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WCCP: A congestion control protocol for wireless multimedia communication in sensor networks

Shahin Mahdizadeh Aghdam [a], Mohammad Khansari [b,*], Hamid R. Rabiee [c], Mostafa Salehi [b]

[a] School of Science and Engineering, Sharif University of Technology, International Campus, Kish, Iran
[b] Faculty of New Sciences and Technologies, University of Tehran, Iran
[c] Department of Computer Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

The growing interest in applications of Wireless Multimedia Sensor Networks (WMSNs) imposes new challenges on congestion control protocols in such networks. In this paper, we propose a new content-aware cross layer WMSN Congestion Control Protocol (WCCP) by considering the characteristics of multimedia content. WCCP employs a Source Congestion Avoidance Protocol (SCAP) in the source nodes, and a Receiver Congestion Control Protocol (RCCP) in the intermediate nodes. SCAP uses Group of Picture (GOP) size prediction to detect congestion in the network, and avoids congestion by adjusting the sending rate of source nodes and distribution of the departing packets from the source nodes. In addition, RCCP monitors the queue length of the intermediate nodes to detect congestion in both monitoring and event-driven traffics. Moreover, to improve the received video quality in base stations, WCCP keeps the I-frames and ignores the other less important frame types of compressed video, in the congestion situations. The proposed WCCP protocol is evaluated through simulations based on various performance metrics such as packet loss rate, frame loss rate, Peak Signal-to-Noise Ratio (PSNR), end-to-end delay, throughput, and energy consumption. The results show that WCCP significantly improves the network performance and the quality of received video in the sink nodes, and outperforms the existing state-of-the-art congestion control protocols.

1. Introduction

Due to rapid development of networked video sensors in recent years, there has been a growing demand in Wireless Multimedia Sensor Network (WMSN) applications such as multimedia surveillance, traffic monitoring, and real-time object tracking systems [1,2]. The Wireless Multimedia Sensor Networks can be described as a group of connected wireless sensors that collect multimedia data (i.e. audio and video) along with scalar data from the environment and transmit them to a base station (sink node) [3]. Achieving higher video quality in base stations is an important objective in WMSNs. The main reason for low video quality in WMSN's base station is bursty traffic which causes congestion in the network, and consequently a large number of lost packets. Furthermore, because of the small size of sensors and hence their limited battery lives, energy conservation is an important issue in WMSNs [4,5].

There are significant number of research efforts in solving the congestion problem of sensor networks [6–9]. Based on the different congestion detection and rate adjustment techniques, one can primarily classify these works into four major categories: (I) queue assisted protocols, (II) priority aware protocols, (III) topology formation protocols, and (IV) resource control protocols. The queue assisted protocols mostly concentrate on the queue length of the nodes and use a simple rate adjustment technique such as Additive Increase Multipartite Decrease (AIMD)

* Corresponding author.
E-mail addresses: s_mahdizadeh@alum.sharif.edu (S. Mahdizadeh Aghdam), m.khansari@ut.ac.ir (M. Khansari), rabiee@sharif.edu (H.R. Rabiee), mostafa_salehi@ut.ac.ir (M. Salehi).

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to keep the queue length of nodes as low as possible [8,10]. However, because of the simple nature of these protocols, they do not have efficient energy consumption. The priority aware protocols consider the different priority of nodes in congestion situations and try to provide equal service for nodes in the same priority class [11–14]. The topology formation protocols adjust the input rate of congested nodes by forwarding some parts of traffic from other nodes or by activating or deactivating nodes near the congested area. However, changing network topology is not always practical, and it may result in lower performance for sparse networks [7,15–17]. The resource control protocols increase the amount of resource consumption (duty cycle) in nodes near the congested area which by itself increases the energy consumption for these nodes. It may also make the interference problem more severe in the congested areas [6,9].

While the above congestion control protocols have achieved high performance in scalar sensors (sensors which sense non-multimedia data such as temperature or humidity), they do not provide high multimedia quality (video and audio) in WMSNs. The main reason for low multimedia quality (specially video) in congestion control protocols is that they are not content aware. In other words, they treat multimedia packets similar to regular data packets, whereas in multimedia communication some packets are more important than other packets. For instance, in the case of video, packets which carry I-frames have the highest priority compared to the other frame types. Moreover, the rate adjustment techniques that are deployed in congestion control protocols, only try to adjust the output sending rate of source nodes without considering the distribution of inter-arrival packets (inter-arrival process of the packets) that can have a great impact on number of lost packets in WMSNs. Recently, several cross-layer studies are presented in the scope of designing efficient protocols for WMSNs [18,19]. However, these protocols provide different congestion control techniques without analyzing or deploying any traffic model.

In this paper we introduce a two-stage WMSN Congestion Control Protocol (WCCP) as follows.

- The Source Congestion Avoidance Protocol (SCAP) is deployed in source and is responsible for predicting congestion using a proposed Group of Picture (GOP) size prediction method. Moreover, the SCAP is responsible for adjusting the distribution of the leaving packets along with the sending rate of the source nodes using the proposed traffic model. To the best of our knowledge, it is the first time in WMSN area that a protocol adjusts the distribution of inter-arrival packets to gain a better video quality.
- The Receiver Congestion Control Protocol (RCCP) is deployed in intermediate nodes and detects congestion occurrence and informs the source nodes about the congestion. RCCP uses a proposed queueing model to detect congestion in intermediate nodes and informs the SCAP protocol in source part about the congestion.

The performance evaluation of the proposed mechanism is carried out by comparing its performance against the state of the art protocols such as XLP [6], PCCP [13], CCF [12], and other classic congestion control protocols. We show the importance of considering the contents of data in multimedia communication, and the affects of using model-based approaches in adjusting the output rate of source nodes. The key contributions of this paper are as follows:

1. A two-stage protocol (WCCP) is proposed to control congestion in WMSNs; SCAP in the source nodes to avoid congestion, and RCCP in intermediate nodes to detect and control congestion.
2. A traffic model is proposed using the inter-arrival process of the packets to adjust the sending rate of the source nodes.
3. An intermediate node's queueing model is proposed using the MMPP queueing model and is used to detect congestion in the receiver nodes.
4. The content of data in transmission is taken into account in WCCP protocol to gain higher video quality in the base station (we preserve the I-frames which are the most important frames in the multimedia communications).
5. A GOP size prediction method is proposed to predict congestion (this method is also applicable to other works such as peer to peer networks, or wireless networks).

The rest of the paper is organized as follows. Related work is presented in Section 2. The WMSN source traffic model and intermediate queueing models are presented in Section 3. Section 4 introduces the proposed protocol. Section 5 provides performance evaluation, and the concluding remarks are presented in Section 6.

2. Literature review

Recently, several studies have been performed on developing efficient congestion control protocols for WMSNs [6,20]. A typical congestion control protocol includes three phases: congestion detection in order to detect congestion in nodes, congestion notification to inform other nodes about the congestion, and rate adjustment to mitigate the congestion problem. Based on the different congestion detection and rate adjustment techniques, we have primarily categorized the congestion control protocols in four major categories: queue assisted protocols, priority aware protocols, topology formation protocols, and resource control protocols, as shown in Table 1.

From the design point of view, we can categorize the congestion control protocols to generic or cross layer protocols. The generic congestion control protocols only use the transport layer and try to solve the problem by using the functionalities of this layer. Whereas, the cross layer congestion control protocols incorporate information and functionalities of other network layers as well.

A common approach to solve the congestion problem in sensor networks is using the queue assisted protocols. These protocols concentrate on the queue length of the