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Improving response time in time critical Visual Sensor Network applications

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ABSTRACT

Wireless sensor network (WSN) consisting of nodes equipped with cameras or advanced low-cost image sensors is known as a Visual Sensor Network (VSN). The main function of VSN is to capture images and send them to sink nodes for processing. Common applications of a VSN are surveillance, tracking, crowd management, scientific research, etc. Such applications require large amounts of data to be exchanged between camera nodes and sink. Image data is considerably larger than common sensor data such as temperature, humidity, and pressure. For data delivery in VSNs, the communication is constrained by many stringent QoS requirements like delay, jitter and data reliability. Moreover, due to the inherent constraints of WSN such as limited energy, low CPU power, and insufficient memory; the architect of VSN must choose appropriate topology, image compression algorithms, and communication protocols depending on application. In literature, different techniques have been proposed to resolve the bandwidth requirements for the VSN. The majority of these techniques are based on the compression of visual data. This paper focuses on one of these aspects, namely the communication protocol for VSN. In this paper, we present Priority Routing Framework for Image Transmission (PRoFIT), a new routing framework for VSN to deliver critical imagery information with system's time constraint. We demonstrate that PRoFIT improves response time in various VSN applications as compared to priority-less routing techniques. We have implemented PRoFIT along with an image processing application using Contiki and simulated it on Cooja simulator to support our claim.

1. Introduction

VSN consists of three types of nodes; visual sensing nodes, intermediate nodes and sink nodes. The visual sensing node is equipped with the sensor that captures images. Depending on the application this sensor can be of type that captures multi-colored images, grey-scale images, thermal, or infra-red images [1], etc. Nodes equipped with these sensors require more power to run additional hardware and software components such as frame-grabbers and image encoders. These nodes capture raw images, encode them, and send them towards the sink.

The main task of intermediate nodes is to send packets from visual sensing nodes to sink nodes. These nodes may also take part in sensing other scalar environmental variables such as temperature, humidity, pressure, and concentration level of certain chemicals depending on the

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nature of VSN application. Additionally, these nodes may also take part in encoding image data as a class of image encoding algorithms [2] offload some processing to intermediate nodes in order to conserve power of visual sensing nodes.

The sink nodes are responsible for processing the images captured by the camera nodes. For this purpose sink nodes are power-rich and have high computation ability. In order to take action depending on the VSN application, these nodes may additionally contain actuators or may be connected to a fourth type of nodes called actuator nodes.

The primary requirement of a WSN is to sense environmental factors using low-power, low-cost sensors and route meaningful data to power-rich sink nodes for processing. This requirement becomes challenging in a VSN as the amount of data to be transferred is much more than a conventional WSN due to the type of data being shared. Applications of surveillance require very large amounts of data to be exchanged between camera nodes and sink. In conventional WSN that sense light, humidity, pressure, etc. the traffic generated by a sensing node is limited to the scalar data [3]. In most cases the memory size required to store and send is 16-bits per reading [3]. On the other hand, a VSN node, equipped with a camera generates vector data. For instance, a raw RGB image of 128×128 pixels with 24-bits per pixel (8 bits per color) will be of $128 \times 128 \times 24 = 393{,}216$ bits (48 kilobytes). This is several orders of magnitude larger than conventional sensor data.

To minimize the size of the image data, image compression techniques such as Discrete Cosine Transforms [4] or Discrete Wavelet Transforms [5,6] can be used. Although these algorithms reduce the size of an image, yet the reduction is not comparable to conventional sensors data. Therefore, image data compression is not enough. The processing power of each node is also limited. Additionally, the topology of the network and routing protocols play a crucial role in transporting imagery information from visual sensing nodes to sink nodes. Hence, the tasks of capturing image data, compressing it, and sending it to sink are some of the most challenging tasks faced by VSN architects.

As mentioned before, using image compression algorithms the size of data can be reduced to some extent. Also, a category of image compression algorithms generates multiple layers of compressed image data. The first layer contains the most prominent features of the image, for example the edges of objects or coarse image data. The subsequent layers contain the details that when merged with the first layer, restore the original image. Some image processing algorithms consist of multiple passes requiring different levels of details of the encoded image for each pass. Using such algorithms in VSNs, system response time can be reduced. If the sink nodes receive image data required for first pass sooner than data required for subsequent passes, it can start processing the first pass and take action accordingly while data of subsequent layers arrive at the sink node. This paper helps alleviate the routing challenges of such image processing algorithms by proposing a routing framework based on the following features:

(1) The visual sensing nodes should be able to specify priority to outgoing packets. In this way, image data for first pass can be sent at higher priority than data for subsequent passes.
(2) The intermediate or routing nodes should be aware of packet priority so that higher priority packets are forwarded before lower priority packets.
(3) If packets from two nodes collide, high priority packets should be retransmitted before low priority packets.
(4) Finally, in event of congestion, lower priority packets should be dropped before any high priority packet is dropped.

The next section summarizes the various communication protocols being used in VSN architectures as of today. Section 3 discusses the VSN application scenario we address in this paper. Section 4 defines PRoFIT, our proposed priority-based routing framework. The implementation of PRoFIT is discussed in Section 5. Simulations were carried out to quantify the usefulness of PRoFIT. In Section 6, simulation environment and results are discussed. Section 7 discusses the transmission of image features for real-time VSN applications using PRoFIT to improve system's response time. Finally, the paper is concluded along in Section 8.

2. Existing routing techniques

Most of the research on routing techniques for image transmission has mostly been limited to wired networks [7–11]. Research on QoS supported routing protocols for mobile ad-hoc networks has been summarized by Chen and Heinzelman [12] and Hanzo-II and Tafazolli [13]. Liebeherr et al. [14], Wang et al. [15], Stoica and Zhang [16], Younis and Fahmy [17], and Soldatos et al. [18] discuss techniques to deliver image data on the Internet. None of these are applicable to VSNs.

Most of the work done in the field of routing techniques for VSNs has been conducted to achieve energy efficiency. The first routing protocol focused on QoS in VSNs by trying to minimize the average weighted QoS metric throughout the lifetime of the network. Sohrabi et al. [19] proposed Sequential Assignment Routing (SAR) that enforces maintenance of routing tables with status of all nodes.

RAP [20] is a priority based routing protocol that uses velocity monotonic scheduling and geographical forwarding to achieve QoS however its requirement of geographical awareness can only be fulfilled by having a pre-defined network topology or additional hardware to determine geographical location. SPEED [21], proposed by He et al., is a spatio-temporal, priority-based, QoS-aware routing protocol for sensor networks that provides soft real-time, end-to-end delay guarantees. SPEED does not provide differentiated packet prioritization. Moreover, a forwarding node can only forward the packet at a speed less than or equal to the maximum achievable speed even though the network can support it.

Real-time Power-Aware Routing (RPAR) [22] is another routing protocol that achieves application specific