks, the amount of data to be transmitted through the network is mentioned as a major problem (Soro and Heinzelman, 2009). Gurses and Akan (2005) mention similar constraints in their research paper. They indicate that most work in the literature focused on conventional data transfer on WSN. They emphasize the need for research on the problems of multimedia communication in WSN. Related to the work proposed in this study, Oztarak et al. (2007) considered transmitting moving object images through the network. They benefit from fuzzy logic in their method. Lecuire et al. (2007) performed packet prioritization using the wavelet transform. Their main aim was the energy efficiency of image transmission. On the other hand, the present study focuses on packet prioritization at the network layer which adapts itself to the application layer requirements and environmental changes using a simple encoding mechanism.

Image coding is the fundamental part of visual data handling in WSNs. There are several researches about different aspects of image coding in WSNs. One of the main concerns of these researches is about compression. Fragility of compressed data makes it hard to handle it on lossy wireless channels. In the real tests of the work (Pekhteryev et al., 2005) 14% of the JPEG 2000 coded images are unrecoverable in a 2-hop transmission. Moreover, compression is sometimes not possible for the methods that require full image, such as JPEG 2000 (Christopoulos et al., 2000), because of the limited available memory of sensor nodes. In this context, Lee et al. (2009) have studied trade-offs in compression parameters in terms of computational cost, energy consumption, speed and image quality. They also proposed optimization methods. For testing the methods on different hardware platforms, they have utilized a framework which automatically generate C codes for the platforms. Their optimized results are used as the baseline of our JPEG comparisons. Kaddachi et al. (2012) propose specialized hardware based image compression in their recent study. They achieve significant gain in terms of processing time and energy. However, the energy cost of their method is still higher than our proposal. Duran-Faundez et al. (2011) proposed a compression method to cope with fragility of traditional compression by independent compression of tiny 2×2 macro-blocks and by utilizing interleaving of the encoded macro-blocks. Watermarking is another method to increase robustness of transmitted image by increasing redundancy (Pizzolante et al., 2011). In our other work, we have studied this method experimentally with a real testbed (Sarisaray et al., 2012). Another coding method is distributed source coding (DSC) (Xiong et al., 2004) to balance the computational load on sensor nodes. There are many studies in the literature about DSC (Wang et al., 2007; Xue et al., 2008; Wu and Chen, 2007; Girod et al., 2005). These studies are mostly based on Slepian and Wolf's (1973) and Wyner and Ziv's (1976) information-theoretic works. In these methods a spatial or temporal correlation between the images taken from different sensor nodes is needed. With regard to still-images, it is only possible when more than one camera views are overlapped. However, our approach successfully works on a single camera view.

3. Macro-block prioritization

In the well-known work of Shannon (1948), he indicates that the redundancy that is already included in the data helps to combat channel impairments. In the light of this, instead of removing the naturally included redundancy in image data by compression, the redundancy can be exploited to increase robustness of the transmitted images in WSNs.

Generally, the border image to be transferred in the WSN is not homogeneous. Therefore, some of its parts contain more information compared to others. If the paths in the network can be divided into two, such as reliable and non-reliable, then it is wise to transfer important packets through the reliable path and not-important packets through the non-reliable path. In this section, we provide several measures to weight the importance of a given packet. Since our motivation is border surveillance by cameras on WSN, we prioritize the packets accordingly. In other saying, the measures should emphasize objects in the image and label the ones containing objects as important.