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Object extraction scheme and protocol for energy efficient image communication over wireless sensor networks ☆

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ABSTRACT

To date, wireless sensor networks lack the most powerful human sense – vision. This is largely due to two main problems: (1) available wireless sensor nodes lack the processing capability and energy resource required to efficiently process and communicate large volume of image data and (2) the available protocols do not provide the queue control and error detection capabilities required to reduce packet error rate and retransmissions to a level suitable for wireless sensor networks. This paper presents an innovative architecture for object extraction and a robust application-layer protocol for energy efficient image communication over wireless sensor networks. The protocol incorporates packet queue control mechanism with built-in CRC to reduce packet error rate and thereby increase data throughput. Unlike other image transmission protocols, the proposed protocol offers flexibility to adjust the image packet size based on link conditions. The proposed processing architecture achieves high speed object extraction with minimum hardware requirement and low power consumption. The system was successfully designed and implemented on FPGA. Experimental results obtained from a network of sensor nodes utilizing the proposed architecture and the application-layer protocol reveal that this novel approach is suitable for effectively communicating multimedia data over wireless sensor networks.

1. Introduction

In recent years, Wireless Sensor Networks (WSNs) have attracted significant research interests [1–3]. A WSN can be defined as a network of a large number of spatially distributed, small, low cost and low power nodes, which can sense the environment and wirelessly communicate the information gathered to other nodes. The collected information is forwarded, normally via multiple hops, to a sink (or controller or monitor) node that uses the information locally or transmits it to other networks (e.g., Internet) through a gateway. WSNs are normally comprised of scalar sensors capable of measuring physical phenomenon such as temperature, pressure, light intensity, and humidity.

With the availability of cheap, small size and low-power CMOS cameras and microphones, there is a strong interest in deploying WSNs for multimedia communication. Such Wireless Multimedia Sensor Networks (WMSNs), with the ability to gather multimedia information from the surrounding environment, is providing the impetus for extending the capabilities WSNs for many new applications such as advanced environmental monitoring, advanced health care delivery, traffic avoidance, fire prevention and monitoring, and object tracking [4,5]. However, the challenge is how to handle the large volume of multimedia data using sensor nodes that are severely constrained in both processing capability and energy. In addition to developing energy aware multimedia processing algorithms and architectures, it equally important to develop efficient communication strategies [5,6] to maximize the network lifetime while

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meeting the application specific QoS constraints such as latency, packet loss, bandwidth, and throughput.

Several proposals have been put forward to achieve image transmission over WSN [7–9]. Ref. [7] aims at providing a reliable, synchronous transport protocol (RSTP), with connection termination similar to TCP. Ref. [8] presents an energy-efficient and reliable transport protocol (ERTP) with hop-by-hop reliability control, which adjusts the maximum number of retransmission of a packet. Ref. [9] proposes another reliable asynchronous image transfer (RAIT) protocol. It applies a double sliding window method, whereby network layer packets are checked and stored in a queue, to prevent packet loss. With protocols providing reliability at the transport [8] or network layers [9], erroneous packets at the application layer can still be forwarded to the base station, requiring retransmission and associated energy cost [10]. In addition, the above protocols do not take into account the practical resource limitations (memory, processing capacity, energy) of the wireless sensor nodes. Consequently, in [11], the authors stated that multi-hop transmission of JPEG2000 images is not feasible due to interference and packet loss. This statement is also cited by other literature [10,12]. In this paper, image transmission over multi-hop WSN is proved to be feasible, using a reliable application layer protocol that reduces packet error rate and retransmissions. The proposed protocol uses an effective queue control strategy with built-in CRC, which helps achieve higher data throughput in error prone environments.

In terms of WMSN hardware, the few off-the-shelf motes reported to date include the Cyclops motes [13], WiSN motes [14], Panoptes motes [15] and SensEye motes [16]. Each of these motes consists of a CMOS camera, a Commercial Off-The-Shelf (COTS) processor, a wireless transceiver and a battery. The COTS processor, being a general purpose processor, often has redundant hardware blocks, which are not utilized by the WSN mote. This leads to higher energy consumption and less than optimum operation. The COTS processor runs at low frequency in order to keep the power consumption low. The limitations in processing speed and memory capacity of the traditional sensor nodes restrict the image processing and transmission capability of these WSN motes. Therefore, implementing complex image processing tasks on these WSN motes is almost impossible.

Instead of using COTS processor, the possibility of using FPGAs to implement WMSN nodes have been explored in recent literature [17–19]. In [17], the authors present a JPEG image compression system for a WMSN node on Altera EP2C35 FPGA using NIOS II soft-core microprocessor. Because the FPGA also incorporates networking functionalities, there is no mechanism to put the system on the FPGA to sleep mode to reduce energy consumption. In [18,19], a dedicated FPGA hardware is designed to handle image processing. These systems require another external (off-the-shelf) microprocessor to perform communication and system operations. This is problematic because the external processor is not optimized to work in a WSN node and therefore has hardware redundancies. There is also significant communication delay between the two processors. In this research, a novel architecture is proposed in which both image processing and networking functions are handled by processors implemented on one FPGA. This approach helps to optimize the operation of the WMSN node, where the image processing block is designed for high performance (high speed), and can be turned on and off as required to minimize energy consumption.

The processing architecture presented in this paper provides high processing speed, and consumes much less energy for both processing and communication of images compared to COTS-based WMSN motes. A simple and efficient background subtraction [20] is applied to detect and extract the object area of interest. Only a portion of the image that contains the updated object is transmitted over the network. Experimental results demonstrate that the total energy consumed for processing and transmitting an image, using the combination of the proposed application-layer protocol and energy efficient processing architecture, is much less than that required for transmitting an entire image although the latter does not involve any image processing overhead.

2. System architecture

Fig. 1 presents the overall architecture of the proposed WMSN processing system. It consists of two major processing elements: a customized networking processor and an image processing block. The network processor performs some standard operations found in a typical processor as well as customized instructions to support the operations of the wireless transceiver. Since the network processor needs to run continuously to keep track of network traffic, it operates at a low clock frequency in order to keep the power consumption low.

On the other hand, due to the complexity associated with most image processing operations, the image processing block must run at a high frequency to process images at a high speed. This will lead to high power dissipation. However, if the processing time is short and if the image processing block is put to sleep mode when inactive then the overall energy consumption for image processing can be kept low. This is the philosophy behind the proposed separation of the network processor and the image

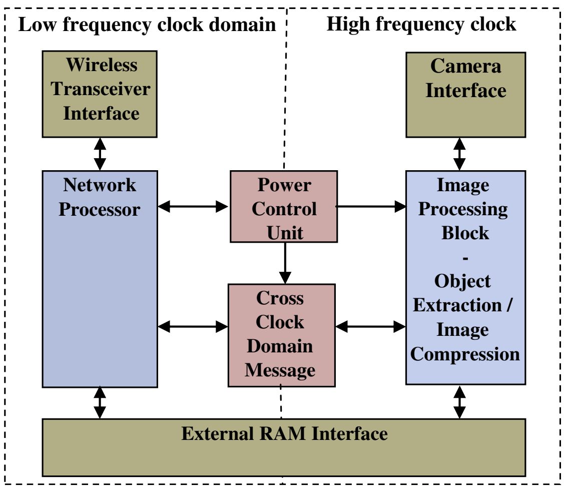

Fig. 1. Proposed WMSN processing system architecture.