A Traffic Congestion Control Algorithm for Wireless Multimedia Sensor Networks

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Abstract—**This paper proposes a traffic congestion control algorithm (TCCA) for wireless multimedia sensor networks (WMSNs). First, TCCA uses a combination of two different congestion indicators to precisely detect congestion. The first indicator is buffer occupancy, and the second indicator is buffer occupancy change rate. Second, we develop a feedback-based rate controller to enhance the video quality of played streams. Finally, we present different retransmission mechanisms for different packets. Lost packets are saved temporarily and retransmitted when free channel is available to eliminate congestion. TCCA is implemented on 14 Raspberry Pi sensor nodes. The test-bed results show that TCCA outperforms previous approaches in terms of rate control and packet loss.**

Keywords—wireless sensor networks, congestion control, error control, wireless video transmission, wireless multimedia sensor networks

I. INTRODUCTION

Recent advances in micro-electro-mechanical systems (MEMS) technology, embedded computing, and wireless communications has motivated the development of wireless sensor networks (WSNs) [1]. Each sensor node can be equipped with inexpensive hardware such as microphones and CMOS cameras. This fostered the development of wireless multimedia sensor networks (WMSNs) [2]. WMSNs consist of a large number of embedded devices that are equipped with low power cameras. These camera nodes are able to retrieve multimedia content from the environment at variable rates and transmit the captured information through multi-hop communication to sink [3-4]. WMSNs have generated much interest in recent years, and it is predicted that WMSNs will become useful in our daily life. WMSNs have been widely applied to video surveillance [5], target tracking [6], and healthcare [7]. Numerous studies have been carried out in recent years on the media access control (MAC) layer [8], the network layer [9], the physical layer [10], and the transport layer [11] in WMSNs.

Nowadays, there has been extensive research in solving WMSNs issues. There are numerous issues that must be addressed such as lack of fixed infrastructure, high variable delays, limited bandwidth, shared channel, high packet loss rate, and mobility in WMSNs [12-15]. However, main issue of providing efficient quality of service (QoS) guarantees for real-time transmission in WMSNs is still open and largely unexplored. WMSNs generate huge amount of video data, therefore occurrence of congestion in WMSNs is more than that of low-speed WSNs. Network congestion is a critical issue to ensure the efficient and fair allocation of network resource among communication flows. Congestion reduces the overall performance of the network and affects reliability due to packet loss. Therefore, wireless transmission for multimedia with guaranteed packet delivery in WMSNs is of substantial significance due to higher data rate requirements.

This article investigates the problem of network congestion in WMSNs. The focus is to ensure reliable transmission of video data from collection of source nodes to a sink node while avoiding congestion collapse. The main contributions of this paper are summarized as follows. (1) We propose a computationally intelligent congestion control algorithm for multi-hop WMSNs. The sensor nodes maintain their data transmission rate and update their data transmission rate according to their parents' congestion level. All sensor nodes have unique IP address and can build a routing path from source node to the sink node through multi-hop communication. (2) To predict the congestion more accurately, we propose a combination of two different congestion indicators to distinguish the congestion levels and dealt with them accordingly. (3) We provide different retransmission mechanisms for different data packets. Lost packets can be temporarily stored and retransmitted when congestion is eliminated. (4) The proposed algorithm is implemented and verified in a multi-hop WMSN network test-bed with 14 raspberry pi sensor nodes. (5) This WMSN test-bed is flexible and scalable. It can be serviced as a multi-purpose platform.

II. A TRAFFIC CONGESTION CONTROL ALGORITHM IMPLEMENTATION

A. Queue scheduler

Different types of packets have different retransmission requirements. According to importance, packets are divided into

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four priorities. We give highest priority to I-frame packets, high priority to P-frame packet, low priority to lost I-frame packets that need retransmission, and lowest priority to lost P-frame packets that need retransmission. Fig. 1 represents the packet transmission and storage mechanism at the sensor node. When a node generates or receives the packets, the packets are moved to the I-frame packet queue or P-frame packet queue depending on their attribute. These queues are used to store the packets, waiting for transmission. I-frame packets are important for supporting the real time traffic. Therefore, I-frame packets have the highest priority because our core objective is to protect I-frame packets. If I-frame packet is lost after retransmission, it goes into lost I-frame queue, and if a P-frame packet is lost after retransmission it goes into lost P- frame queue.

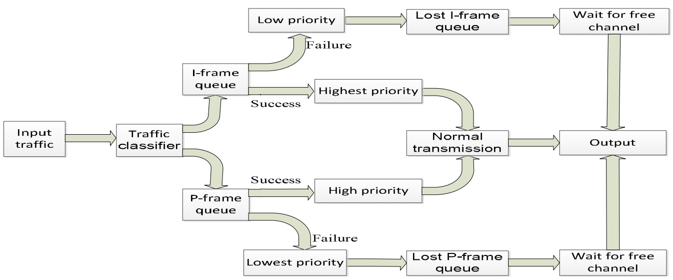

Fig. 1. Queue schedular

B. Congestion detection

We propose a mechanism that uses buffer occupancy and its change rate together to handle congestion at each node in an efficient manner. The buffer occupancy B is divided into two different thresholds B_1 and B_2, and the buffer occupancy change rate δ is defined as

$$\delta = \frac{B(t+\Delta t) - B(t)}{\Delta t} \quad (1)$$

where $B(t+\Delta t)$ and $B(t)$ illustrate the buffer occupancy in last and current round. Larger value of δ shows that queue of a sensor node has more probability of overflow. Similarly, lower value of δ shows that buffer occupancy has minimized. We classify the sensor nodes into three states according to buffer occupancy and buffer occupancy change rate. In the beginning, the every node's buffer is in empty state. When the packets come, the sensor node turns to the normal state. The buffer occupancy fluctuates between [0, B_1] and buffer occupancy change rate is fewer than ρ. ρ is the predefined threshold of δ. In slow state, a sensor node is near to congestion. Buffer occupancy fluctuates between $[B_1, B_2]$. The buffer occupancy increases quickly until δ exceeds ρ. In this condition, sensor node switches to slow state which shows that a sensor node will soon be congested. In urgent state, congestion happens at the source nodes. Therefore, source nodes suffer heavy packet loss. The buffer occupancy continuously fluctuates within $[B_2, B_{max}]$ regardless of δ. Children nodes should immediately reduce their sending rates to send fewer data to parent node. Children nodes only send higher-priority packets to the parent node because their parent's buffer occupancy is very high in this state.

C. Distributed rate control

If packet loss occurs due to buffer overflow, the transmission rate should be reduced smoothly to eliminate congestion. In our proposed mechanism, source nodes maintain their data transmission rates and adjust their data transmission rates based on the degree of congestion of their neighbors. Each sensor node establishes a path from itself to the parent node. This feedback mechanism is implemented to send data rate information from the parent node to the children nodes to enhance the video quality of transmitted streams. The proposed feedback process analyzes the buffer occupancy of every node and sends the feedback information to the children nodes. The children nodes obtain feedback information, analyze it, and make necessary amendments accordingly.

Let β be the dropping ratio of the sending rate of a node. Therefore, the sending rate at node n is illustrated as $S_n = \beta S_N$, where S_n represents reduced sending rate and S_N represents normal sending rate. The normal sending rate, β, and the reduced sending rate can be calculated from experiments.

D. Traffic control protocol

TCCA retransmission process is shown in fig. 2. Both I frame and P frame packets have different traffic control mechanism. The parent node returns an acknowledgment (ACK) to inform its children nodes to complete the packet transmission process. If the parent node cannot get packets from a child node, it sends the sequence number of those particular packets to its child node. The corresponding child node will retransmit the missing packets. A child node ensures that these lost packets are received. A child node sends a timeout message to its parent node, if it is not able to get corresponding packet. The parent node resends lost packets. If parent node receives an out of order packet, it adjusts the order of packets according to their sequence number.

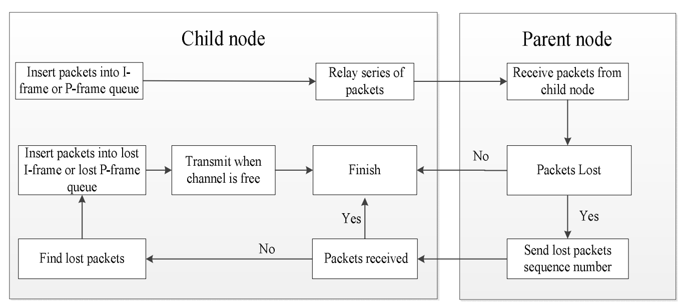

Fig. 2. Retransmission mechanism

III. EXPERIMENTAL RESULTS

In this section, we demonstrate the performance of TCCA. Extensive experiments are performed on 14 Raspberry Pi sensor nodes. We use the video camera to record the videos in the cubicle environment. In each Raspberry Pi, we store a stream of that pre-recorded video. All raspberry pi nodes are deployed in a static position. Video data from each raspberry pi source node is transferred to the sink node. Fig. 3 represents our network topology. Node 1 is linked to computer where information of each node can be visualized. We build a network by assigning IP address to each node. The following algorithms are compared:

(1) TCCA: It is the algorithm implemented in this article.

(2) ECODA: It is the algorithm implemented in [16].

(3) NoTCCA: In NoTCCA, no congestion control scheme is used. We consider NoTCCA as a baseline algorithm.

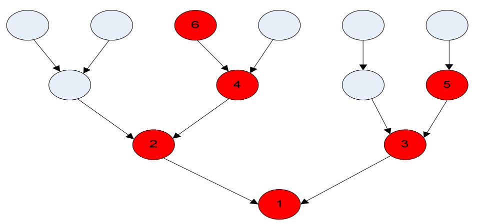

Fig. 3. Routing topology used in TCCA.

We analyze the buffer occupancy of nodes marked in red color. Fig. 4 represents buffer occupancy without TCCA. In Fig. 4, x-axis is time in seconds, and the y-axis is buffer occupancy. Congestion occurs at nodes 1-5 when data rate approaches to 0.5Mbps as shown in fig. 4. Fig. 4 also shows that there is no congestion at node 6. This is because node 6 only generates data and does not relay any traffic. Therefore, node 6 is unlikely to be congested. Fig. 5 represents buffer occupancy with TCCA. Fig. 5 shows that TCCA can effectively adopt network conditions. The TCCA's buffer occupancy begins to rise, but decreases immediately before the buffer begins to overflow. In the case of NoTCCA, the buffer overflows immediately because it does not have any rate control mechanism. Therefore, TCCA attains an efficient congestion-free rate.

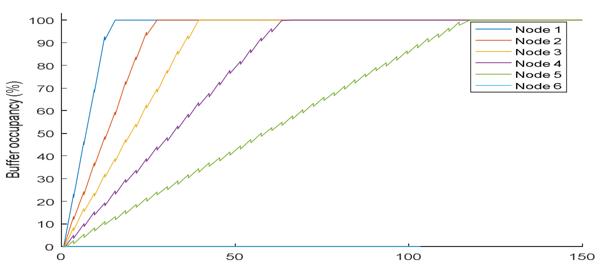

Fig. 4. Buffer occupancy with NoTCCA at 0.5Mbps

Fig. 6 represents the packet delivery ratio of I frame packets. Since the purpose of TCCA is to secure I-frame packets during congestion, I-frame packets are given highest priority. Fig. 6 shows that at 2 minutes, I- frame packets has 96.5%, 90.5%, and 67.2% packet delivery ratio for TCCA, ECODA, and NoTCCA. The packet delivery ratio of TCCA is much higher that NoTCCA and ECODA, because ECODA and NoTCCA algorithms do not save I-frame packets in congestion situation. Fig. 7 represents the packet delivery ratio of P frame packets. The packet delivery ratio of P frame packets in TCCA is higher that NoTCCA and ECODA. Fig. 7 shows that at 2 minutes, I-frame packets has 93.7%, 85.5%, and 63.5% packet delivery ratio for TCCA, ECODA, and NoTCCA.

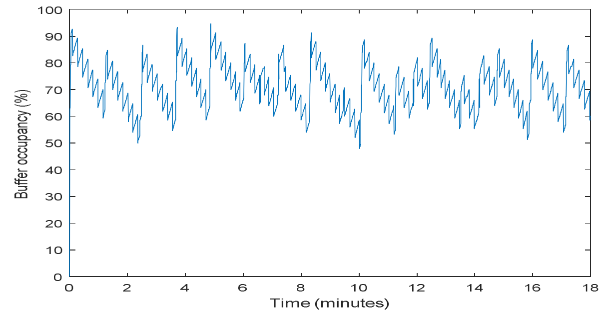

Fig. 5. Buffer occupancy with TCCA

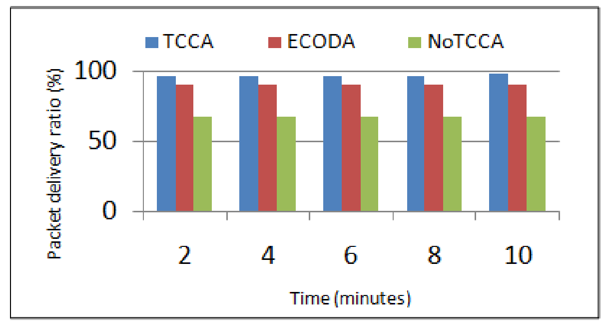

Fig. 6. Packet delivery ratio of I Frame packets.

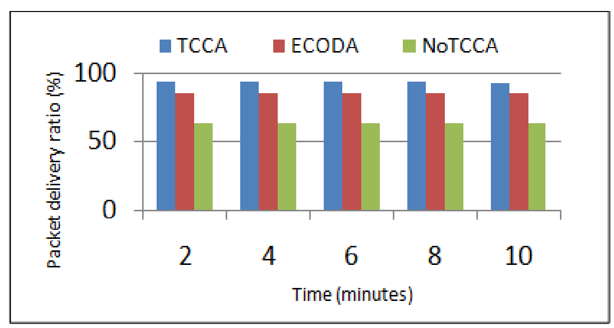

Fig. 7. Packet delivery ratio of P Frame packets.

IV. CONCLUSIONS

In this article, we propose a traffic congestion control algorithm for wireless multimedia sensor networks (TCCA). TCCA addresses the buffer overflow problem in WMSNs and solves this problem by adjusting the data rate of the sender nodes in case of congestion. Moreover, different retransmission techniques are applied to different types of packets. Lost packets can be saved temporarily and retransmitted when congestion is alleviated. We show that TCCA outperforms NoTCCA and ECODA in terms of packet delivery ratio and rate control.

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