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Congestion control in IPTV over PON using Digital Fountain forward error correction

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ABSTRACT

In a passive optical network (PON), the optical line terminal (OLT) is a bottleneck and congestion prone. Although bit error rate (BER) is ignorable in a PON, but PON may suffer from congestion problem that causes packet loss. Our problem is to reduce packet loss due to congestion. In this paper, two novel frameworks are proposed based on the Digital-Fountain (DF) forward error correction (FEC) with erasure coding approach at IP layer combined with Weighted Round Robin (WRR) and multicast property of PONs in order to achieve efficient video multicasting over PON. The first framework is called Digital-Fountain (DF) Forward Error Correction (FEC) with erasure coding Congestion control (DFC). The second framework is based on the nature of video coding and intelligent packet drop mechanism (called Intelligent Packet Drop with Digital Fountain Correction (IDFC)) to overcome packet-loss due to congestion in the OLT. In DFC, an IPTV service provider uses the DF coding and generates redundant packets from regular IPTV packets in such a way that an optical network unit (ONU) can recover lost packets from received packets, thus resulting in a better video quality. In IDFC, we use the nature of video coding to maintain video quality under congestion. In video coding by a codec, several types of frames can be produced. These types of frames are different based on their scale of information, and therefore, they have different importances. Under congestion state, our DFC and IDFC first drop packets with less importance. Simulation results show that using the proposed frameworks, an ONU can recover lost packets and achieve better video quality under different traffic loads.

1. Introduction

Digital television (TV) is the most advanced version of TV technology in the last century. Digital TV should provide more choices and interactivity for customers. New technology called IPTV uses digital TV technology and transmits TV programs over IP-based network (Driscol, 2008; Moawad, 2008). However, provision of quality of service (QoS) requirements for these services in terms of loss, delay and jitter is much more difficult than for regular data (Jeong et al., 2008), especially when the number of IPTV users grow rapidly.

Fig. 1 shows a typical IPTV networking infrastructure with three main sections (Driscol, 2008):

- **IPTV data center** (**Headend**): This center receives content from content producers, local video centers, and terrestrial and satellite channels and delivers the content through the distribution network to its subscribers.
- **Distribution network**: This network obtains contents from the IPTV data center and delivers them to the subscribers. Since IPTV services are very sensitive to packet-loss, delay and jitter, distribution networks must satisfy these factors as well.
- **IPTVCD**: An IPTV customer device allows a customer to use IPTV services. Since several services such as TV, telephone and Internet are connected to distribution networks, this device should be able to process, separate, and send the relevant traffic of these services to associated devices. In addition, it should receive requests from users and send them to the distribution network.

Since IPTV traffic is voluminous and sensitive to delay, jitter and packet loss, it is necessary to use the property of video streams to code a video in order to reduce the volume of the video and preserve its quality. In addition, due to voluminous data in IPTV, an audio/video (A/V) content should be compressed to match the capabilities of the channel and the decoding capabilities of the receiver. Audio and video contents are multiplexed into a single bitstream after being separately compressed (Appleby et al., 2006).

Fiber to the home (FTTH) technology is used in access networks, where service providers try to solve the bandwidth

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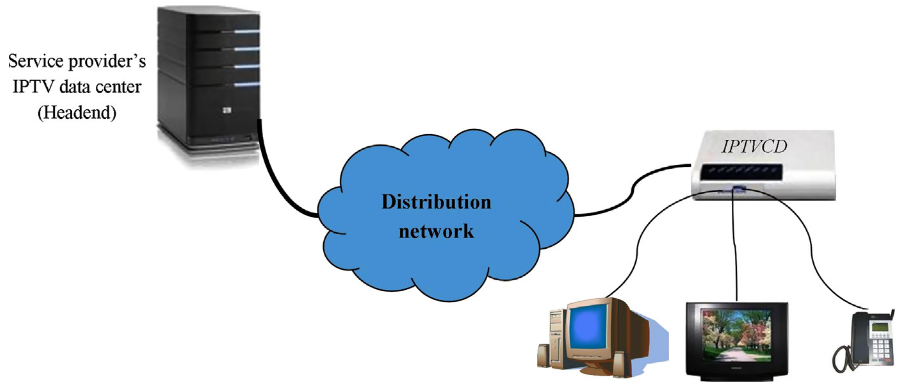

Fig. 1. IPTV networking infrastructure.

requirements of next-generation applications (Jiang and Liu, 2009). A passive optical network (PON) is a broadband technology for access networks. A PON is a point-to-multipoint optical network that has no active elements between the optical line terminal (OLT) and optical network units (ONUs) (Ikeda et al., 2008). All communications in a PON are between the OLT and ONUs (Zhang et al., 2009). Some of the benefits of using PON as an access network include fiber deployment cost due to sharing a fiber line with customers, inexpensive passive elements used between the OLT and ONUs, large bandwidth, and low cost for maintaining the fiber line (Ikeda et al., 2008). Note that in a point to point optical system, each user is directly connected to a central office, but users must share some links to connect to central office in a PON. Therefore, a PON system is more complex than a point to point optical system (Nakanishi et al., 2008).

Besides delay and jitter, IPTV streams are sensitive to packet loss in such a way that a very little packet loss in an IPTV stream may cause a significant degradation in video quality (Asghar et al., 2009). Congestion is the main problem leading to packet loss in IPTV (Lambert and Debevere, 2009). Note that using larger buffers for resolving congestion is not a suitable approach since it results in increasing delay of IPTV packets in OLT. In addition, using faster processors for congestion resolution could not always be possible because of its cost. In addition, IPTV traffic will be growing in near future.

Bit error rate (BER) is ignorable in PON. However, PON suffers from congestion problem that leads to packet loss. To reduce the packet loss problem, we use channel coding, intelligent packet loss mechanism, broadcasting property of PON, and weighting of IPTV flows and video frames.

The objective of this paper is to propose two novel frameworks based on the Digital-Fountain (DF) forward error correction (FEC) (Raptor, 2010b) with erasure coding approach (Li and Ramamoorthy, 2010; Raptor, 2010a) at IP layer (Raptor, 2010a) to reduce congestion effect in IPTV service over PON. The first framework is FEC combined with Weighted Round Robin (WRR) and multicast property of PONs called DFC. The second framework is based on the nature of video coding and intelligent packet drop combined with WRR, called (Intelligent Packet Drop with Digital Fountain Correction) IDFC. Under DFC, the IPTV service provider (SP) generates redundant packets for regular IPTV packets using the DF FEC at the IP layer. The IPTV packets arrive at the PON network, where the WRR scheduler used in the OLT schedules IPTV traffic channels toward ONUs. We preserve the multicast packets desired for many receivers more than those desired for fewer receivers. For this purpose, a weight is assigned to each multicast IPTV channel by the WRR scheduler. This weight is based on the number of channel receivers in the DFC method, and based on both number of channel receivers and type of frames in the IDFC method. In the video coding by a codec, several types of frames can be produced. These types of frames are different based on their scale of information, and therefore, they may have different importance. When congestion occurs in the OLT and some IPTV packets are lost, a destination ONU can recover the contents of lost IPTV packets using received IPTV packets.

Shortly, we discuss two methods in this paper. In the first method, we assess our previous method (Zare and Rahbar, 2012) with DF. In the second method (IDFC), we add intelligent packet loss mechanism to DFC and then assess it. For FEC, we use the Digital-Fountain (DF) channel coding. The DF encodes k original data symbols with size s into n symbols, where $n=k+h$, and $h>0$ is the number of redundant symbols in such a way that the original symbols can be recovered from any $K'>k$ received encoded symbols in a computationally efficient method (She et al., 2009). Using broadcasting property of PON, we send one IPTV broadcasting channel for all ONUs instead of sending one IPTV broadcast channel for each ONU, thus improving traffic load of the network.

Our contribution is to propose DFC and IDFC frameworks in IPTV over PON that combine Digital-Fountain FEC with erasure coding at the IP layer and the WRR scheduling in the OLT. In short, we combine DF, WRR, intelligent packet drop, and multicast property of PON at different layers to reduce congestion in the OLT and improve video quality.

2. Related work

Congestion is the main reason for packet loss in OLT. Some methods try to overcome congestion by using multicast property of IPTV. One approach (Ikeda et al., 2008) uses the property of PON in which each ONU can receive the data for other ONUs. For example, assume that one IPTV multicast channel (i.e., a TV channel) is being sent to an ONU. If another ONU requests the same multicast channel, the multicast router will duplicate the multicast packet on the multicast channel. However this method wastes bandwidth due to the time slots transmitting duplicated multicast data.

Fig. 2 shows a typical IP broadcasting network over a typical PON system (Ikeda et al., 2008), where the Round Robin (RR) scheduling is used in the OLT to service the packets in queues. Fig. 2 illustrates the IP broadcasting system architecture proposed in Ikeda et al. (2008), where the OLT in the local central office transmits High Definition TV (HDTV) streams to all ONUs using Multicast IDentifier (MID) in such a way that for the ONUs requesting the same multicast channel, the same MIDs are associated. All ONUs receive the broadcast frames on