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Coding based wireless broadcast scheduling in real time applications

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ABSTRACT

Using network coding in wireless networks can increase throughput and reduce energy consumption. However there are only a few works considering the quality of service which is important to real time applications. This paper focuses on network coding based broadcast scheduling problem in real time wireless networks with packet delay constraint and aims at minimizing the number of packets which miss their deadlines under two receiver models. In the first model, receiver drops the encoded packet which cannot be decoded immediately. We formulate the broadcast scheduling problem with an integer linear programming and prove that it is NP-hard. We also propose a packet encoding and broadcasting algorithm based on the maximum weight clique in the graph. In the second model, receiver can buffer all received encoded packets and decode out their wanted packets when enough packets are received. According to marking colors on the vertices of the weighted graph, an effective heuristic algorithm is proposed in this paper. Simulation results show that our algorithm significantly reduces the deadline miss ratio in most cases, which is an important performance metric in real time applications.

1. Introduction

Wireless networks are becoming increasingly pervasive with the introduction of WiFi, 5G cellular systems, and mobile devices in the recent years. Recently there are many works (Yan et al., 2012; Zeng et al., 2014; Ebrahimi and Assi, 2015) focusing on how to utilize network coding to increase throughput and reduce energy consumption in wireless networks. The network throughput gain using network coding has been studied in Yan et al. (2012). The network throughput using network coding and how the maximum throughput can be achieved in a two-way relay wireless network have been studied in Zeng et al. (2014). The joint application of compressive sensing and network coding to the problem of energy-efficient data gathering in wireless sensor networks has been studied in Ebrahimi and Assi (2015). The achievable tradeoffs between the throughput and decoding delay performance of network coded wireless broadcast has also been better understood and extended in Yu et al. (2014). However there are only a few works considering the delay guarantee of data packets which is an important aspect of the quality of service.

Recently, the development of commercial wireless services has created large scale demands for transmission of traffic like multimedia, voice and video that require stringent quality of service (i.e. delay, etc.) guarantees (Esmaeilzadeh et al., 2014; Zhou et al., 2011). Real time applications have distinct characteristics: they have strict and urgent deadlines, i.e. a packet is useless (or less useful) after a short amount of time. For example, in wireless financial services, many users are interested in the up-to-minute (or even second) stock quotes in order to react to dynamic and rapid market developments. In the wireless real-time video streaming transmission application, the video can be divided into many segments, every segment has some delay threshold beyond which the user cannot be tolerant. Thus, the issue of delay is one of the key concerns when applying coding ideas to networking problems.

Consider a single hop broadcasting scenario, similar to Le et al. (2013). A wireless sender needs to broadcast packets to a set of receivers. According to the prior transmissions or overhearing, each receiver already has some packets and notices these information to sender with feedback. Once the sender wants to transmit, it can encode based on the packet information that receivers want and already have. As shown in Fig. 1, there are a sender s and five clients r_1, r_2, r_3, r_4, r_5. Suppose that s needs to transmit packets p_1, p_2, p_3, p_4 to the five clients, each client has an access to some of the packets overheard from prior transmissions. Suppose that r_1 has p_3, p_4, r_2 has p_1, p_4, r_3 has p_1, p_2, r_4 has p_1, p_3, and r_5 has p_2, p_4. Assume that the time taken for a packet transmission is 1 time slot, and all the deadlines of packets are 2 time slots except that the deadlines of p_3 to r_3 and r_5 are 3 time slots.

Without coding, s will transmit p_1, p_2, p_4, p_3 in sequence since the deadline of p_1 is the smallest. Using this transmission

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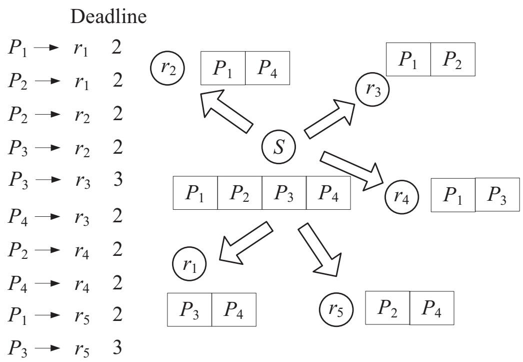

Fig. 1. An example.

strategy, there are three packets missing deadlines, the packet p_3 needed by r_2, the packet p_4 needed by r_3 and the packet p_4 needed by r_4. According to the coding method introduced in Le et al. (2013), every time slot the sender will send an encode packet to maximize the number of clients which can decode a packet, thus s will transmit $p_1 \oplus p_4, p_2 \oplus p_3, p_2, p_3$ in sequence. With $p_1 \oplus p_4$, r_1 can get p_1 since it already has p_4. Similarly, r_3 and r_4 can get p_4, while r_5 can get p_1. Although transmitting $p_1 \oplus p_4$ can make more clients decode their wanted packets, some packets may still miss their deadlines. For example, the packet p_2, p_3 needed by r_2 will miss their deadlines since r_2 cannot decode out p_2, p_3 with only $p_1 \oplus p_4$ and $p_2 \oplus p_3$.

Intuitively, it will be better that the packets with smaller deadlines are encoded and delivered earlier. Thus, if s transmits $p_2, p_1 \oplus p_4, p_3$ in sequence, then the packet p_2 needed by r_2 can now be received within its deadline. Using this transmission strategy, there are only one packet missing its deadline, i.e. the packet p_3 needed by r_2.

The above encoding strategies based on the assumption that if a client receives an encoded packet and it cannot decode any packet in its wanted list, it will throw the encoded packet away. If each receiver can buffer its received encoded packets, it can accumulate the useful information to recover all its needed packets, which can reduce the number of packets missing their deadlines. For example, s can transmit $p_1 \oplus p_2 \oplus p_4, p_1 \oplus p_3 \oplus p_4$ in sequence. When r_1 receives $p_1 \oplus p_2 \oplus p_4$, the packet is useless for r_1 because r_1 needs both p_1, p_2. If r_1 can buffer such received packet, when it receives the second encoded packet, it can recover p_1 since it already has p_3, p_4. After p_1 is recovered at r_1, r_1 can use the first encoded packet to recover p_2 since it has p_1, p_4 by now. Similarly, with the two encoded packets, r_2, r_3, r_4, r_5 can decode out their needed packets. Thus, there is no packet missing its deadline.

In this paper, we aim to determine the encoding strategy at the sender to minimize the number of packets which miss their deadlines under two receiver models. In the first model which is referred to as the *memoryless model*, the memory size of receiver is small. The receiver just drops the encoded packet which cannot be decoded immediately. In the second model which is referred to as the *memory model*, receiver has enough memory. The receiver will buffer all received encoded packets and decode out their wanted packets when enough packets are received. Our work mainly focuses on the encoding strategy based on the needed packets set and packets already had at each receiver.

Our contributions are summarized as follows:

- We study the coding based scheduling problem with the packet delay constraint under two receiver models, the memoryless model and the memory model.
- We propose an encoding algorithm under the memoryless model based on the maximum weight clique in the graph, and the method is to assign vertex weight as a decreasing function of packet deadline.
- We analyze the effect of weight function and show that some typical application requirements can be realized by different weight function settings.
- We propose an effective heuristic encoding algorithm for the memory model, and the method is to mark colors on the vertices of the weighted graph to illustrate the needed packets can be decoded using the buffered encoded packet.

The remainder of this paper is organized as follows. Section 2 introduces the related work. In Section 3, we will give the system framework and problem statement. Section 4 introduces a weighted graph model for scheduling problem under the memoryless model and presents an encoding algorithm based on maximum weight clique. In Section 5, we will analyze the effect of different weight functions. In Section 6, we will study the scheduling problem under the memory model. Simulation results will be shown in Section 7. Finally, we will conclude the paper in Section 8.

2. Related work

Network coding was first introduced in Ahlswede et al. (2000) to improve the performance of multicast routing. Network coding is a general approach to packet routing that allows an intermediate router to encode an outgoing packet by mixing multiple incoming packets appropriately. The throughput of the network can thus be improved significantly. Li et al. (2003) and Koetter and Mdard (2003) mixed packets with a linear equation, and each variable in the equation represents an original packet.

Broadcasting common file content to a group of wireless nodes within proximity and transmission range of each other is gaining increasing interest. The wireless broadcasting nature in wireless networks makes it feasible to improve network throughput and achieve energy efficiency with network coding (Li et al., 2009; Hwang and Kim, 2011). Theoretical studies (Li et al., 2009) had demonstrated that applying network coding to wireless network can improve the system throughput, minimize energy and alleviate the system congestion. Hwang and Kim (2011) presented a cross-layer optimization over routing and power control for multihop multicasts in wireless mesh networks.

In the wireless broadcast scenario, wireless nodes may receive partial content due to packet losses over wireless broadcast link. The remaining missing content can be recovered according to retransmission or local recovery. It has been shown that RNC (Ho et al., 2006) can reduce the number of necessary transmissions and satisfy all nodes in the group. However, RNC requires a block of packets to be encoded. Instantly decodable network coding (IDNC) which requires instant decodability of the transmitted encoded packets is introduced in Sadeghi et al. (2010). Sorour and Valaee (2010) studied generalized IDNC which relaxes instant decodability constraint of IDNC to target more receivers, and later they considered the problem of minimizing the decoding delay of generalized IDNC in persistent erasure channels. Liu and Sung (2014) characterized the quality of erroneous packets by SNR and designed a IDNC retransmission scheme with the knowledge of the SNRs of the erroneous packets.

The advantages of network coding in broadcast make it an attractive candidate for multimedia applications (Magli et al., 2013). In this paper, we are interested in real-time applications, which have a distinct characteristic. It has a hard deadline such that the packets need to be decoded on-time to be usable at the applications. Therefore, it is desirable to design network coding schemes so that the received packets before the deadline