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Exploiting Awareness of Network Topology and Relay Capability for P2PTV Traffic Localization

by

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"A good person can make another person good; it means that goodness will elicit goodness in the society; other persons will also be good"

His Majesty King Bhumibol Adulyadej The Great

To my grand parents who incent family's members to see the importance of education.

To my parents for their eternal love and inspiration.

To Wechtaisong and Rakngam family who stay beside me in every situation.

To every teacher who kindly teach, advise, instruct and motivate me for achieving my dream...

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Abstract

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The live video streaming application using peer to peer (P2P) multicasting called P2PTV attracts attentions as a means to delivery live streaming video to a large number of users since the server load becomes low compared with a unicast-based delivery. Most P2PTV systems select a neighbor peer in an overlay network either randomly or using RTT without considering the underlying network. They generate large volume of inter-ISP(Internet Service Providers) traffic, which is a serious problem for ISPs.

Recently, delay insertion approach for traffic localization is in which ISPs can achieve traffic localization only by deploying functions of inducing localization at edge routers or gateway routers. The localization function installed into the router estimates geographical distance from a new viewer peer to each neighbor peer and inserts additional delay when forwarding P2PTV packets from/to non-local neighbor peers. The literatures report this scheme leads P2PTV application to preferentially select neighbor peer in the same ISP or AS(Autonomous System) as the new viewer peer and reduces inter-domain traffic. This scheme does not require dedicated server installation, collaboration between ISPs and P2PTV content provider and modification at either P2PTV servers or applications. However, it considers geographical distance or intra/inter AS, ISP network between a pair of source/destination peers.

The geographical distance and intra/inter AS, ISP does not correspond with the distance along with the physical network in some cases and traffic localization is not sufficiently achieved. In addition, this scheme sometimes leads the newly joining peer to connect to a neighbor peer to which the path has small available uplink bandwidth resource and insufficient for serving P2PTV video data and other applications' traffic simultaneously.

This dissertation presents a novel scheme to achieve P2PTV traffic localization based on delay insertion approach to overcome aforementioned problems. This dissertation mainly offers the following contributions.

Firstly, it proposes the traffic localization scheme using finer-grain distance metric along with the physical network between source and destination peers, specifically AS hop distance. This is based on our observation that end-to-end traffic that traverses less number of different ASes is preferable in terms of reducing traffic charge between ISPs. The results of experiments conducted in the real network show the proposed scheme can lead P2PTV application of a newly joining peer to preferentially connect with neighbor peers distant with smaller AS hop distance greatly reduce cross-AS traffic compared to existing schemes.

Secondly, it proposes the traffic localization scheme considering relay capability of neighbor peers. It estimates the minimum of either available bandwidth of path between peers or relaying performance of neighbor peer's devices by sending ICMP ping packets to each of candidate neighbor peers for the predetermined time duration. This scheme leads a newly joining peer to avoid connecting with low-relay-capability neighbor peers, such as those participating into P2PTV network via 3G mobile access though they are close to the newer peer in terms of AS hop distance. When the newly joining itself has low relay capability, the proposed scheme allows existing viewer peers in the P2PTV network to connect to the newly joining low-relay-capability. The evaluation results show that the newly joining peer can avoid connecting to a low-relay-capability peers, and show that high-relay-capability peers can smoothly upload streaming content to the new peer even when the new peer is a low-relay-capability peer, while realizing efficient traffic locality.

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Chapter 1

Introduction

The demands of Internet use are rapidly increasing, especially for Internet video. Cisco forecasted that Internet video traffic will constitute 80% of total Internet traffic, 1.3 ZB, in 2019 [1]. Popular Internet video services such as YouTube [2], Ustream [3] and Hulu [4] deliver video files to every client on a unicast basis, and they must provide the content servers with high processing capability and the Internet access bandwidth required to cope with the increasing computation load and network traffic load, which is proportional to the number of downloading users. Content Delivery Network (CDN) service was introduced for reducing the content server load by redirect traffic to plural replica servers. However, this is a costly method for the content providers. For this purpose, P2P streaming services called P2PTV have recently received attention because they greatly reduce the server load compared with conventional unicast-based services. P2PTV services exploit P2P multicast for live streaming and P2P for the delivery of recorded video to alleviate server load. Many P2PTV services, such as PPLive [5], SopCast [6] and PPstream[7], are widely used in personal computers and portable devices, thus encouraging the increasing amount of video traffic on the Internet.

1.1 Traffic Localization Problem in P2PTV

Although video streaming based on P2P is beneficial for reducing the server load, existing studies that analyze the network traffic caused by the current P2PTV services have noted that there are many cases in which the content delivery paths are not efficient in terms of network bandwidth utilization [8–12]. For example, P2PTV applications select neighbor peers to download streaming packets by considering RTT or a random method without an underlying network consideration. Each peer tends to select its upstream peers among the ones in different Internet Service Providers (ISPs), though there are other peers joining the same P2PTV session in the same ISP. Network traffic crossing different ISPs generally increases the cost for both ISPs, and traffic localization in P2PTV is thus a prominent issue to be addressed.

1.2 Limitations of Existing Research Works

Existing schemes for traffic localization in P2PTV can be classified into two categories: centralized and decentralized control. In centralized control, ISPs cooperate with P2P services and then operate an oracle service to provide them with information about the underlying networks [13–16]. Although this approach can achieve high efficiency for traffic localization, difficulties remain in ensuring cooperation between every P2P service and every ISP. In contrast, in decentralized control, each peer independently estimates the network distance towards their neighbor peers, such as the router hop count or information about the ISP to which they belong; estimates network performance, such as delay or packet loss; and then selects appropriate upstream peers [17–23]. This approach is easier to deploy because the disclosure of topology information by ISPs is unnecessary. In particular, the delay insertion scheme [20, 22] has the advantage that it does not require modification to P2P application software. However, the current scheme exploits coarse-grained distance information regarding whether the peer and the other peer belong to the same ISP, and the benefit of traffic localization is exhibited for limited peer distribution patterns.

1.3 Objective

The purpose of this dissertation is presenting a scheme that indirectly leads the P2PTV applications to operate such that a peer shares video packets with neighbor peers whose hop distance is as small as possible. Simultaneously, relay capability of candidate neighbor peers is one of major priorities for peer selection to optimize available uplink bandwidth and workload at peer's terminal. In this dissertation, I present a novel scheme to achieve finer-grained delay-insertion-based P2PTV traffic localization by obtaining the network distance information between peers in the units of AS (Autonomous System) and determining delay values based on the AS hop distance. Moreover, the proposed scheme includes a function of postponing delay insertion after a new peer first finds a new neighbor peer to maintain the playing start-up time of P2PTV programs.

1.4 Structure of This Dissertation

The rest of the dissertation is organized as follows. First, the related works are discussed in Chapter 2 to prepare the background information for this dissertation. Chapter 3 present traffic localization considering precise physical network named AS hop based Traffic Localization (ATO) scheme. The ATO scheme is evaluated and presented in Chapter 4. Chapter 5 present the development based on ATO scheme by considering relay capability issue named Localization considering Relay Capability and AS hop Distance (LoRCAD) scheme. Chapter 6 presents experiment and results of the LoRCAD scheme. Chapter 7 conclude this dissertation and discuss the future work.

Chapter 2

Background

2.1 Internet Video Delivering Methods

The Internet video was initially launched on Internet's World Wide Web [24]. Currently, the popularity of Internet services using especially video contents create the high traffic. Many delivering methods have been deployed to handle a huge amount of receivers. In this Chapter, the Internet video delivering methods are classified into two major categories, client-server based method and peer-to-peer-based method. Their description including discussion about their advantages and limitations are presented in this section.

2.1.1 Client-Server-Based Method

The default method for delivering video over the Internet network is unicast-based, in which a single video servers send video streaming to each unique client as shown in Figure 2.1. A separate copy of the streaming data is delivered from the server to each client. In this delivery scheme, the server utilization in terms of CPU load and traffic load increases in proportional to the number of clients. The unicast-base scheme has a limitation on scalability. The video server may not provide sufficient video streaming to all clients when the large numbers of clients access the same video content at the same time. Furthermore, the volume of generated traffic is one of the drawbacks of this scheme. Video traffic is delivered from a single video server, at a single location, towards every client at a variety of location, which consumes transmission resource (i.e. bandwidth) between pairs of the server and the clients.

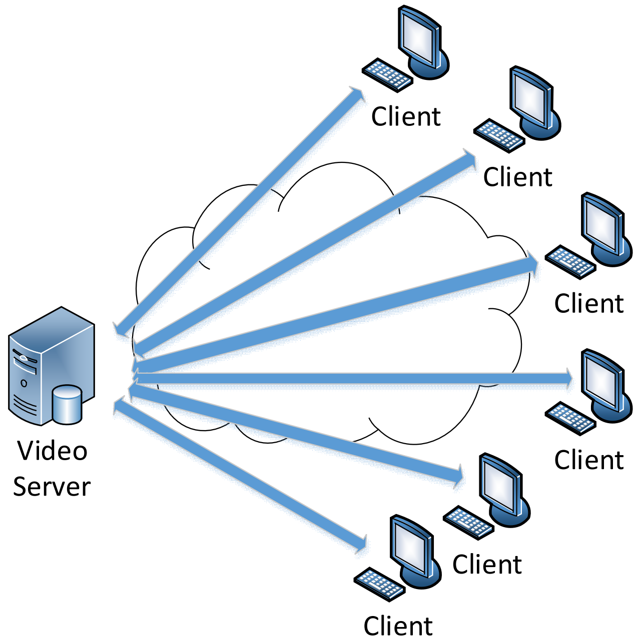


FIGURE 2.1: Unicast based for internet video delivery.

To overcome of limitations of a single server based unicast scheme, Content Delivery Network (CDN) is considered for delivering Internet video. The delivery mechanism of each scheme is discussed in this subsection.

A content delivery network or content distribution network (CDN) [25] is an enormous cache system which acts as multiple servers on the Internet. Figure 2.2 briefly presents Internet video delivery by CDN scheme. The original server can offload traffic and CPU load to the CDN replica servers. When a client requests video content from the original video server, the server can redirect the video content request to one of replica servers for serving the content to a client. The client can connect to a replica server which is geographically closer compared to the original video server. This scheme can reduce download time [26, 27]. Unlike the peak demand makes heavy load at the video server in a single server scheme, replica servers in CDN scheme can reduce this impact and serve quality of experience for users [28]. Commercial CDN operators such as Akamai [25] and Limelight [29] have become famous in the recent years. Most of major Internet video service websites and applications usually serve video content to end users via CDN.

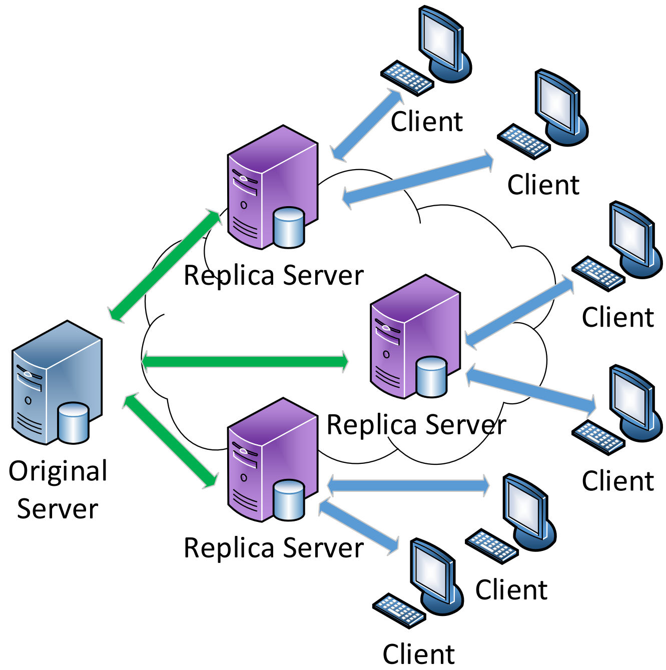


FIGURE 2.2: Internet video delivery via replica servers in CDN scheme.

2.1.1.1 Peer to Peer (P2P) Scheme

Peer to Peer video streaming system, which will be called P2PTV hereafter, has surged in popularity in recent years. Figure 2.3 shows an example of video streaming delivered by a P2P scheme. In P2PTV systems, clients ,which will be called peers hear after, act as users and servers simultaneously. The video file which downloaded by a peer may be also uploaded to other peers in the system. The collaboration of peers can establish a decentralized system for exchanging video streaming content between each other which can offload from the P2PTV server. P2PTV systems can serve both live streaming video and on-demand video. This system can be established by private individuals which require only P2PTV server and P2PTV application installed on client's devices. The reason that P2PTV is inexpensive that it require less server processing capability and less bandwidth at the access line from the server to the internet. Consequently the server is inexpensive, the cost of delivering video via a P2PTV system is usually lower than client-server schemes. The examples of current P2P video streaming services are PPTV[5], SopCast[6], and PPstream[7].

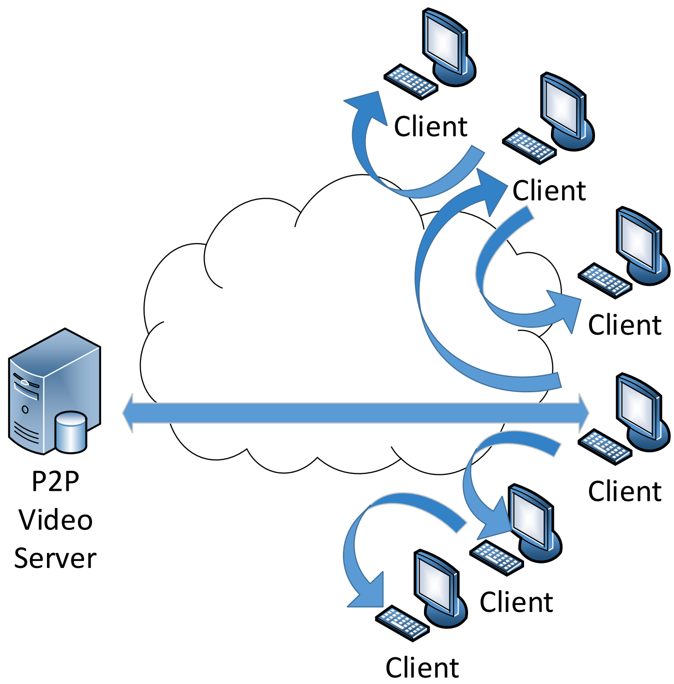


FIGURE 2.3: Internet video delivery in P2P scheme.

The process for selecting the neighbor peer, the P2PTV client who uploads streaming data to other viewers, in P2PTV system is explained in [30, 31]. Figure 2.4 shows an example of neighbor peer selection sequence in P2PTV system. There are a P2PTV server and several current viewers in each ISP network which are viewing the same P2PTV program. The neighbor peer selection sequence is described in five steps. (1) The new viewer which needs to watch P2PTV program requests a peer list from the P2PTV server. (2) After the P2PTV server received the request, it answers the new viewer by providing a peer list. (3) When the new viewer received the peer list information, the new viewer sends a connection request packet to every current viewer. (4) After several current viewers receive the connection request packet, they will response to the new viewer. Response packets may arrive at the new viewer at different times depending on available bandwidth or processing performance, of each current viewers. (5) The new viewer usually selects the earliest-responded peer and makes a connection to the peer. In this example, it makes the connection with the firstly-responded peer which is placed in ISP IV, in spite that a near route can be connected with the internal ISP network peer (peer A).

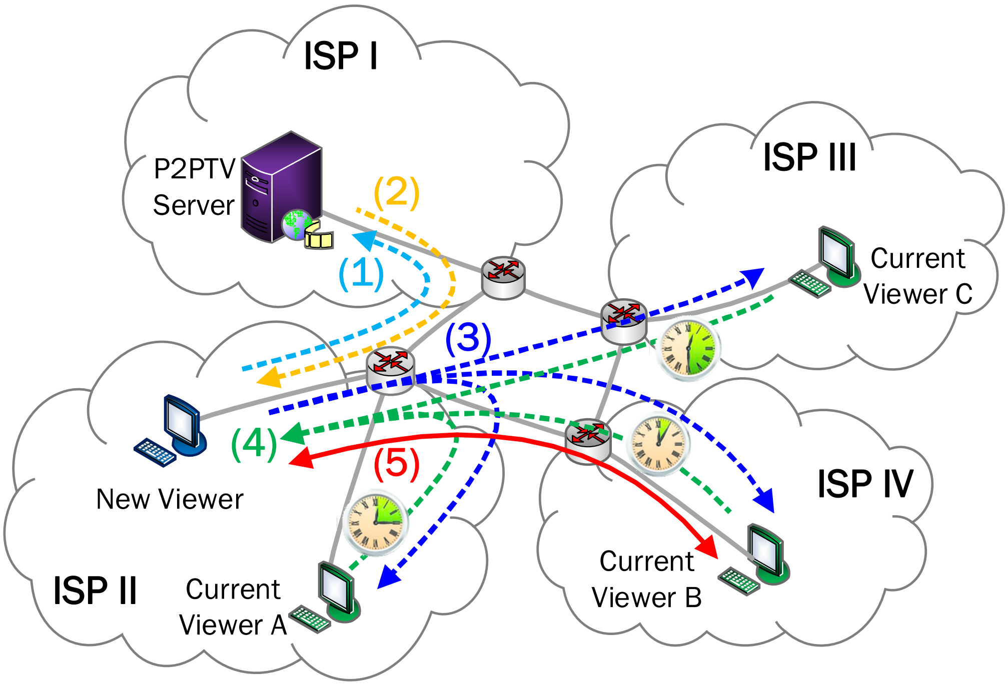


FIGURE 2.4: Control sequence for neighbor peer discovery.

Figure 2.5 presents streaming process of P2PTV application performed at each user [31]. The major component built in the P2P application is the streaming engine. Its main duty is downloading video chunks from neighbor peers on the

Internet and providing downloaded chunk data to the media player component. The streaming engine can offer downloaded content to other neighbor peers which are watching the same program at that time. The P2P application installed on the user's devices downloads chunk data from neighbor peers at data rate much larger than playing data rate to minimize the playing start-up time. When the media player receives sufficient content data, so that the video can be played at a stable data rate video playing gets started on the screen. The streaming engine provides streaming content to the media player in normal playing rate. In some case, if the streaming engine cannot provide streaming content in time, video playing may be freezing or skipping and degrades user perception quality.

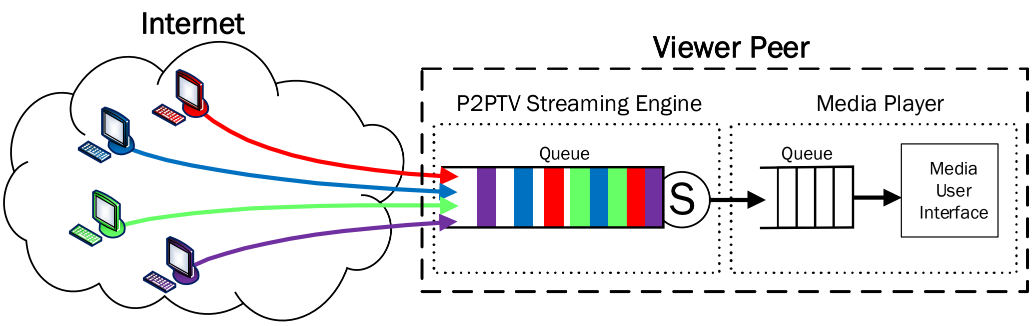


FIGURE 2.5: Streaming process of user device installed P2PTV application.

2.1.1.2 Comparison of CDN and P2P scheme

As described before, CDN and P2P scheme have their own benefits and drawbacks. The comparison of both scheme was presented in [32] and [33, 34] in terms of file sharing and video streaming delivery respectively. Table 2.1 summarizes the comparison between CDN and P2P. In addition, [33] briefly guides about the combination of CDN and P2P scheme and [34] introduces a hybrid idea of combining these delivery schemes for serving video streaming content.

From Table 2.1, CDN is a high cost delivery system which requires installation of multiple replica servers.

TABLE 2.1: Comparison between CDN and P2P.

Comparison Item	**CDN**	**P2P**
Intermediate Node	Replica servers	Client nodes
Intermediate Node Authentication	Center certification	Distributed certification or non-certification
Service Capability	Limited	Grow up with number of users
Installation and Expansion Cost	High	Low
Reliability	High	Dynamic
Stability	Good	Acceptable
Network(ISP)-friendly	Friendly	Unfriendly
Traffic Management	Traffic is ordered in different regions	Traffic disorder, cross-ISP expansion in the whole network
QoS	Guarantee	Best-effort
Content Source Monitor	Can be monitored	Difficult to monitor
Content Copyright and Security	Manageable	Unmanageable
Client Management	Centralized client management	Non or less client management

[32–34]

The number of CDN replica servers should be increased according to the increase of end users. Although CDN is reliable and manageable delivery scheme, the scalability and investment cost are major drawbacks in implementation. On the other hand, P2PTV system is a low-cost delivery system which is easily implemented. To operate a P2PTV system, a P2PTV server is implemented at the service provider side and P2PTV application is installed on each end user's devices which means no additional network device installation is required. This delivery system is suitable for start-up content providers which have the limitation in implementation budget. In terms of the scalability benefit, P2PTV delivery scheme is suitable for video contents which content provider cannot predict the amount of end users in advanced. For video content management, the illegal copyright issue is a quite typical and negative impression of P2P system because there are illegal copyright files shared over P2P file sharing system which are freely uploaded from P2P users. However, in P2PTV system, P2PTV server can control and manage both broadcasting and on-demand content.

2.2 Problem Statement in P2P Streaming System

P2PTV is a low-investment-cost system which can efficiently reduce server load in terms of traffic and CPU utilization. However, many research works indicate that physical network unawareness of P2P system can rise up inter-domain traffic. This is a serious treat for ISPs which need to manage traffic problem from P2P system.

In P2P systems including P2PTV services, logical link are established between peers and they form the overlay network on top of the Internet infrastructure. The logical links on the overlay network are often established without considering locality of the physical network topology[8–12]. Figure 2.6 shows an example of the overlay network of P2P system which is built over physical network topology. It does not reflect the physical network topology. Each peer usually establishes connection to neighbor peers which belong to different ISP. From this reason, P2PTV can bring the huge amount of inter-ISP traffic which is costly traffic for ISP. An example of the geographical distribution of peers in a P2PTV application presented in Figure 2.7. There are P2PTV viewer in Japan which watch P2PTV program on the SopCast application and multiple upstream neighbor peers, which upload streaming data to the new viewer, distributed on the other side of the world. Streaming traffic was sent across the long distance from upstream peers to the viewer. So, the neighbor peers selection should consider topologically closer ones for avoiding inefficient utilization of network resources and reducing inter-domain traffic.

To solve problems brought by P2P systems, numbers of traffic management schemes were introduced. The summary of existing P2P traffic management schemes will be discussed in the next section.

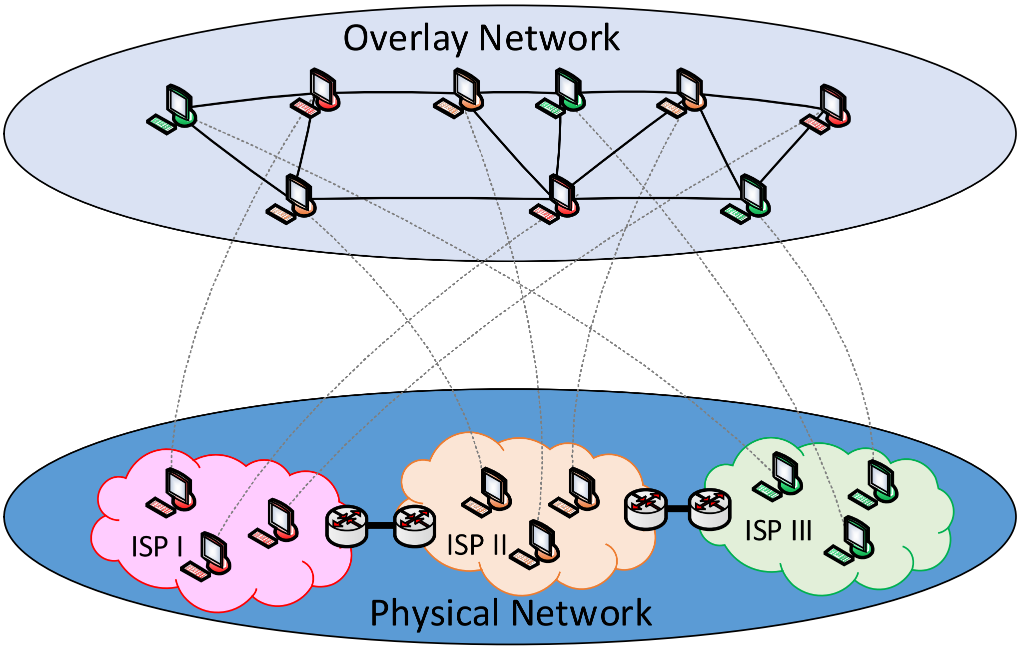


FIGURE 2.6: Connection of peer on overlay network without physical network consideration.

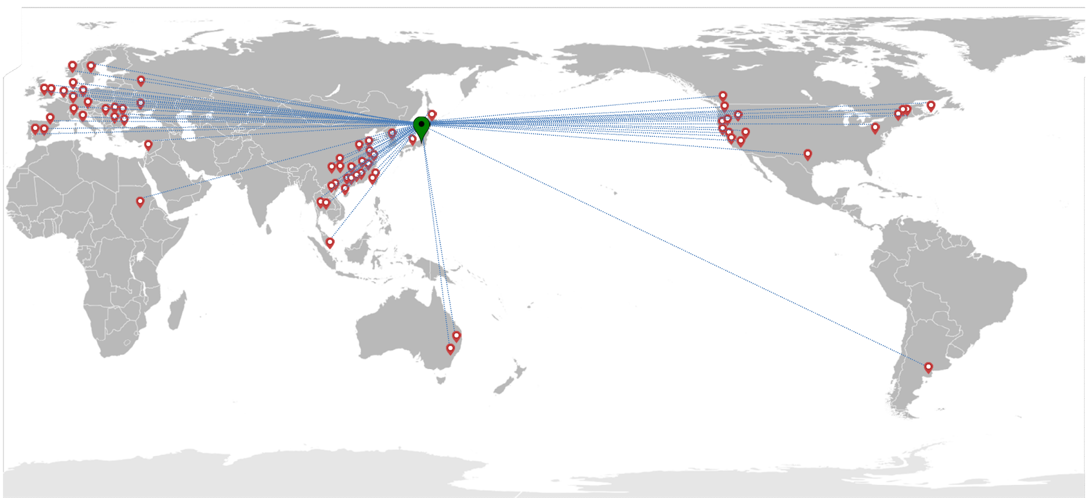


FIGURE 2.7: An example of peer distribution for SopCast.

2.3 Conventional Traffic Management for P2P System

2.3.1 Bandwidth Capacity Expansion

P2PTV streaming data require the high bandwidth resource which may make congestion at backbone network and inter-domain link. Bandwidth expansion is one of the possible solutions which ISPs do their best for solve the congestion problem [35]. However, it is a costly solution for investment. In addition, while the scalability of P2PTV traffic cannot be predicted, ISPs cannot solve the traffic problem from P2PTV alone by only the bandwidth expansion solution.

2.3.2 Blocking P2PTV Traffic

The use of P2PTV and P2P file sharing is usually prohibited in institute or organization networks. They block some ports which are usually used by popular P2P applications [36]. From the policy of each network, the network administrators can block unnecessary traffic and some unsuitable websites for security reasons such as preventing spywares, malwares, and computer viruses. In commercial ISP networks, it is very difficult to block P2P traffic mainly from the business perspective. Customers can stop their contract if they do not satisfy any services. To maintain revenue and market share, commercial ISPs have to provide satisfactory services for their costumers.

2.3.3 Deep Packet Inspection

Deep Packet Inspection (DPI) has been normally used for firewall, spam filtering, and intrusion prevention. Currently, the DPI is also deployed in traffic management process [37]. ISPs use the DPI for service classification by payload inspection since policing packet header and port number cannot yield a reliable differentiation [38]. This system analyzes traffic in real-time by scanning only first few packets, 1-3 packets and 3-20 packets for unencrypted and encrypted protocol respectively, of each flow without total flow analysis. The DPI based bandwidth management can be implemented in ISP networks in three steps: packet inspection, packet prioritization, and differential handling. To manage traffic, ISPs can limit or block P2PTV and other high-data-consuming applications.

2.3.4 Service Pricing Strategies

Some ISPs use service pricing and terms of agreement for controlling traffic demand of end users. Many limitation plans such as volume based, time-based are options for optimizing end user's traffic. On the other hand, Fair Usage Policy (FUP) is a popular flexible option which ISPs can launch agreement with users for preventing high traffic consuming [39]. Available bandwidth for users will be limited if their usage exceeds threshold volume and resumed after new billing cycle started. The usage limitation scheme is sometimes deployed in broadband wired networks [40]. In contrast, it is quite common in broadband wireless networks. This scheme can lead end users to avoid using high-data-consuming applications, especially P2P services. However, the pricing strategies cannot solve congestion problem in the network during peak hour [41].

2.4 Existing Studies on Traffic Localization for P2P System

To overcome the negative impact of the conventional traffic management, many research groups, and ISPs have studied various solutions for realizing traffic locality in P2P both file sharing and video streaming system which can maintain the quality of P2P services. The typical method is trying to estimate physical network topology between a pair of upstream neighbor peers and the viewer peers then lead the P2P application to select neighbor peers in the same ISP network. In this dissertation, I classified P2P traffic localization scheme into three groups; centralized approach, decentralized approach, and delay insertion approach. For the centralized approach, repository node is required for mainly providing physical network topology information to an application layer. There is a collaboration between ISPs and P2P content providers or among ISPs themselves in order to implement the centralized approach. On the other hand, the decentralized approach can be implemented solely by ISPs or P2P content providers. The different from the centralized approach is that the physical network topology information is estimated at peer nodes by exchanging probing among them. The delay insertion scheme is a part of the decentralized approach which estimates physical network distance at the gateway router and inserts additional delay into packets from/to non-local neighbor peers for leading P2PTV applications to connect to local peers. The summary of traffic localization schemes in centralized, decentralized and delay insertion approach are described and compared in this section.

2.4.1 Centralized Approach

In this approach, dedicated servers are implemented like an intermediate server for collecting physical network information from ISPs side and providing this information to P2P applications. P2P applications can select local neighbor peers which improve physical topology unawareness problem in P2P system.

2.4.1.1 Caching

Caching method is a common solution which was deployed in P2P systems for objectives of improving service quality [42, 43] and traffic management [44, 45]. P2P traffic localization by caching scheme was developed in P2P file sharing system [45]. The cache-based solution called B-Proxy is implemented by ISPs which can reduce the data transmitted from external ISP network peers by caching the previous requested content. The simulation results showed that B-Proxy can save more than 30% of inter-ISP traffic. The cache scheme also improves traffic management in P2P video streaming system [44]. ISPs can efficiently use their P2P caches by collaborating cache servers between ISPs to serve clients which belong to each other. The result showed that cooperative caching method can solve the resource allocation problem and increase cache efficiency.

2.4.1.2 P4P

P4P is a simple and flexible framework to enable collaboration between P2P application and ISPs [14, 46]. In P4P scheme, P2P systems can inquire of ISPs useful physical network information. Each ISP which is interested in using P4P protocol installs information server named "iTracker". The iTracker keeps physical network information of the ISP where it placed. P2P applications which support P4P protocol named "appTracker" interact with iTrackers and distribute the P4P information to peers. The newly joining peer joins network and requests neighbor peer information from the appTracker. The appTracker makes the decision about candidate peers selection for each newly joining peer. The group of peers in P4P scheme are defined by PID (opaque ID) to preserve provider privacy at a coarse grain. The appTracker selects candidate neighbor peers for the newly joining peers in three stages (1) intra PID, (2) inter PID and intra AS, (3) inter AS. Evaluation result from [47] showed that P4P traffic localization scheme can greatly improve download speed of P2P applications and decrease traffic across ISPs. In addition, [48] enhance the P4P algorithm for supporting P2P video streaming system using playback synchronization mechanism which can reduce the time difference in playback between the peers and improve network efficiency.

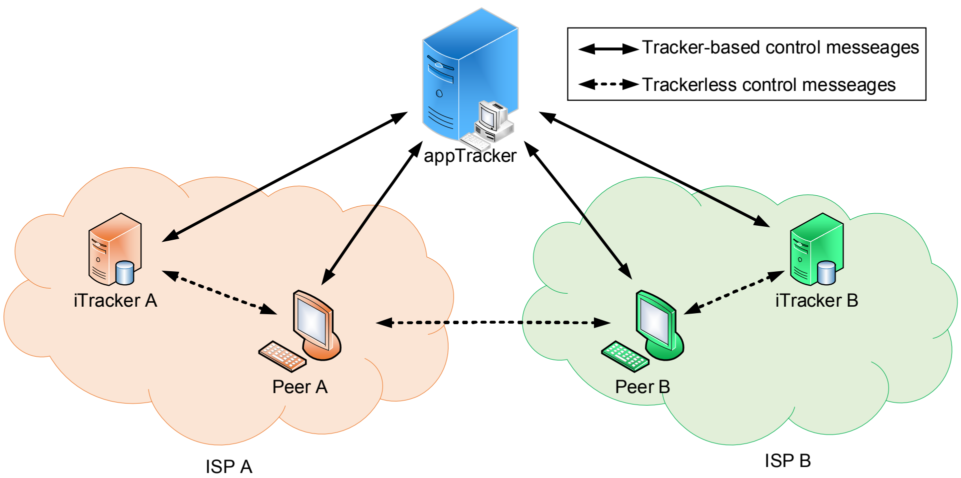


FIGURE 2.8: Concept of P4P traffic localization scheme.

2.4.1.3 ALTO

Following the P4P paradigm, the Internet Engineering Task Force (IETF) realized the standard of collaboration between the application and the physical layer in the context of P2P traffic localization and formed the Application-Layer Traffic Optimization (ALTO) Working Group (WG)[15]. The goal is to develop better-than-random initial peer selection by providing physical network information. The strategy based on query-response protocol which P2P applications can query physical network information to optimize neighbor peer selection as shown in Figure 2.9. There are four basic steps of ALTO. (1) The newly joining peer receive candidate neighbor peers list from the P2P server. (2) The ALTO component which implemented in the newly joining peer asks the ALTO server, directly or via the application tracker, for a guidance about neighbor peer selection. (3) The ALTO component receives the guidance from the ALTO server and informs the P2P application. (4) The P2P application uses the received guidance along with its own estimation for selection some neighbor peers from candidates.

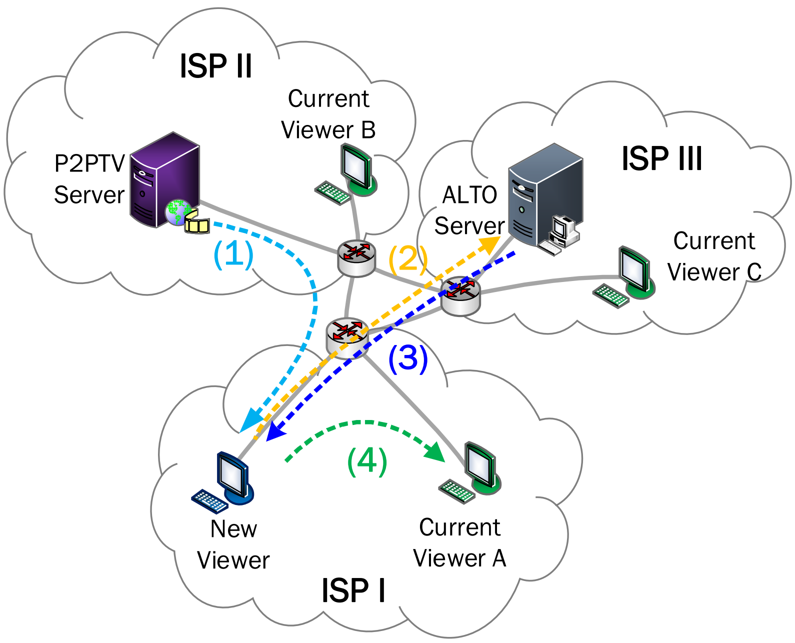


Figure 2.9: Concept of ALTO.

In [49], the ALTO scheme is implemented in a real network which reported that the deployment of the ALTO significantly improves the capability of a service provider. The ALTO scheme was deployed with P2P streaming system [50] whose experimental result also shows benefit in terms of reducing overall transmission costs while keeping delay low, thus fulfilling streaming requirements.

2.4.1.4 NAPA-WINE

NAPA-WINE (Network Aware Peer-to-peer Application over WIse NEtwork) project group proposed a network-aware architecture in which the application layer and the underlay network layer cooperate to optimize the peer to peer high-quality TV (P2P-HQTV) service offered to end users [51, 52]. Figure 2.10 presents schematic of the NAPA-WINE approach. The NAPA-WINE architecture regulates a total design that consists of users, overlay, messaging, monitoring, repository modules, and data communication and signaling among the modules. The NAPA-WINE approach can be implemented by installing the plug-in into P2PTV clients for being monitoring and controlling component. The ALTO working group collaborates with NAPA-WINE as a partner and provides ALTO guidance for peer selection strategies.

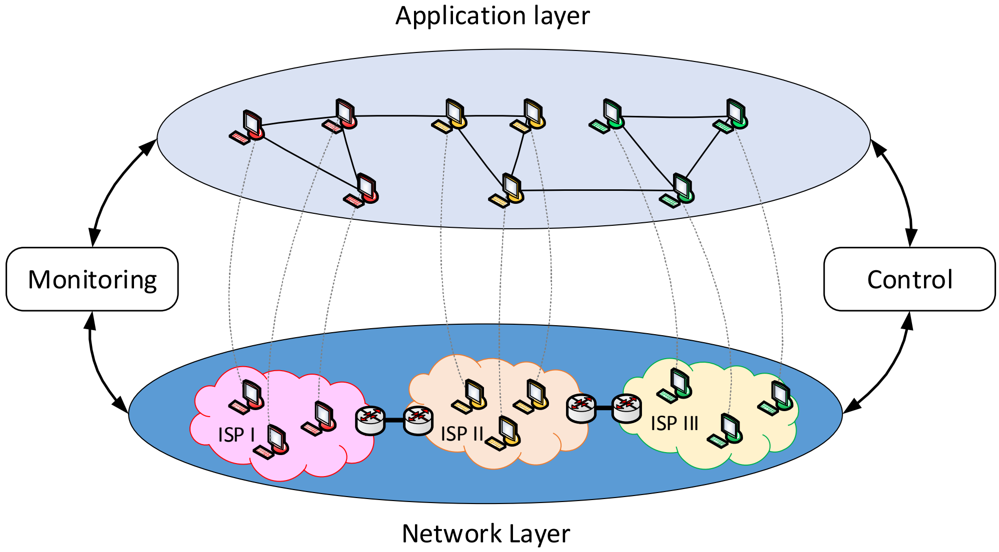


FIGURE 2.10: Concept of NAPA-WINE.

2.4.2 Decentralized Approach

2.4.2.1 Biased Neighbor Peer Selection

The idea of biased neighbor peer selection (BNS) was presented in [53] for improving P2P traffic localization. The technique of this scheme is selecting mainly neighbor peers from the local network and few neighbor peers from external networks. The k parameter was defined as the number of neighbor peers from external ISP networks. This scheme drives the newly joining peer selects $35 - k$ neighbor peers from the internal ISP network and k neighbor peers from external ISP networks. There are two options to implement the biased neighbor peer selection technique which is the tracker and client modification and the P2P traffic shaping device installation. From the simulation result, the idea of biased neighbor peer selection can reduce traffic across ISP by controlling the number of neighbor peers while maintaining performance of P2P application.

2.4.2.2 Probing

The traffic locality by the eMule system is developed based on P2P file sharing system [18]. In the eMule system, there are eMule servers and eMule clients which reflect P2P server and peers in P2P system. The simple traffic localization mechanism was deployed in the eMule system. The newly joining eMule client received a list of candidate neighbors from the eMule server. The eMule client estimates distance to every candidate neighbor in the list by sending ICMP ping packets and then analyzing ICMP responded packets from each candidate neighbor considering TTL (Time To Live) or RTT (Round Trip Time). It majorly selects small distance candidate neighbors for making connection and downloading contents. The simulation results show that eMule system can reduce cross-domain traffic and improve download performance of eMule clients.

The ePAD system is introduced which enhances the eMule system for supporting P2P video streaming traffic localization [54]. The chunk selection algorithm is deployed which makes ePAD system have a playing-as-downloading capability. The simulation results show that ePAD clients can achieve a good streaming playback performance and maintain the overall downloading throughput even when there are a few neighbor candidates in system for uploading streaming content.

2.4.2.3 Ono

Ono is a decentralized traffic localization scheme which is implemented as plug-in of P2P application on user devices without any probing or path monitoring [55]. The Ono approach is based on assumption that two clients are near each other if they exhibit similar redirection behavior. The Ono clients observe CDN redirections by performing DNS lookup and collect locality information. The Ono client selects candidate neighbors which have the same redirections behavior to make connection. This approach is implemented in a real network and the evaluation results show that it can reduce cross-ISP traffic while increasing user experience.

2.4.2.4 Localiser

The localiser algorithm is a latency management method which is proposed for driving physical network awareness on overlay networks [56]. The self-organizing overlay network function in localiser is a fully decentralized technique and only relies on local information available at each node without previous knowledge or third-party aid in term of collecting physical network information. The simulation result indicates that the proposed localiser algorithm serves multiple objectives: (1) it reshapes the overlay network to reflect geographic locality of physical network which can reduce load for network (2) it achieves load balancing by evenly balancing the number of neighbors of each client node in the overlay and finally (3) it significantly improves the resilience to failures or disconnections.

2.4.3 Delay Insertion Based

In recent years, delay insertion approach for P2P traffic localization has been studied. The additional delay is inserted into P2PTV packets at gateway router by considering the geographical area of candidate neighbor peers. P2PTV application detects degradation of RTT brought by delay insertion and avoids connection to the non-local candidate neighbor peer. This approach can be implemented only at the ISP side without P2PTV software modification and collaboration between ISPs and P2PTV content providers.

2.4.3.1 P2P-DISTO

P2P-DISTO (Delay Insertion Scheme for Traffic Optimization) [20] is one of initially-proposed traffic localization schemes based on delay insertion for applying to P2PTV systems. Figure 2.11 shows the concept of P2P-DISTO scheme. The functions of P2P-DISTO are implemented at the gateway router of ISP. They are assumed to process only P2PTV packets by using packet classification such as DPI. When an IP address of candidate neighbor peer is detected, it is mapped with geo-location database for identifying the country where the candidate peer is located. The delay insertion router inserts additional delay into non-domestic P2PTV packets. This localization scheme can lead P2PTV application to connect with domestic neighbor peers and localize traffic in the country level.

P2P-DISTO can induce a logical link reestablishment that is preferable for traffic localization in P2PTV by intentionally inserting delay for each packet depending on its destination address. This approach takes advantage of typical current P2PTV services behavior, in which each peer tries to select its upstream peer such that the link delay to the peer is smaller than to any other peer. For example, by inserting delay only for packets whose destination IP addresses belong to a different country from the source peers IP address, the source peer is less likely to select a peer on a different country as its upstream peer because the RTT between the source peer and these peers becomes longer through the delay insertion.

P2P-DISTO achieves a certain degree of traffic locality in P2PTV system. However, the location of candidate neighbor peer in term of domestic/non-domestic is quite rough for criteria of locality. Moreover, it may not reflect the real physical network topology of the Internet.

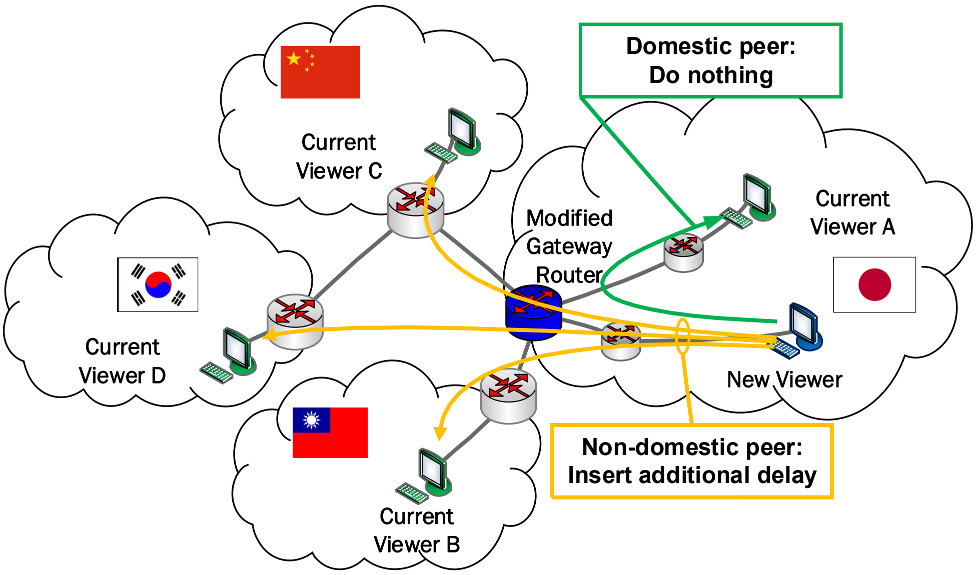


FIGURE 2.11: The concept of P2P-DISTO traffic localization scheme.

2.4.3.2 P2P-HDISTO

P2P-HDISTO (Hierarchical Delay Insertion Scheme for Traffic Optimization) [22] was developed from the P2P-DISTO. The value of the delay that the gateway router inserts to each packet are differentiated, depending on the network distance and physical distance between peers. Specifically, the value of the delay d is calculated as

$$d = T_{max} \times \frac{D}{20000} \tag{2.1}$$

$$D = f_1(as_i)e^{-\frac{1}{n_1+\epsilon}} + f_2(isp_i)e^{-\frac{1}{n_2+\epsilon}} + f_3(isp_i, cc_i)e^{-\frac{1}{n_3+\epsilon}} \tag{2.2}$$

$$f_1(as_i) = \begin{cases} 0 & \text{if } (as_i = as_0) \\ \theta_1 & \text{if } (as_i \neq as_0) \end{cases} \tag{2.3}$$

$$f_2(isp_i, isp_0) = \begin{cases} 0 & \text{if } (isp_i = isp_0) \\ \theta_2 & \text{if } (isp_i \neq isp_0) \end{cases} \tag{2.4}$$

$$f_3(isp_i, cc_i) = \begin{cases} 0 & \text{if } (isp_i = isp_0) \\ d(peer_i, peer_0), & \text{if } (isp_i \neq isp_0) \text{ and } (cc_i = cc_0) \\ \theta_3 + d(peer_i, peer_0) & \text{if } (cc_i \neq cc_0)) \end{cases} \tag{2.5}$$

Here, T_{max} denotes the maximum value of delay length. n_1, n_2 and n_3 denote the number of peers in internal AS, ISP and country, respectively. as_0, isp_0 and cc_0 denote the AS number, ISP, and country of the viewer peer, whereas as_i, isp_i and cc_i denote the AS number, ISP and country of the neighbor peer, respectively. $d(peer_i, peer_0)$ is the linear function of the physical distance between peers, which is estimated by using the GeoIP database [57]. The delay performance of every streaming packet is degraded if there are no peers that belong to the same AS network as the viewer peer while playing the P2PTV program, and the value of degradation is proportional to the geographical distance between each pair of peers. Thus, problems in terms of QoS (quality of service) can occur. This technique is beneficial because it can be applied to essentially any P2P application without modifying the application software at each peer. However, geographical distance does not always correspond to the distance of the network topology, and the effect of traffic localization is thus limited.

2.5 Comparison of Existing P2P Traffic Localization Schemes

As mentioned before, there are various positive attributes in each P2P traffic management schemes. To summarize all mentioned P2P traffic localization scheme, The conclusion of each scheme was compared and presented in Table 2.2.

From the comparison of P2P traffic localization scheme in Table 2.2, many traffic localization schemes still be evaluated by simulation method (BNS, Caching, Probing, and Localizer). Their evaluation results present the good efficiency, however, they can improve the reliability of their traffic localization scheme by proving their efficiency and realization on the real network experiment. Some traffic localization schemes conduct their experiments in the real internet network (P4P, ALTO, Ono, P2P-DISTO, and P2P-HDISTO) and deployed on the commercial networks

TABLE 2.2: Comparison of each P2P traffic localization scheme.

Approach	**Localization Scheme**	**Evaluation method**	**Operator node**	**Application**	**Localization level**	**QoS**
Centralize	**Caching**	Simulation	Cache server	File sharing, Video streaming	Intra/inter AS	N/A
	P4P	Real Network	iTracker	File sharing, Video streaming	Intra/inter PID, AS	Improve
	ALTO	Real Network	ALTO server	File sharing, Video streaming	Intra/inter AS	Maintain
	NAPA-WINE	Real Network	Oracle Server/-Clients	Video streaming	Intra/inter AS, bandwidth available	Maintain
De-centralize	**BNS**	Simulation	Tracker/-Clients or Shaping devices	File sharing	Intra/inter ISP	Improve
	Probing	Simulation	Client	File sharing, Video streaming	Router hop	Maintain
	Ono	Real Network	Client	File sharing	Intra/inter DNS group	Improve
	Localiser	Simulation	Client	N/A	LAN	Improve
Delay insertion	**P2P-DISTO**	Real network	Edge router	Video streaming	Intra/inter Country	N/A
	P2P-HDISTO	Real network	Edge router	Video streaming	Intra/inter AS, ISP, Country	Maintain

(P4P and ALTO). All scheme presented improving traffic locality in various level of physical networks.

The delay insertion based scheme, P2P-DISTO and P2P-HDISTO, also presented good impact to realize traffic locality. ISPs can implement these scheme alone without collaboration with the content provider. Although, their localization may not completely reflect the real physical topology of the Internet network as well as without peers' relay capability consideration, this limitation is interesting for developing improvement.

Chapter 3

Traffic Localization Considering Precise Network Information

As mentioned before, network traffic across ISPs generally creates extra cost for both ISPs. Considering this property, this chapter presents a novel traffic localization for P2PTV system based on delay insertion scheme in which the amount of delay is differentiate depending on the distance between peers along the physical networks considering precise network information.

3.1 Conceptual Framework

I focus on the number of different ASs through which a logical link connecting two peers passes in P2PTV, that is the AS hop distance of the link. For example, the AS hop distance of a link is zero when two peers belong to the same AS, and it is one when two peers belong to different ASs that are directly connected. The objective of this scheme is localizing P2PTV traffic by letting each peer establish logical links to neighbor peers with as small an AS hop distance as possible.

To enhance the accuracy of traffic localization of delay insertion scheme, the proposed scheme introduces the AS hop distance as a metric to decide the value of the inserted delay. I named the proposed scheme **AS hop based Traffic Optimization (ATO)** which aims to localize P2PTV traffic by letting each peer establish logical links to neighbor peers with as small an AS hop distance as possible. The proposed ATO is developed based on the existing P2P-HDISTO scheme which modifies the delay calculation policy from the geographical distance based to fine-grained physical network distance based in the unit of AS network. Moreover, ATO scheme realizes traffic locality under an assumption that every peer has sufficient relay capability in terms of available downlink/uplink bandwidth and terminal's performance for downloading and relaying video data while playing P2PTV program on screen simultaneously. Figure 3.1 illustrates the concept of the proposed scheme. The proposed delay insertion function is applied to the edge routers in ISPs. The router inserts delay into packets, which are either from or to the peers in the network to which the router directly connects. The amount of inserted delay is proportional to the h AS hop distance between source and destination peer.

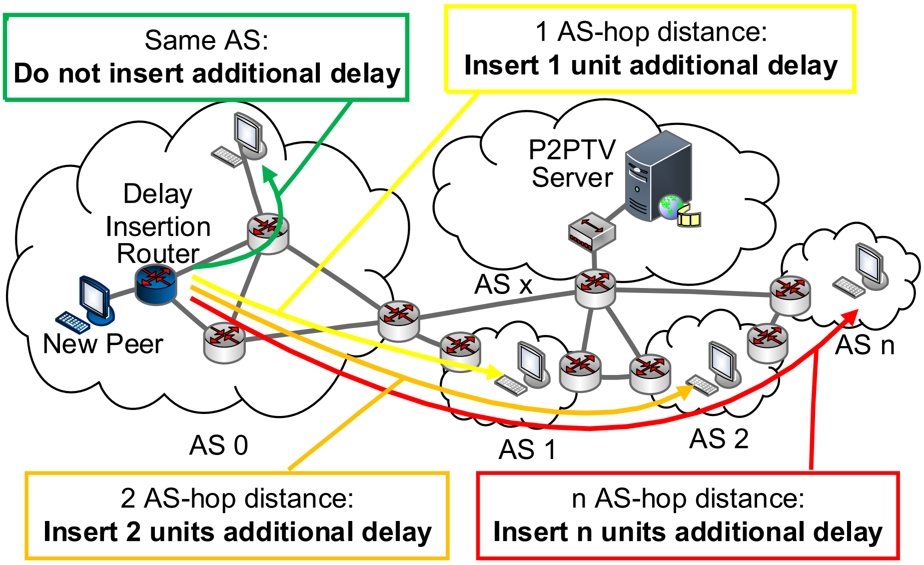


FIGURE 3.1: Conceptual illustration of delay insertion related to AS hop distance.

Here, the amount of delay inserted for packets destined for the peer with h AS hop distance $delay_{ins}$ is defined as

$$delay_{ins} = h \times d_{unit} \tag{3.1}$$

Here, d_{unit} is a constant time unit that is configured depending on the characteristics of the underlying networks or P2PTV services. This delay differentiation will force the P2PTV application to maximally share streaming data with two peers within the same AS or a small AS hop distance away from each other.

3.2 AS hop Distance Estimation

In this scheme, the AS hop distance calculation is a newly developed function to enable delay insertion for the packets depending on their AS hop distance. The AS hop distance is counted along an AS-path, i.e., the route history of the BGP (Border Gateway Protocol) packets recorded in the packets themselves. The router periodically retrieves AS path information from an Internet topology database [58]. The router collects data of the AS-paths, which either originate the AS in which the router is located or contain the AS as an intermediate AS. An example of the calculation is presented in Table 3.1, in which the AS number where the router is located is 4713. Using this AS-path information, an AS hop distance dataset can be created as shown in Figure 3.2. If the AS to which the destination peer belongs is missing in this dataset, it estimates the hop count towards the destination AS derived by using AS neighbor information stored in the topology database. The estimation of Internet topology between ASs has been extensively studied, and it has been reported that a path between a pair of ASs can change dynamically in certain cases [59, 60]. The AS hop distance dataset obtained by routing information represents a real physical topology; thus, I believe that this calculation approach is sufficiently effective to justify the benefit of the proposed scheme.

Table 3.1: An example of AS hop distance information obtained by AS-path.

Origin Network	Raw Data of AS-path	Number of AS hop from the viewer				
		0	**1**	**2**	**3**	**4**
AS4713	"path": [4608,1221,4637,2516,4713]	4713	2516	4637	1221	4608
AS4713	"path": [37989,4884,2914,4713]	4713	2914	4884	37989	-
AS4713	"path": [22652,3356,2914,4713]	4713	2914	3356	22652	-
AS4713	"path": [50300,2914,4713,10015,2512]	4713	2914	50030	-	-
			10015	2512	-	-
AS27706	"path": [25152,4713,209,721,27706]	4713	209	721	27706	-
			25152	-	-	-

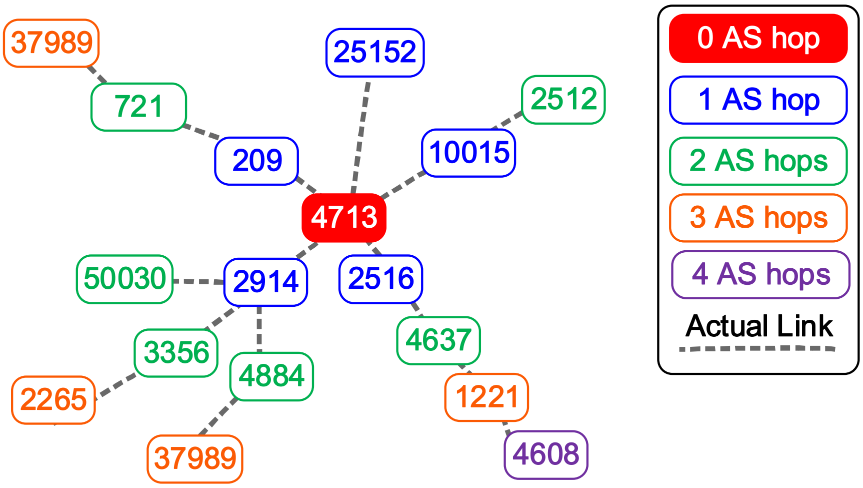


Figure 3.2: An example of an AS hop distance database constructed using the data shown in Table 3.1.

3.3 Methodology

3.3.1 Mechanism of Maintaining Playing Start-up Time

The P2PTV traffic localization technique should both achieve traffic locality and maintain QoS for users simultaneously. As one of the major QoS factors in P2PTV, I focus on playing start-up time, which is the duration of time that the user must wait from when a P2PTV program is selected until video playing of the program actually starts on the screen. This has a great influence on the users perceived quality of the P2PTV application. I aim to maintain the playing start-up time of P2PTV applications when the proposed scheme is applied as the same as that of the existing P2PTV application with no packet delay insertion system.

When the scheme inserts delay into the packets immediately after the new peer joins the P2P network, it will delay not only the video packets but also the control packets issued by the peer. Control packets in the P2PTV application issued at an early time after joining the network are typically used to estimate RTT between the peer and its neighbor peers or to request one of the neighbor peers to connect. Delaying these control packets will severely degrade the playing start-up time. I solve this problem by postponing the delay insertion. Starting time for inserting delay (t_{th}) is the time constant unit for which the router retards the starting of delay insertion after the new peer first sends a packet to its neighbor peer. For example, $t_{th} = 0$ means that the delay is inserted into packets immediately after the router forwards the first packet from the new peer to its neighbor peer. If define $t_{th} = 20$ is defined, the router will postpone the delay insertion for 20 seconds after the router detects the first packet from the new peer to its new neighbor peer. Refraining from delay insertion into early P2PTV packets will achieve a short video playing start-up time.

3.3.2 Mechanism of Delay Insertion

Because the proposed router generally accommodates a number of peers according to the role of an edge router, the amount of $delay_{ins}$ calculated is different depending on the address pair of the packet, namely, that of the source IP address and destination

IP address. Thus, the process of the proposed delay insertion is illustrated by the diagram in Figure 3.3. First, it classifies input packets into P2PTV packets and non-P2PTV packets, and the following processes are applied only to P2PTV packets. It extracts the source and destination IP address and checks that the amount of delay insertion $delay_{ins}$ for the packets of this address pair was already determined. If not, it calculates $delay_{ins}$ after forwarding the packet. It identifies the AS number to which the packet destination IP address belongs, estimates the AS hop distance and then calculates $delay_{ins}$ by using equation (3.1). If $delay_{ins}$ was already calculated before, it inserts the delay of this amount if the present time is after t_{th} and forwards the packet. `dummynet` [61] is applied as the delaying function.

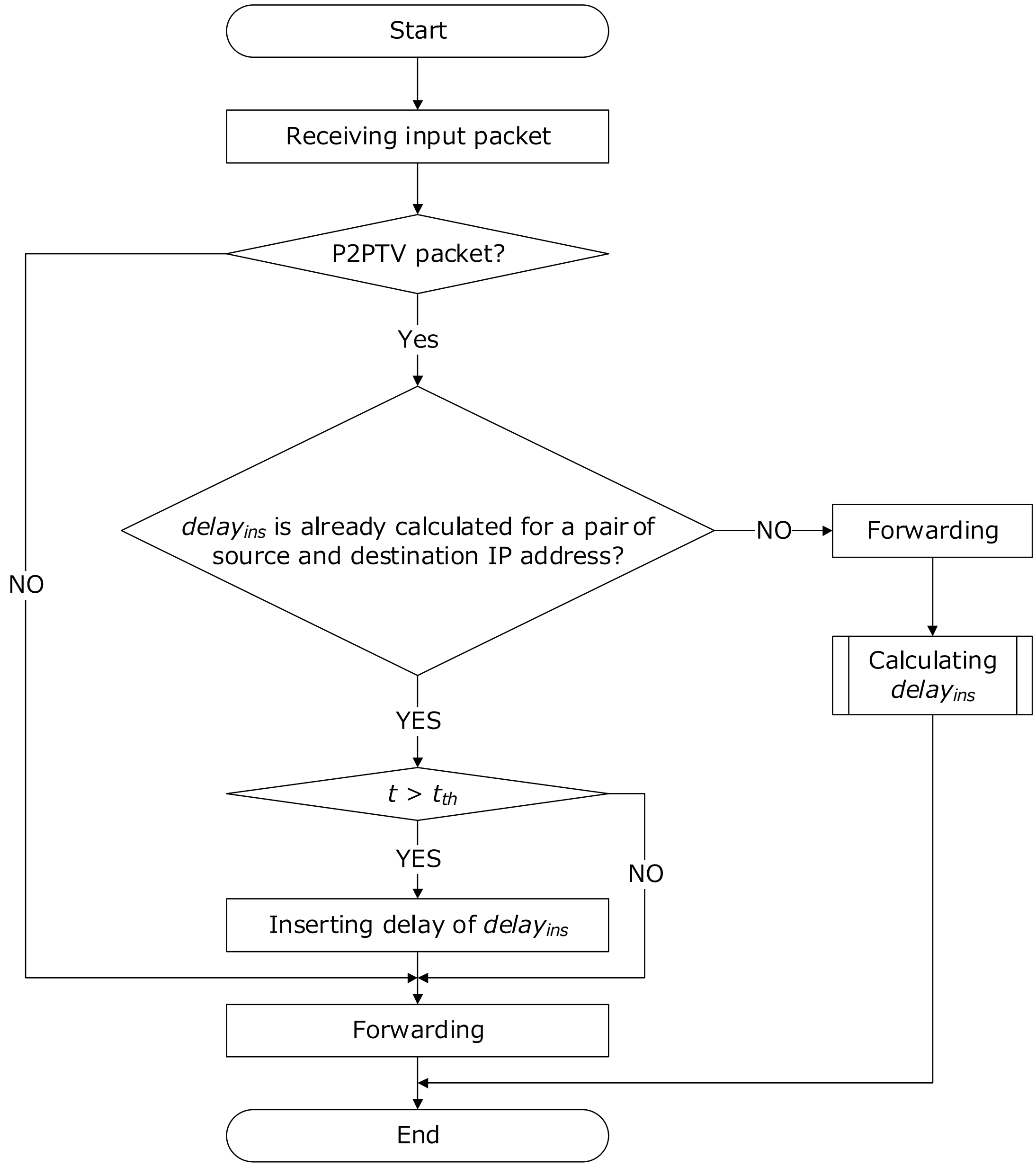


FIGURE 3.3: Flow chart of delay insertion into P2PTV packet by the proposed ATO scheme.

Chapter 4

Experiment and Results of ATO Scheme

This Chapter first evaluates the suitable value of parameter t_{th} which is the starting time for inserting delay for maintaining playing start up time of P2PTV applications. Moreover, the constant time unit that configured depending on the characteristics of underlying networks, parameter d_{unit}, is evaluated. The purpose is defining the suitable value for localizing traffic and maintaining video quality of P2PTV application simultaneously.

4.1 Experimental Setup for ATO Scheme Evaluation

The proposed router was implemented on a PC with FreeBSD release 9.2, Intel Core i7 3.5 GHz processor, 8 GB of RAM. All of the packets entering the router were captured using the packet capture library (`libpcap`)[62], obtaining the source and destination IP address. The identification of AS number for each IP address is performed using the GeoLite ASN database, an IP-address-to-AS-network mapping database provided by MaxMind [57]. For the delay insertion, `dummynet`, a standard facility of FreeBSD, was applied which allows the emulation of bandwidth limitation, packet delay, and packet loss.

Figure 4.1 shows the overview of experimental setup. An Internet access line of 100 Mbps was served by Open Computer Network (OCN), a major internet service provider in Japan. The proposed router was placed to connect the Internet access line and the private network accommodating the P2PTV peers. A statistical measurement function was implemented in the proposed router to capture traffic statistics. For comparison, I evaluated the normal P2PTV application with no delay insertion (denoted as No delay control hereafter) and P2P-HDISTO added to ATO. Three PCs were configured as P2PTV viewer peers in the private network for the performance evaluation of the above three schemes implemented at the proposed router. Three peers played the same TV program to obtain fair experimental results. Furthermore, to obtain stable results under the condition that peers frequently join and leave the P2P network, I arbitrarily provided an additional two peers in the different ISPs from the viewer peer, which continuously played the same TV program throughout the experiments. The ISPs to which they connect are SoftBank Broadband(AS17676) and J:COM(AS9824), respectively, which are both in Japan.

Table 4.1: Devices specifications used in experiment.

	Delay Insertion Router	**Viewer Peers**
Connection	OCN FTTH 100 Mbps	LAN 100 Mbps
Operation System	FreeBSD 9.2	Windows 8
CPU	Intel Core i7 3.5 GHz	Intel Celeron 1.2 GHz
RAM	8 GB	2 GB

For evaluation in both the PPLive and SopCast applications, the maximum value of $delay_{ins}$ in ATO was set as fivefold of d_{unit} under the conditions of d_{unit} = 150 ms and d_{unit} = 300 ms, respectively. The values of parameters in the P2P-HDISTO scheme,$\in, \theta_1, \theta_2, \theta_3$ and the function of $d(peer_i, peer_o)$, were set equal to those presented in [22]. The time unit parameter of P2P-HDISTO, i.e., the maximum value of delay length (T_{max}), is configured as equal to the maximum value of $delay_{ins}$ in ATO for fair evaluation. In the evaluation of ATO and P2P-HDISTO, the delay insertion into P2P streaming packets is conducted in both the upload and download links.

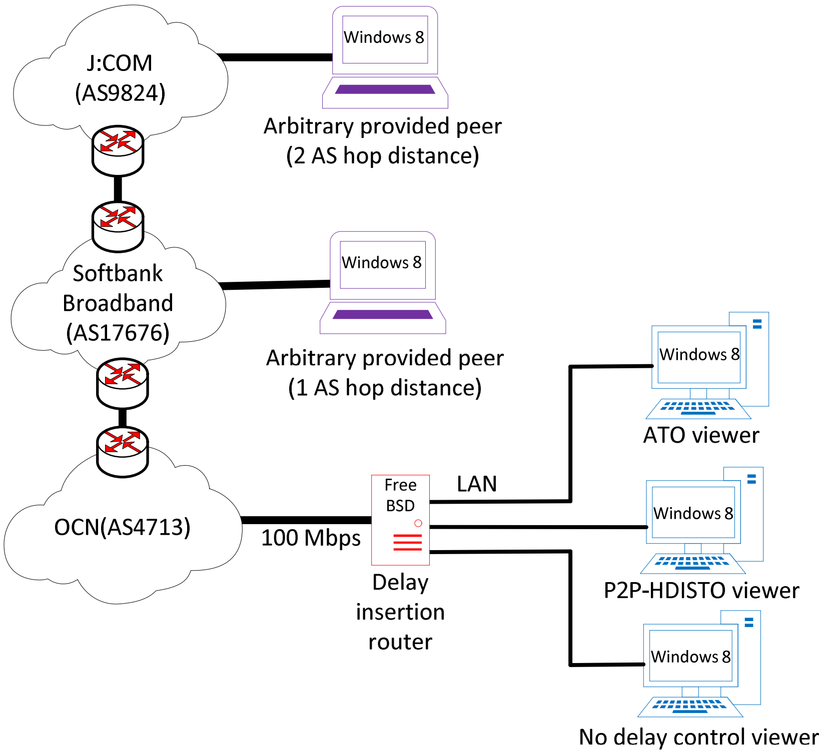
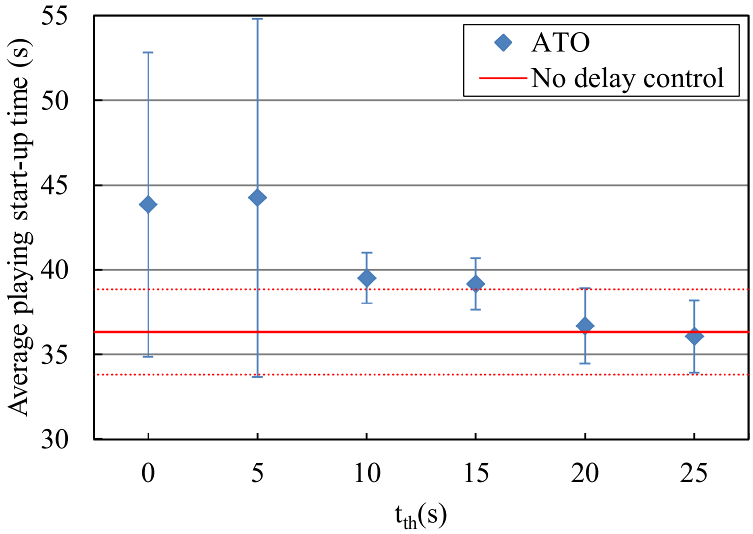


FIGURE 4.1: Experimental setup.

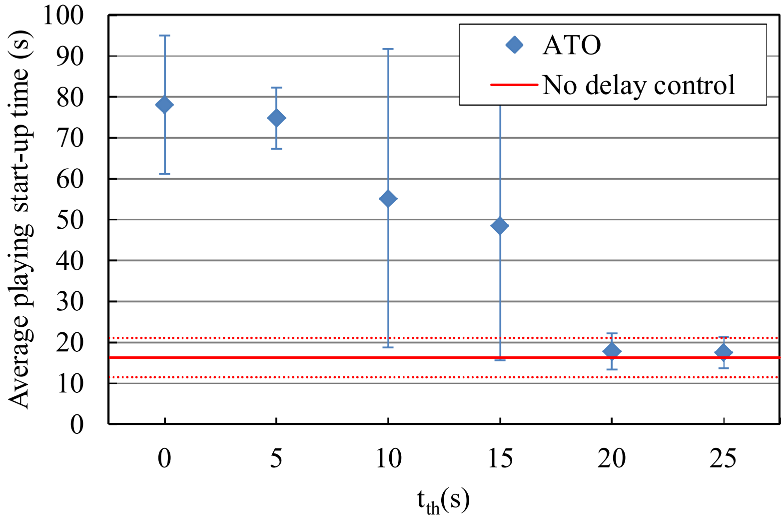
4.2 The Effect of Starting Time for Inserting Delay on the Playing Start-up Time

Figure 4.2 shows the average playing start-up time by varying the starting time for inserting delay (t_{th}) from 0 to 25 seconds. A stopwatch was used to measure the playing start-up time and averaged the results of 10 trials per each value of t_{th}. Each error bar represents the standard deviation. The solid and dotted lines represent, respectively, the average and average plus or minus standard deviation of playing startup time regarding the normal P2PTV system without any delay insertion, shown as No delay control. I set d_{unit} = 150 ms in this experiment. In the case where $t_{th} \leq 20s$, playing start-up time decreases according to the increase of t_{th} in the results of both PPLive and SopCast. When $t_{th} \geq 20s$, the scheme can effectively maintain the value of playing start-up time similar to that of the normal

P2PTV system. It can be concluded that setting t_{th} equal to or larger than 20 seconds is effective for maintaining the QoS in terms of playing start-up time. For the rest of the dissertation, I show the results of the proposed scheme with $t_{th} = 20$ s.



(a) PPLive



(b) SopCast

FIGURE 4.2: Effect of varying starting time for delay insertion (t_{th}) on the playing start-up time in P2PTV applications.

4.3 Traffic Result

This dissertation focus on the amount of P2PTV data received from the peers in the AS of $h = 0$, i.e., in the internal AS, and the amount of data received from the peers in the neighbor ASs ($h = 1$), referred to as the **low distance ASs** . On the other hand, other AS networks whose $h \geq 2$ are judged to be the **high distance ASs** network hereafter.

4.3.1 Traffic Result for PPLive Application

Figure 4.3 presents the cumulative amount of data received by the viewer peer versus the AS hop distance of each packet in each scheme while viewing PPLive programs. The total amount of data received from the peers with 0 AS hop distance is quite close between ATO and P2P-HDISTO. ATO substantially improves the amount of data received from the peers with 1 AS hop distance compared with P2P-HDISTO. To observe these results in detail, Table 4.2 shows an example of the inserted delay length when d_{unit} in ATO was set to 150 ms and T_{max} in P2P-HDISTO was set to 750 ms. As noted in Chapter 2, the delay value in P2P-HDISTO is determined according to whether the neighbor peer is in the same AS, the same ISP, and the same country as the viewer peer. Furthermore, the delay is increased depending on the physical distance between the ASs. As shown in the table, Softbank Broadband (AS17676) and J:COM (AS9824) are both in the same country as OCN, where the viewer peer is located. Thus, the amount of inserted delay d for the packets destined to the peers in both ASs is calculated by Equation 2.1: $d = \frac{T_{max}}{20000}(\theta_1 + \theta_2 + d(peer_i, peer_o))$.

The geographical distance from OCN to Softbank Broadband and J:COM is 10 and 60 km, respectively, and there is a large difference between them. However, the value of $\theta_1 + \theta_2$ is dominant compared with $d(peer_i, peer_o)$ in the above equation. Consequently, there was a small difference between calculated delay for these ASs; 62 ms was inserted into peers in Softbank Broadband and 64 ms was inserted into peers in J:COM. Then, the viewer peer connected with peers in both ASs with almost equivalent probability. In terms of AS hop distance, however, SoftBank Broadband

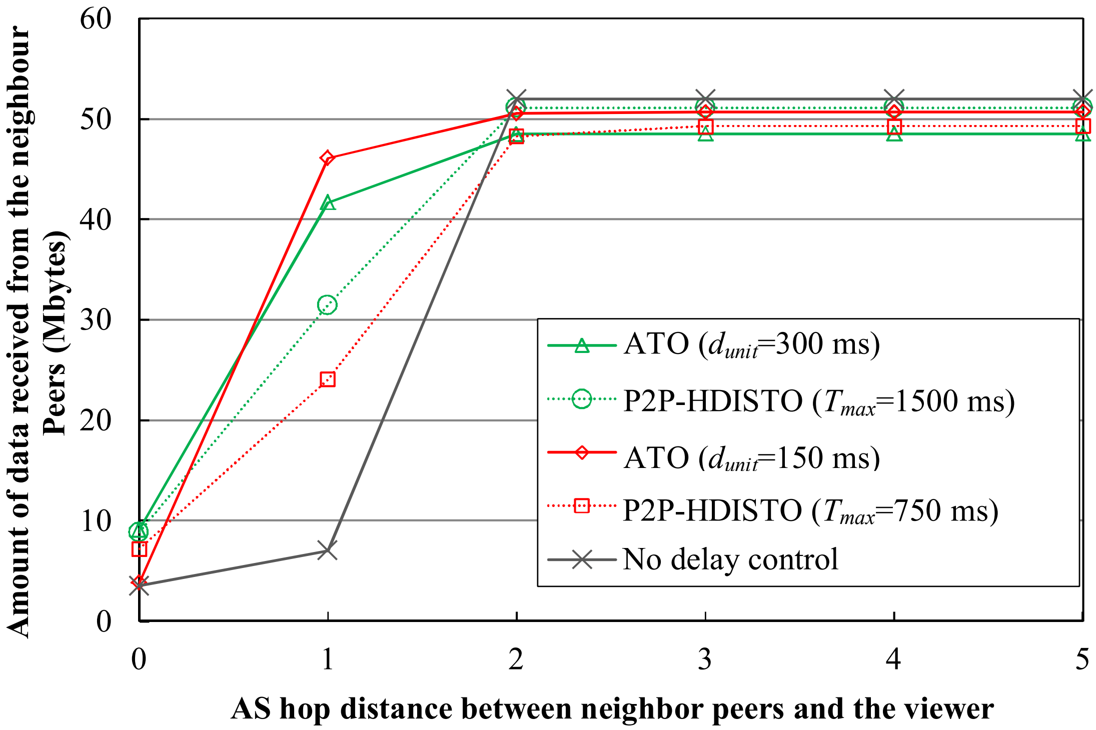


FIGURE 4.3: Cumulative amount of data received for PPLive application.

is 1 hop and J:COM is 2 hops from OCN. These account for the results of P2P-HDISTO shown in Figure 4.3, in which the amount of video data the viewer peer downloaded from the peers with 1 AS hop distance was close to the video data downloaded from peers of 2 AS hop distance.

In contrast, in ATO, the value of inserted delay to the packets is purely proportional to AS hop distance. The AS hop distance of Softbank Broadband and J:COM from OCN are 1 and 2 hop, respectively, so the delay inserted to the packets destined to these peers were set to 150 ms and 300 ms. Thus, the viewer peers connected with and download data from peers in Softbank Broadband with higher probability than peers in J:COM, and the data received from 1 AS hop distance is dominant in ATO, as shown in Figure 4.3.

Next, I vary the value of d_{unit} in ATO from 50 ms to 300 ms to evaluate its

TABLE 4.2: An example of inserted additional delay length for PPLive application when d_{unit}=150 ms and T_{max} = 750 ms.

Country		Japan			China	
ISP		Open Computer Network	Softbank Broadband	J:COM	China-net	China Unicom
AS number		4713	17676	9824	4134	17816
Geographical Distance from the viewer peer (km)		0	10	60	3273	2911
AS hop distance (hop)		0	1	2	2	3
Delay value (ms)	P2P-HDISTO	0	62	64	299	248
	ATO	0	150	300	300	450

effect on traffic localization. In each condition of d_{unit}, T_{max} in P2P-HDISTO is set to be equal to the maximum value of $delay_{ins}$. I introduce a new metric called the normalized AS hop distance for easier evaluation and comparison of localization. The normalized AS hop distance $h_{normalized}$ is defined as

$$h_{nomorlized} = \frac{\sum_{h=0}^{h_{max}} (h \times S_h)}{S_{total}} \tag{4.1}$$

Here, S_h is the total amount of data that the viewer peer downloaded from peers that were h AS hop distance away from the viewer peer. h_{max} is the maximum value of h, and S_{total} is the total size of data that the viewer peer downloaded from all peers. Figure 4.4 shows the results of the normalized AS hop distance versus the value of maximum $delay_{ins}$ and T_{max} in ATO and P2P-HDISTO, respectively, while viewing PPLive programs. The normalized AS hop distance ATO scheme is lower than P2P-HDISTO for all the value of maximum $delay_{ins}$ and T_{max}. The effective range of maximum $delay_{ins}$ values is from 500 to 1000 ms which ATO scheme can reduce around 30% of $h_{normalized}$ compared to the existing P2P-HDISTO scheme.

Figure 4.5 shows the throughput of each scheme over elapsed time. The graph represents download throughput from the neighbor peers that were h AS hop distance away from the viewer peer. ATO substantially increases the amount of received

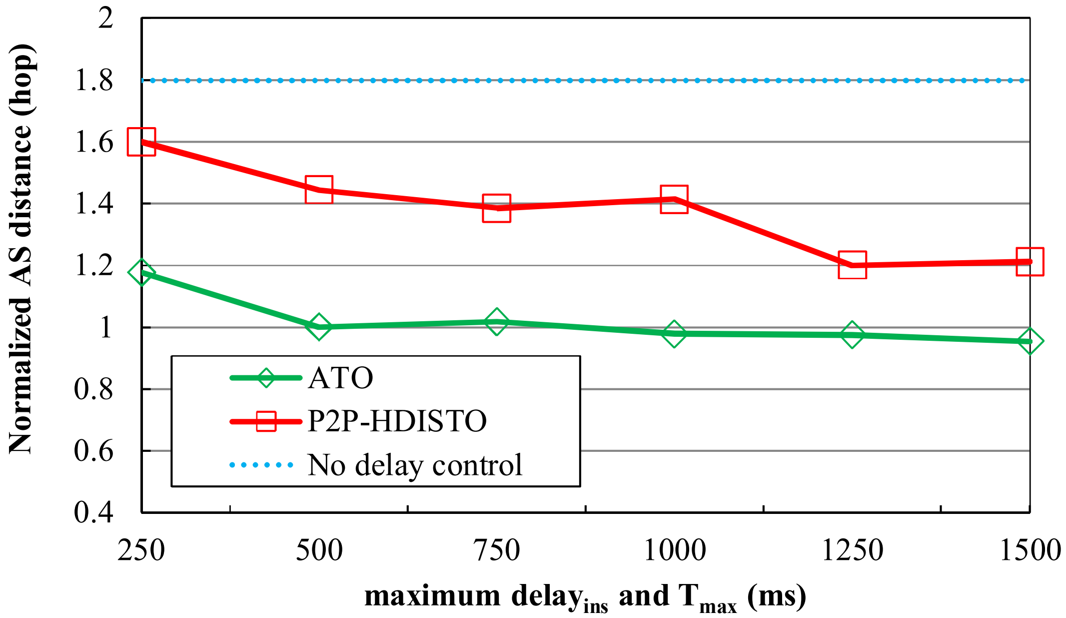
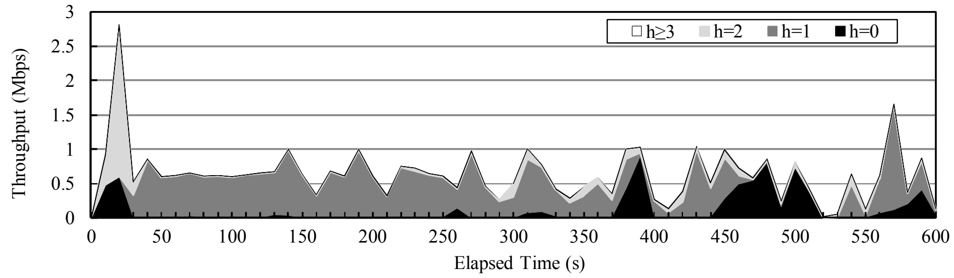
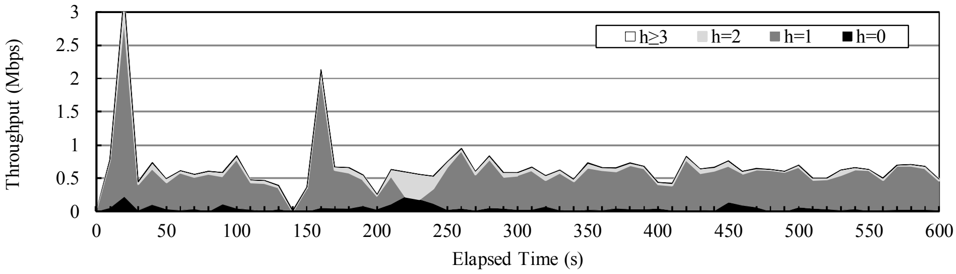


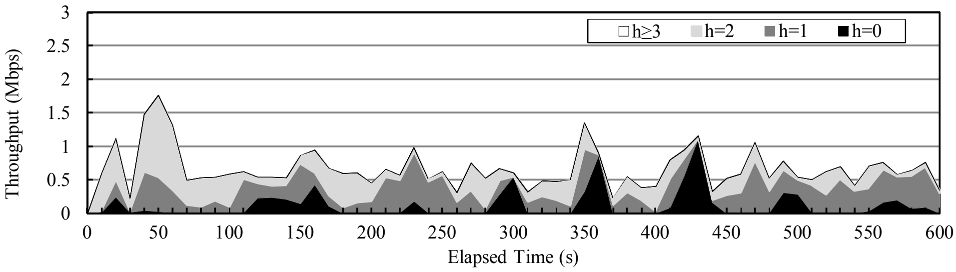
FIGURE 4.4: Normalized AS hop distance versus amount of delay insertion in PPLive application.



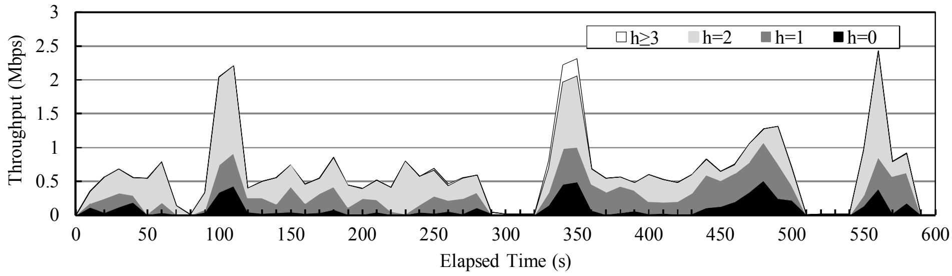
(a) ATO (d_{unit} = 300 ms, maximum $delay_{ins}$ = 1500 ms)



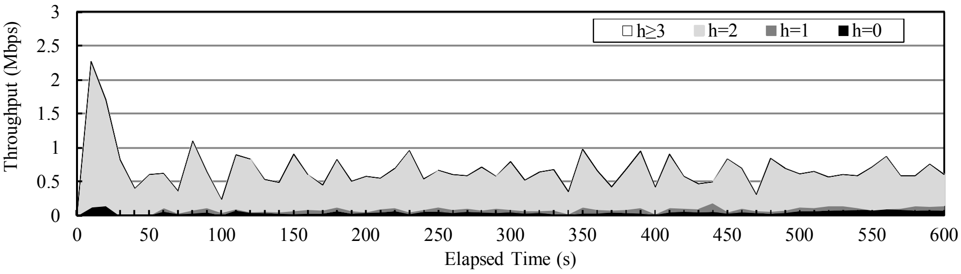
(b) ATO (d_{unit} = 150 ms, maximum $delay_{ins}$ = 750 ms)



(c) P2P-HDISTO (T_{max}= 1500 ms)



(d) P2P-HDISTO (T_{max}= 750 ms)



(e) No delay control

FIGURE 4.5: Download throughput in PPLive application.

throughput from the peers in the low distance ASs compared with P2P-HDISTO and No delay control, as shown in Figure 4.5(a)-(e).

Regarding the received video quality, the proposed scheme maintained good quality in the case of $d_{unit} = 150$ ms, whereas I found quality degradation in the case of d_{unit} =300 ms. The video quality is evaluated in detail and discussed in Section 4.4.

4.3.2 Traffic Results for SopCast Application

Figure 4.6 presents the cumulative amount of data received by the viewer peer versus the AS hop distance in each scheme while viewing SopCast programs. As with the results for PPLive, ATO substantially improves the amount of data received from the peers with 1 AS hop distance compared with P2P-HDISTO. Table 4.3 shows an example of inserted delay length, in which d_{unit} is 150 ms and T_{max} is 750 ms. As for PPLive, there was a small difference in the calculated delay lengths for Softbank Broadband and J:COM in P2P-HDISTO: 54 ms and 56 ms, respectively. Thus, the viewer peer connected with peers in both ASs with almost equivalent probability. Thus, the amounts of data received from peers in 1 and 2 AS hop distance networks are close to each other.

TABLE 4.3: An example of inserted additional delay length for SopCast application when d_{unit}=150 ms and T_{max} = 750 ms.

<table>
<tr><td colspan="2">Country</td><td colspan="3">Japan</td><td>China</td><td>Canada</td></tr>
<tr><td colspan="2">ISP</td><td>Open Computer Network</td><td>Softbank Broadband</td><td>J:COM</td><td>CNC Group</td><td>Canaca Com INC.</td></tr>
<tr><td colspan="2">AS number</td><td>4713</td><td>17676</td><td>9824</td><td>4837</td><td>33139</td></tr>
<tr><td colspan="2">Geographical Distance from the viewer peer (km)</td><td>0</td><td>10</td><td>60</td><td>1571</td><td>10345</td></tr>
<tr><td colspan="2">AS hop distance (hop)</td><td>0</td><td>1</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td rowspan="2">Delay value (ms)</td><td>P2P-HDISTO</td><td>54</td><td>56</td><td>147</td><td>665</td><td>248</td></tr>
<tr><td>ATO</td><td>0</td><td>150</td><td>300</td><td>300</td><td>450</td></tr>
</table>

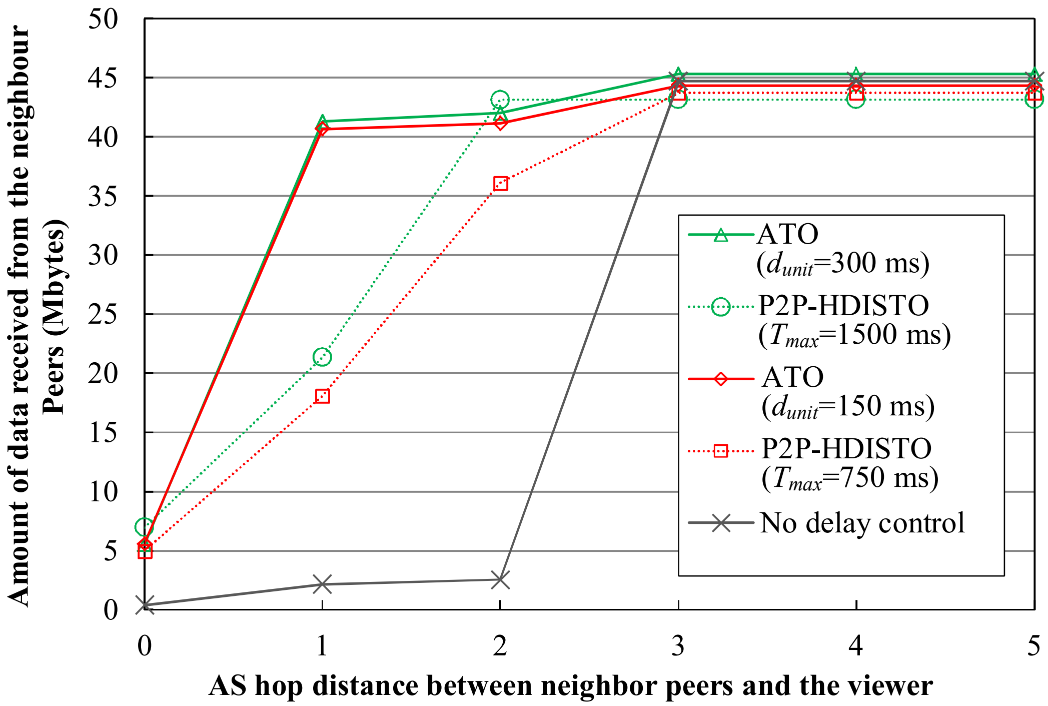


FIGURE 4.6: Cumulative amount of data received for SopCast application.

In ATO, delay length is calculated in proportion to AS hop distance, and delay of 150 ms and 300 ms was inserted into the packets from peers located in Softbank Broadband and the J:COM network, respectively. Thus, video data were downloaded from peers in Softbank Broadband with higher probability than peers in J:COM, and the data received from 1 AS hop distance away was thus higher than that from 2 AS hop distance away.

Figure 4.7 shows the normalized AS hop distance versus each value of d_{unit} while viewing SopCast programs. The value of normalized AS hop distance in both ATO and P2P-HDISTO decrease with increasing maximum $delay_{ins}$ and T_{max}, respectively; however, the value of normalized AS hop distance in ATO is lower than that in P2P-HDISTO for every value of maximum $delay_{ins}$ and T_{max}. The value of maximum $delay_{ins}$ = 750 is the most effective value which can reduce $h_{normalized}$

around 38% compared to the existing P2P-HDISTO scheme. Throughput evaluation is presented in Figure 4.8. These graphs also show the improvement of traffic localization by ATO compared with P2P-HDISTO and No delay control scheme. ATO localize download almost data received within low distance ASs. Moreover, the degree of traffic localization depends on the parameter d_{unit}. The amount of data received from the low distance ASs increases with increasing d_{unit}, while the amount of data received from the peers with high distance ASs, $h \geq 2$, is reduced.

With these results, it can be concluded that the proposed ATO achieves a finer-grained traffic localization in terms of reducing AS hop distance of the neighbor peers to which the viewer peer connects compared with the existing P2P-HDISTO, which leads the P2PTV application to download streaming content from peers in the internal AS, in the same ISP, in the same country and with lowest geographical distance.

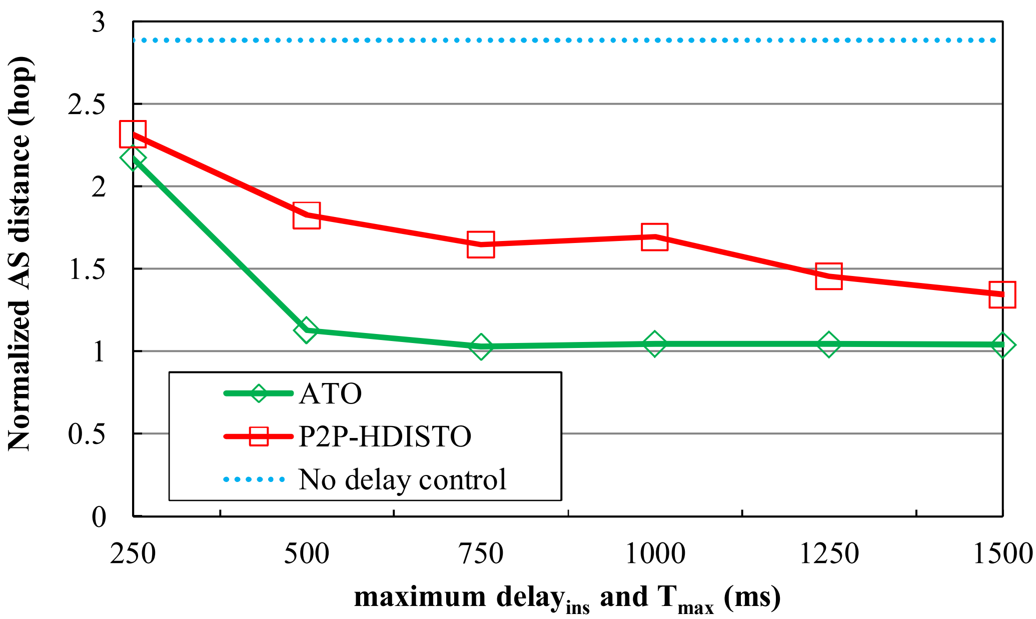
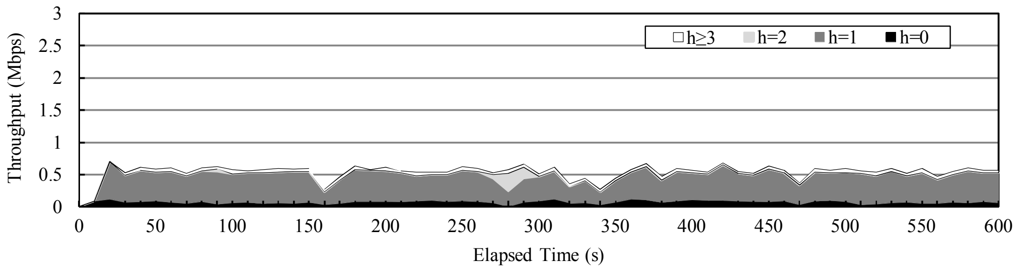
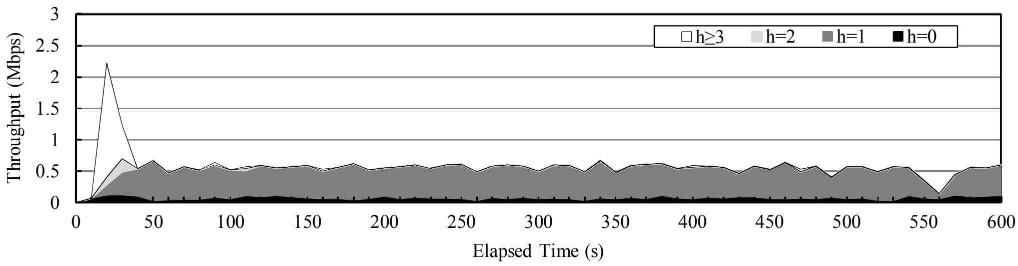


Figure 4.7: Normalized AS hop distance versus amount of delay insertion in SopCast application.

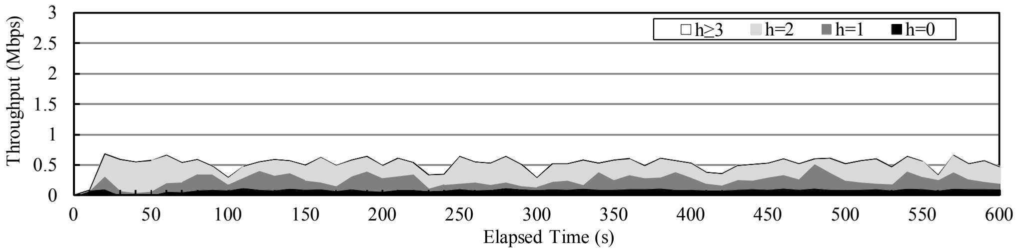
Similar to the case of PPLive, video degradation is detected in the case of d_{unit} = 300 ms. The topic of video quality is discussed in the next section.



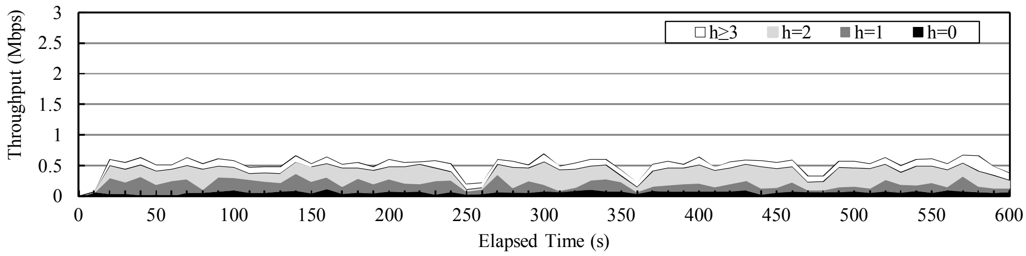
(a) ATO (d_{unit} = 300 ms, maximum $delay_{ins}$ = 1500 ms)



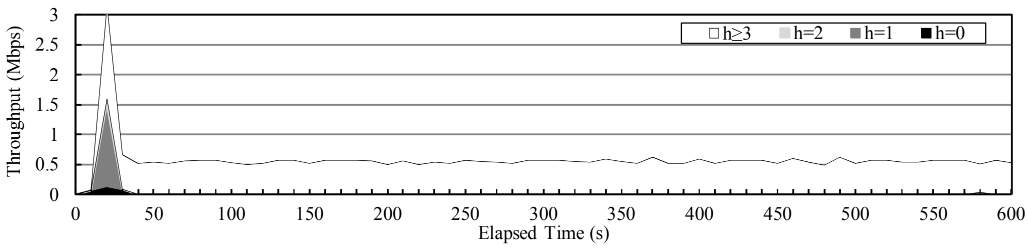
(b) ATO (d_{unit} = 150 ms, maximum $delay_{ins}$ = 750 ms)



(c) P2P-HDISTO (T_{max}= 1500 ms)



(d) P2P-HDISTO (T_{max}= 750 ms)



(e) No delay control

FIGURE 4.8: Download throughputs in SopCast application.

4.4 Video Quality Evaluation

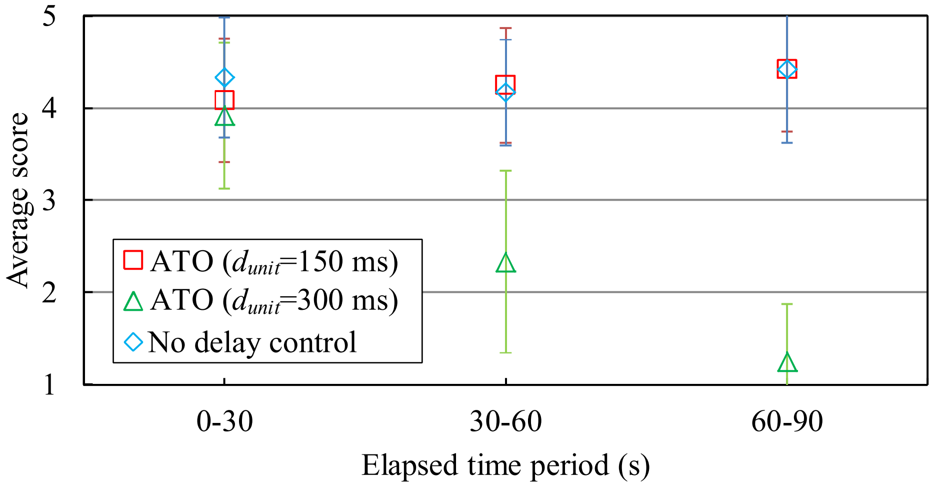
Degradation Mean Opinion Score (DMOS) [63] was used to evaluate the quality of video downloaded using the No delay control scheme and the ATO scheme, with d_{unit} = 150 and 300 ms. A video screen of 90 seconds duration from P2PTV applications was captured from when the playing started and separated them into 3 parts that were each 30 seconds in length. There were 10 subjects who watched each part of the captured video. Subsequently, he/she evaluated the quality of the video downloaded by each scheme in terms of degradation using the ratings shown in Table 4.4.

Table 4.4: Rating Scale for Video Evaluation.

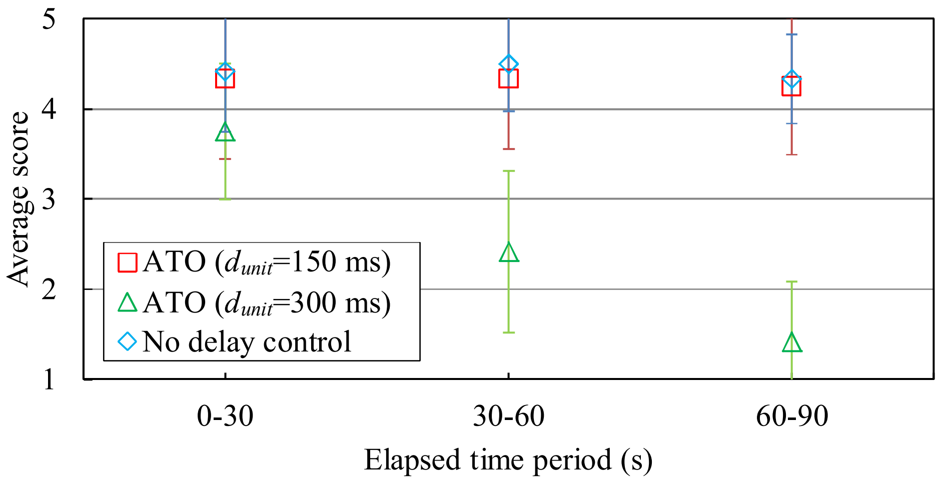
Level	**Description**
5	Imperceptible
4	Perceptible but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

[63]

Figure 4.9 presents the results of video quality evaluation in the PPLive and SopCast applications. The error bars represent standard deviation. In ATO with the d_{unit}= 150 ms scheme, the average rating score is close to the No delay control scheme for every elapsed time period. When d_{unit} = 300 ms, the average rating score of the first period in ATO is satisfactory because there is sufficient buffer during postpone time before inserting delay (t_{th}=20 s). However, the effect of delay insertion appeared after the first period (30 sec), and the rating score fell into the worst level in the third period. This result shows that d_{unit} = 300 ms brings serious video quality degradation, though this delay condition can efficiently localize traffic, as shown in Section 4.3. Thus, d_{unit} should be set to less than 300 ms.



(a) PPLive application



(b) SopCast application

FIGURE 4.9: Rating score of video quality in P2PTV applications from ATO and existing schemes.

4.5 CPU utilization Evaluation

Figure 4.10 shows the CPU utilization of the delay insertion router while each traffic localization scheme (ATO, P2P-HDISTO, and No delay control) runs by varying the number of the viewer peers connected to the router and simultaneously starting the video. As shown in the graph, there is a linear relationship between the number of viewer peers connected to the router and the CPU utilization in each scheme. The CPU utilization both in P2P-HDISTO and ATO increases compared with that in No delay control. P2P-HDISTO scheme consumes highest CPU utilization among all scheme because of its delay table update process. The ATO scheme can greatly reduce CPU utilization compared to P2P-HDISTO scheme. From the linear formula of the ATO scheme, it can be estimated that the delay insertion router can support 4188 users if the CPU utilization threshold is set at 80%. Memory buffer of the delay insertion router is estimated by simply calculating using the average data rate of the PPLive and SopCast applications. The ATO scheme consumes 61.3 and 46.1 MB of memory, respectively, when supporting the maximum amount of users and setting the maximum $delay_{ins}$ at 750 ms.

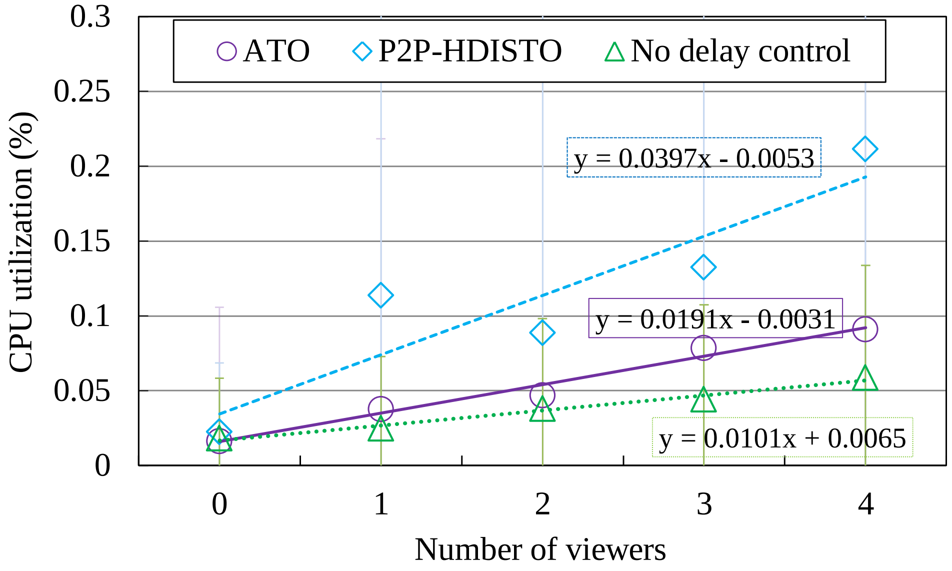


FIGURE 4.10: CPU utilization of delay insertion router.

4.6 Conclusion

A novel decentralized traffic localization scheme for P2PTV applications was presented, in which the ISP's edge routers insert an additional delay for P2P streaming packets depending on the AS hop distance between peers to induce the establishment of logical links between peers with lower AS hop distances. This experiments showed that applying the proposed ATO scheme led each peer downloaded streaming packets from neighbor peers in the internal AS or ASs with smaller AS hop distances. The ATO scheme achieved efficient P2PTV traffic localization and maximally improved 38% of traffic locality in the AS hop distance domain compared to the existing P2P-HDISTO scheme. Moreover, it was confirmed that the proposed ATO scheme can avoid increasing the playing start-up time by postponing the start of delay insertion for a predetermined time duration after detecting a new connection with any new neighbor peer. Additionally, it was confirmed that the quality of service is still maintained when inserting the optimized value of delay. The proposed scheme does not exploit the behavior of specific P2PTV services and can be applied to new services without modification of the software at each peer or at the streaming server. Additionally, in terms of deployment, the adoption of this scheme only by ISPs that need to reduce inter-AS traffic is sufficient to achieve the benefit for the ISPs, and collaboration with other ISPs is not necessary.

However, this ATO scheme consider only physical precise network between a pair of source and destination peer without relaying capability consideration. It assumes that every peer has sufficient capability for relaying video data to other peers. When the ATO scheme leads a peer to connect to a low available uplink bandwidth neighbor peer that is close to itself. The neighbor peer cannot provide sufficient uplink bandwidth to support P2PTV streaming data and other applications' traffic simultaneously. It is necessary to incorporate the factor of estimated relay capability into the delay value calculation formula. The evaluation of the video quality when this approach is applied will also be a prominent issue.

Chapter 5

Traffic Localization Considering Precise Network Information and Relay Capability

5.1 Limitation of ATO

The proposed traffic localization scheme in Chapter 3 (ATO scheme) which inserts the additional delay into P2PTV packets proportional to AS hop distance between a pair of source and destination peers can efficient realize traffic locality. The delay value of ATO scheme which is calculated from equation 3.1 can lead P2PTV application to consider local neighbor peers for making the connection. The newly joining peers which belong to the proposed delay insertion router can download most of streaming data from neighbor peers placed at the same AS network or the low distance AS networks.

The conventional delay-insertion-based traffic localization schemes, including ATO, have the common problem. They consider only geographical or physical network distance between peers without relay capability consideration as shown in

Figure 5.1. In this dissertation, the peer which join the P2PTV session with low-performance devices or via the low-speed connection will be defined as the **low-relay-capability peer**. In contrast, peers in other conditions will be defined as the **high-relay-capability peer** hereafter. The low-relay-capability peers are not appropriate for relaying video data, however, they are close to the newly joining peer. Without any relay capability consideration, the localization schemes drive the newly joining peer mainly to connect to local upstream peers for downloading streaming data. These peers have to relay streaming data for the newly joining peer. The device's performance or upload bandwidth resource of the upstream peers may be insufficient for serving P2PTV and other applications' traffic simultaneously. The operation of other applications can be disturbed because of this insufficient available resource.

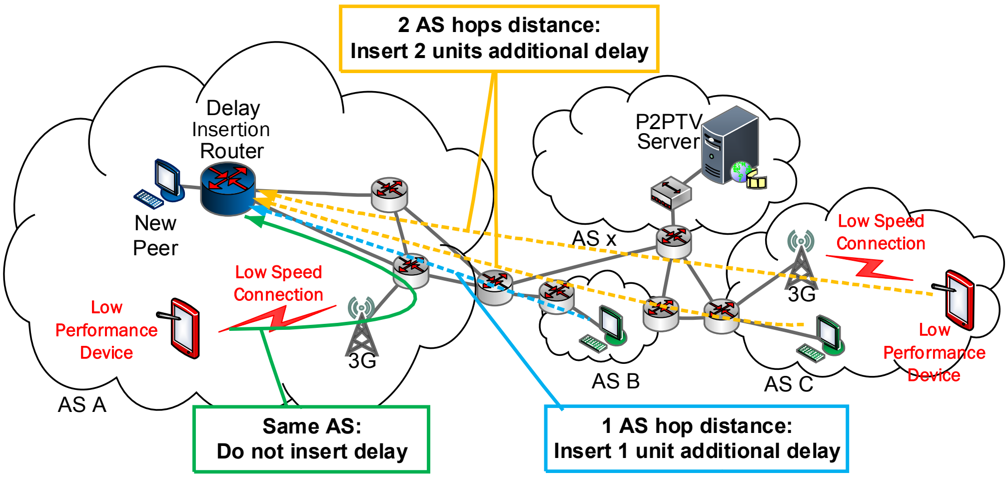


FIGURE 5.1: Limitation of ATO scheme which insert delay proportional to AS hop distance without relay capability consideration.

From limitations described above, the traffic localization scheme needs to consider not only physical network distance, but also relay capability of neighbor peers. In addition, the direction of relayed streaming data should be considered to avoid upload streaming data from the low relay capability peers which have the limitation in uplink bandwidth resource or processor performance.

5.2 Conceptual Framework

The proposed scheme presented in this chapter is developed from ATO scheme in Chapter 3. This proposed scheme named **Localization considering Relay Capability and AS hop Distance (LoRCAD)** which localizes P2PTV traffic considering peers' relay capability, the direction of streaming data and the AS-hop distance between a pair of source and destination peers simultaneously. The major objective of the LoRCAD scheme is to manage uplink bandwidth usage for the low-relay-capability peer which aim to save available uplink bandwidth as much as possible. The proposed delay insertion router attempts to realize traffic locality and to avoid the newly joining peer download streaming data from the low-relay-capability source peer and also to allow existing viewer peers in the P2PTV network to upload data to the low-relay-capability destination peer simultaneously. The concept of LoRCAD scheme is briefly described as follows.

5.2.1 Operation of the Router to Video Data Packet

In the LoRCAD scheme, the direction of video data is one of the conditions to calculate additional delay. The router can detect video packet delivered between a pair of source and destination peer and estimate video streaming direction. The router calculates delay insertion under conditions of the relay capability and the video streaming direction. The traffic localization can be considered on the high-relay-capability peers which have satisfy resources. On the other hand, the low-relay-capability peers are differently operated for maintaining their available bandwidth and CPU workload. There are two examples which are different relay capability of the newly joining peer placed belonging to the router.

• **The operation when detecting the high-relay-capability newly joining peer:** Figure 5.2 illustrates the concept of LoRCAD scheme when the newly joining peer is the high-relay-capability peer. In order to have video data delivered from any high-relay-capability source to destination peers, the delay insertion router tries to localize traffic. For traffic from any low-relay-capability neighbor peers, the router tries to lead other peers to avoid downloading video data from these peers without AS hop distance consideration for preventing these data by inserting a large amount of additional delay into packets. The proposed LoRCAD scheme aims to lead P2PTV application to connect to the neighbor peers in as small AS hop distance as possible while avoiding relaying streaming data from the low-relay-capability neighbor peer which can realize traffic localization and save available uplink bandwidth at the low-relay-capability peer simultaneously.

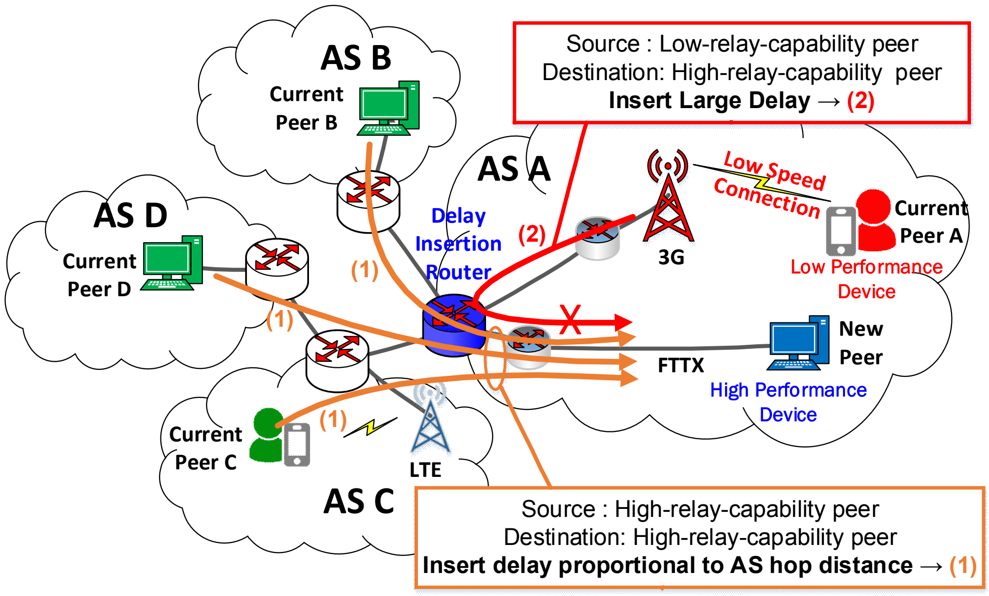


FIGURE 5.2: Operation of the delay insertion router when detecting the high-relay-capability peer.

• **The operation when detecting the low-relay-capability newly joining peer:** The proposed LoRCAD scheme in this chapter also considers the low-relay-capability newly joining peers which have the limitation in terms of available bandwidth on the paths or relaying performance of peer's devices. As shown in Figure 5.3, the new viewer is the low-relay-capability peer which is a low-performance device and has limited bandwidth to access the Internet via wireless 3G connection. The proposed delay insertion router will avoid inserting delay into streaming packets if detecting P2PTV streaming data sent from high-relay-capability source peer to low-relay-capability destination peer. With this function, the low-relay-capability

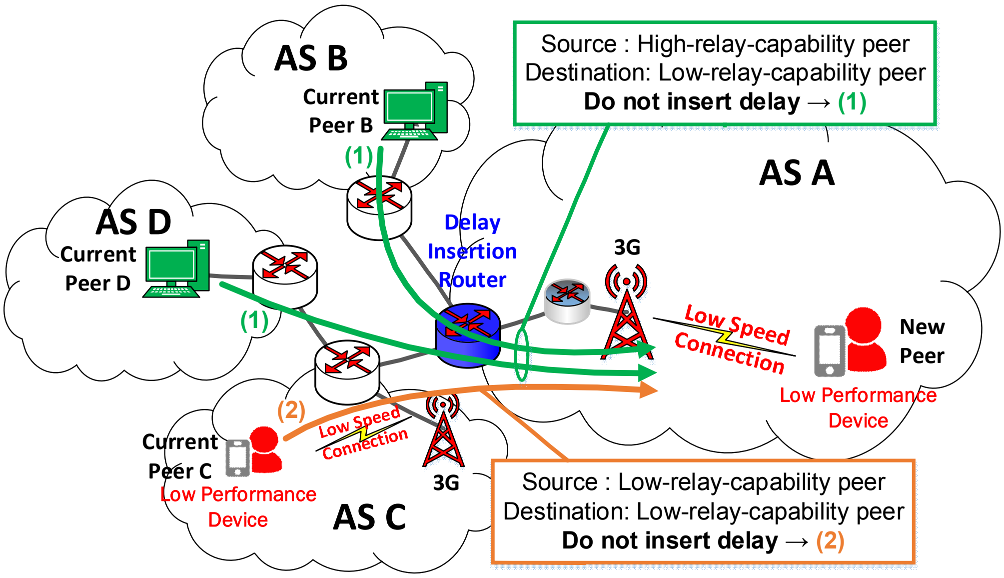


FIGURE 5.3: Operation of the delay insertion router when detecting the low-relay-capability peer.

destination peer can normally connect to and download data from the high-relay-capability source peer. In the case that both source and destination peers have low-relay-capability, the router also allows data between these peers by avoiding delay insertion. With these functions, LoRCAD scheme can realizes traffic locality, avoids data being relayed from the low-relay-capability source peer to the high-relay-capability destination peer and allows relaying data from both high and low relay-capability source peers to the low-relay-capability destination peers simultaneously.

5.3 Methodology

To realize functions mentioned in Section 5.2, relay capability estimation function and streaming direction detection function are newly developed. Using estimated relay capability and streaming direction information, the additional delay will be calculated and inserted into P2PTV packets.

5.3.1 Time Sequence of the LoRCAD Scheme when Deployed to P2P Application

Based on the control sequence for neighbor peer discovery explained in Chapter 2, Figure 5.4 presents time sequence for neighbor peer discovery while deploying the LoRCAD scheme into the delay insertion router. The original processes of P2PTV system and the additional process by the LoRCAD router are represented by Roman and Arabic items respectively. The detail of the time sequence under condition that the new viewer peer belongs to the LoRCAD router is explained as follows:

(I) The new viewer peer requests peer list from P2PTV server and then the server responses peer list.

(II) The new viewer peer sends hello packet to existing viewer peer in the list after that the hello packet is replied back.

(1) The delay insertion router detects the hello packet and captures source and destination IP address from the header. Then, it estimates AS hop distance between this pair of peers.

(2) The delay insertion router estimates relay capability to the new viewer peer and the existing viewer peer by sending ICMP packets.

(III) The new viewer peer requests video data to the existing viewer peer. Then, the existing viewer peer sends video data to the new viewer peer.

(3) The router estimates video streaming direction from video data packet.

(4) The router calculates additional delay by considering AS hop distance, relay capability and video streaming direction information.

(5) The router postpones inserting the delay into packet between this pair of peers until the present time is after t_{th} to solve a problem about playing start-up time as evaluated in Chapter 4.

(6) The delay insertion router inserts the additional delay into packets between this pair of peers.

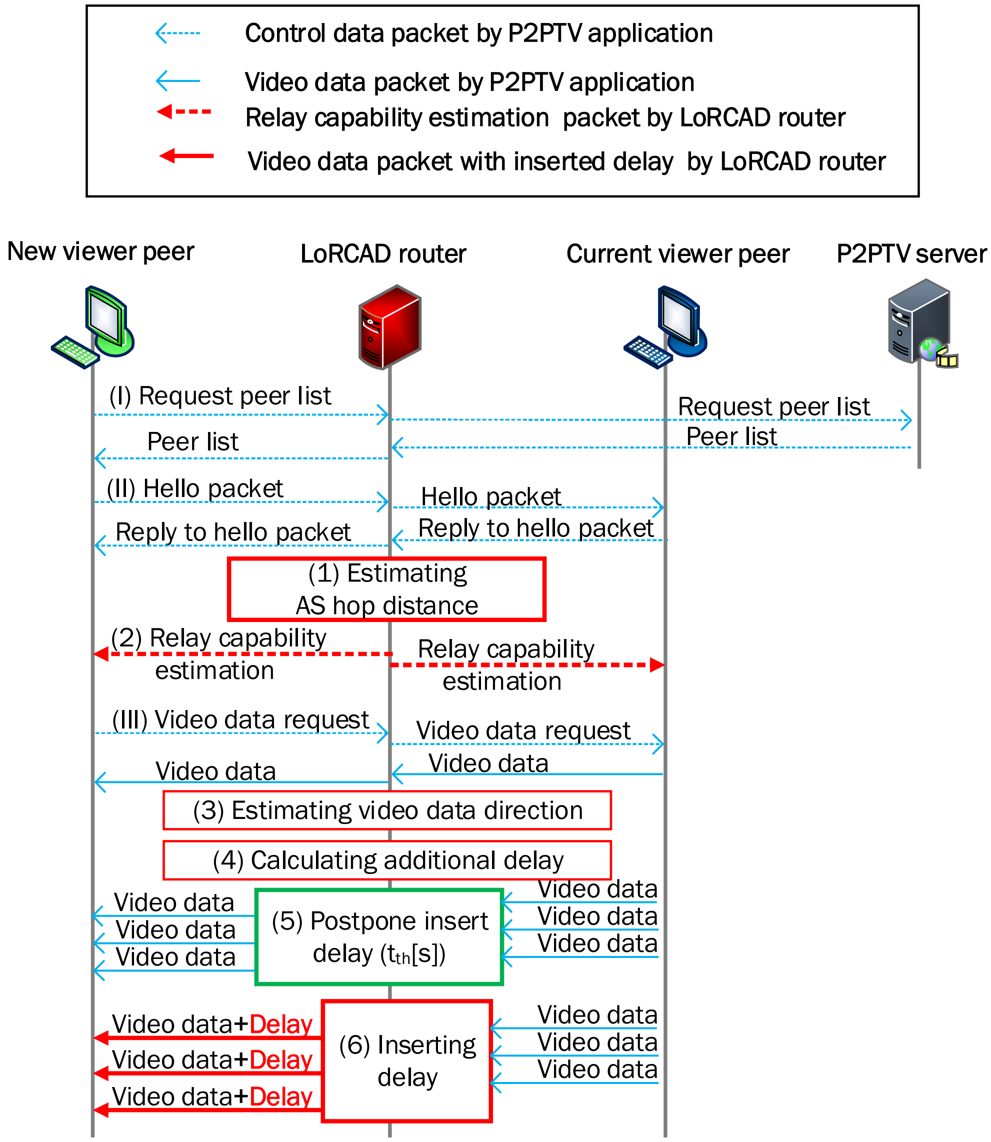


FIGURE 5.4: Time sequence of the LoRCAD Scheme when deployed to P2P application.

5.3.2 Flow Chart of the LoRCAD Scheme

The operation of LoRCAD is illustrated by a diagram in Figure 5.5. To be the comprehensive description, the whole process of LoRCAD is described in this subsection. The newly introduced functions in LoRCAD compared to ATO are the process of relay capability estimation. Firstly it classifies input packets into P2PTV packets and non-P2PTV packets and the following processes are applied only to P2PTV packets. It extracts source and destination IP address and checks that the AS hop distance and the relay capability of this address pair have already been determined. If not, it forwards the packet to the process of AS hop distance and the relay capability estimation. AS number which the destination IP address belongs to is identified. After that, AS hop distance can be estimated in the same way as ATO mentioned in Chapter 3. Then, it estimates relay capability of the destination peer. Once the relay capability to destination peer is estimated, the router detects the video streaming direction between this address pair and then calculate $delay_{ins}$. The amount of delay $delay_{ins}$ which is determined based on the AS hop distance, the results of relay capability estimation and the video streaming direction will be described in Subsection 5.3.4. The router inserts delay into every packet delivered between a pair of peers if the present time is after t_{th} and forwards the packet. The t_{th} is the postpone time for inserting the delay into the packet for solving the problem about playing start-up time.

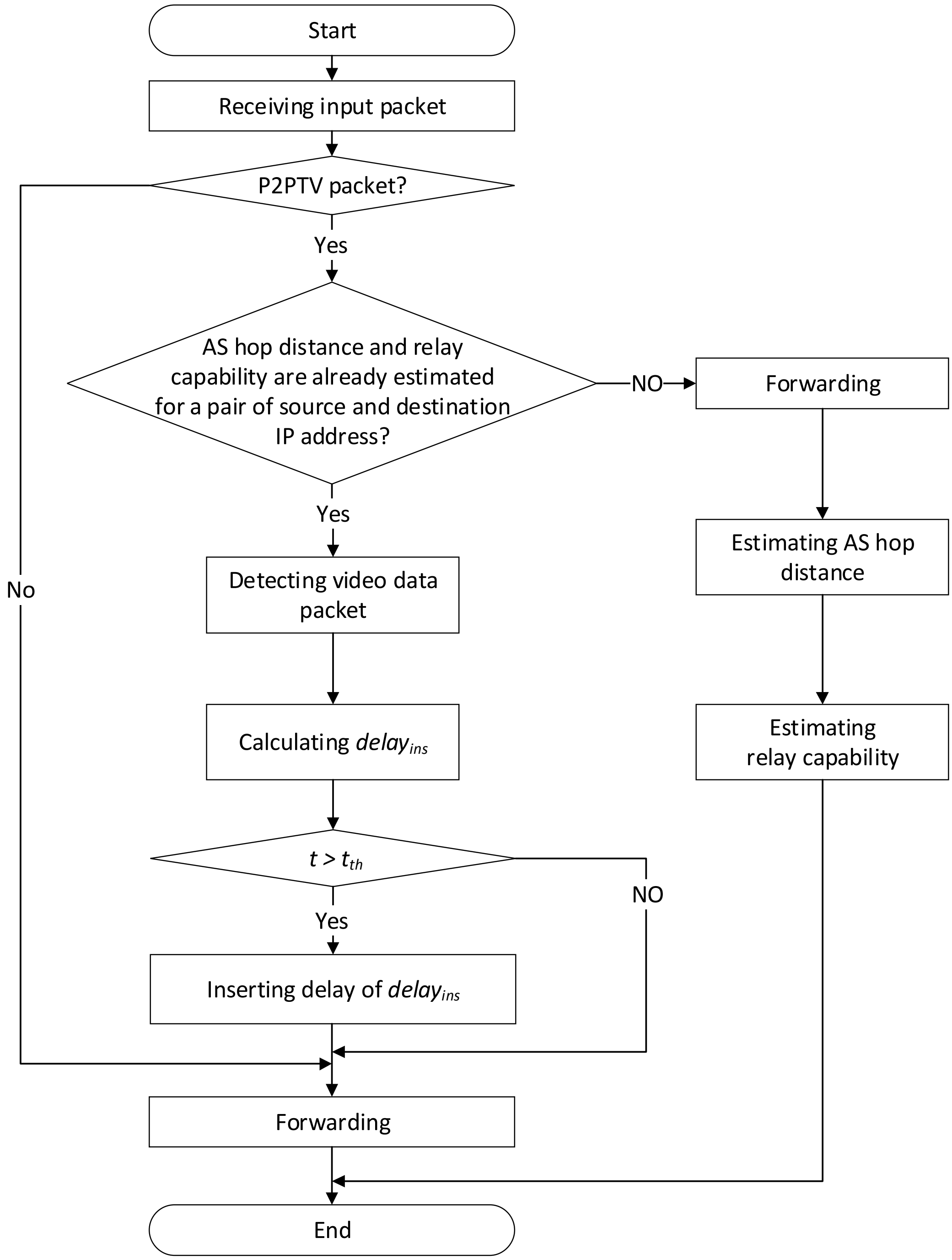


FIGURE 5.5: Flow chart of delay insertion into P2PTV packet by the proposed LoRCAD scheme.

5.3.3 Relay Capability Estimation Method

In P2PTV applications, measuring relay capability or available bandwidth between peers is not trivial because client nor server functions to measure throughput such as FTP are not built in each peer. Although a bandwidth estimation scheme using TCP packets was presented for large networks [64], this method will not be suitable for applying to delay insertion based traffic localization scheme because it requires information of the precise absolute time at which each packet arrives at the destination peer.

The proposed LoRCAD scheme deploys relay capability estimation method using frequently transmitting ping packets and observing response packets as illustrated in Figure 5.6. Definitions of notation in relay capability estimation method are presented in Table 5.1. The delay insertion router sends ping packets with the length of L bytes to the destination peer by N_{sent} times. The sending time interval between each ping packet is denoted by T_{int}. $TIME\_S$ and $TIME\_E$ denote the time when the first and the last ping response packet come back to the delay insertion router respectively. The number of ping response packets the router receives from the $TIME\_S$ and $TIME\_E$ is denoted by $N_{received}$. The relay capability to the destination RL_{cap}[bps] can be estimated by using equation (5.1).

Table 5.1: Definitions of notations in relay capability estimation method.

Notations	**Definitions**
L	Length of ping packet (byte)
T_{int}	Time interval between each ping packet (ms)
N_{sent}	Number of ping packets sent to the estimated peer (packet)
$Time\_S$	Time when the first ping response packet arrived at the delay insertion router (s)
$Time\_E$	Time when the last ping response packet arrived at the delay insertion router (s)
$N_{received}$	Number of ping response packets arrived at the delay insertion router (packet)
RL_{cap}	Estimated relay capability to the peer of $IP(i)$ by the router (bps)
B_r	Data rate of video played (bps)

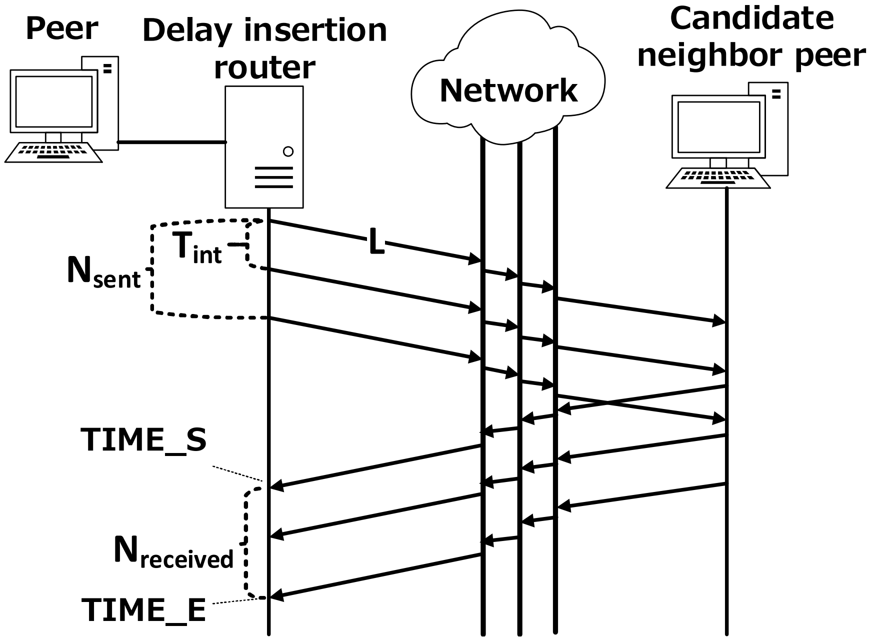


FIGURE 5.6: Relay capability estimation mechanism.

$$RL_{cap}[bps] = \frac{N_{received}[packet] \times L[byte] \times 8}{TIME\_E[s] - TIME\_S[s]} \tag{5.1}$$

The value of RL_{cap} calculated from equation (5.1) can indicate relay capability of destination peers in term of available bandwidth and available processor performance. For example, a low CPU performance terminal slowly responds to ping packets from the delay insertion router although connected to the high-speed access line.

According to the value of RL_{cap}, the system classifies peers into either high-relay-capability peers or low-relay-capability peers. The delay insertion router can detect the video played data rate B_r of the P2PTV program from a statistical measurement function which is built into the router to capture traffic statistics. Then, the router defines referenced bandwidth value as the double of the video played data rate $2 \times Br$ and distinguishes high/low-relay-capability peers. The estimated peer is a high-relay-capability peer when estimated relay capability RL_{cap}

is larger than $2 \times Br$[bps] and it is a low-relay-capability peer when RL_{cap} is equal to or smaller than $2 \times Br$[bps].

5.3.4 Determination of Delay Amount ($delay_{ins}$)

Using relay estimation information and video streaming direction information obtained by the method mentioned in Subsection 5.3.3, the LoRCAD scheme judges the condition and calculates the amount of additional delay for inserting into P2PTV packet. Notations used in this section are defined in Table 5.2. The amount of delay inserted to the packets from or to the each neighbor peer is determined as follows.

Table 5.2: Definitions of notations for delay insertion calculation.

Notations	Definitions
$delay_{ins}$	The amount of delay inserted to the data packets destined to the peer (ms)
h	AS hop distance from the router to the peer
d_{unit}	Constant time unit configured depending on the characteristics of the underlying networks or P2PTV services (ms)
$delay_{insmax}$	Predefined maximum amount of $delay_{ins}$ (ms)

$$delay_{ins} = \begin{cases} 0 & \text{if do not detect any video data delivered between a} \\ & \text{pair of peers} \\ delay_{insmax} & \text{if video data delivered from a low-relay-capability} \\ & \text{source peer to a high-relay-capability destination peer} \\ 0 & \text{if video data delivered from a low-relay-capability} \\ & \text{source peer to a low-relay-capability destination peer} \\ h \times d_{unit} & \text{if video data delivered from a high-relay-capability} \\ & \text{source peer to a high-relay-capability destination peer} \\ 0 & \text{if video data delivered from a high-relay-capability} \\ & \text{source peer to a low-relay-capability destination peer} \end{cases} \tag{5.2}$$

Here, d_{unit} is the time unit as used in the ATO scheme. As such, $delay_{insmax}$ of additional delay is inserted to streaming packets from the low-relay-capability source peer to the high-relay-capability destination peer which becomes to have the largest RTT from the newly joining peer among candidate neighbor peers. The P2PTV application can detect this degradation and avoid the connection between this pair of peers.

5.3.5 Video Packet Classification

The LoRCAD scheme simply classifies P2PTV packet between a pair of peers using information from the `libpcap`. This is an easy and uncomplicated process. The packet capture library (`libpcap`) is the major tool for capturing traffic passed through the delay insertion router. The `libpcap` inspects header of each packet and extracts the source IP address, destination IP address, the length of each packet, packet's format and so on.

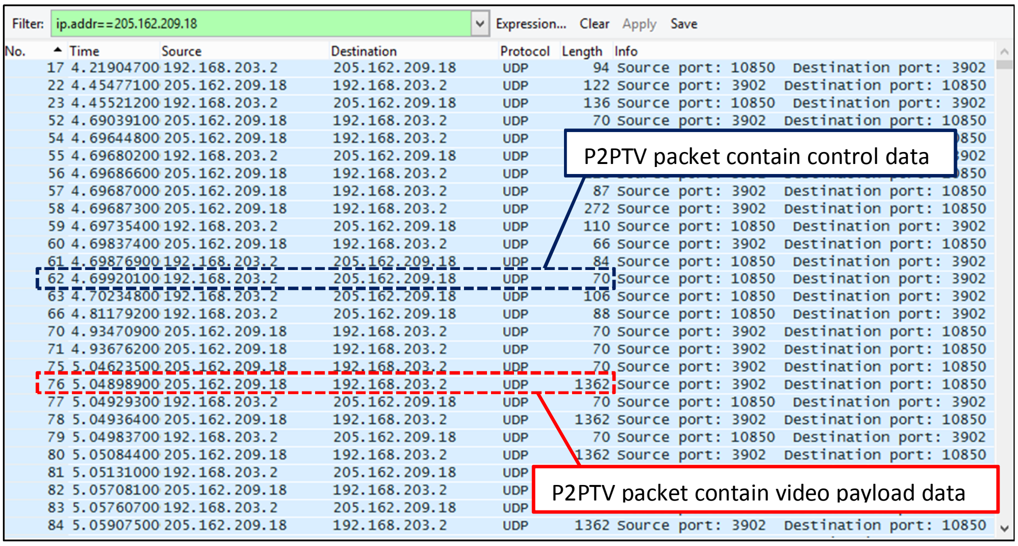


FIGURE 5.7: An example of control packet and payload packet in P2PTV.

The length of P2PTV packet is considered for classifying P2PTV packet into video data packet or other control packets. Figure 5.7 show an example of P2PTV streaming packets captured by Wireshark software [65]. There are control data (i.e. request packet, hello packet and buffer map) and video payload data delivered between a pair of source and destination peers. The large size packet can indicate that video data was contained inside. After that, the source and destination IP address of packet which contains video data are considered for streaming direction definition. The LoRCAD scheme considers the length of P2PTV packet and source/destination IP address for analyzing video streaming direction.

Chapter 6

Experiment and Results of LoRCAD scheme

This Chapter evaluates the value of relay capability estimation parameter L[bytes] and T_{int}[ms] which are the length of ping packet and the time interval between each ping packet respectively. The purpose is defining the suitable value for providing relay capability estimation and avoiding peer's device performance disturbance. Moreover, there are traffic locality, video quality, and CPU utilization evaluation of the proposed LoRCAD scheme compared to existing schemes for verifying suitable value of delay insertion parameters.

6.1 Experimental Setup for LoRCAD Scheme Evaluation

Figure 6.1 and Table 6.1 show network configuration and describe specification of each device in this experiment. The delay insertion router is implemented on a PC with FreeBSD release 9.2, Intel Core i7 3.5 GHz processor, 8 GB RAM. The Internet access line of 100 Mbps was served by Open Computer Network (OCN), a major Internet service provider in Japan. The proposed router was placed to connect to the Internet access line and the private network accommodating. The high-relay-capability peer was set up by Windows 8 PC, Intel Celeron 1.2 GHz processor, 2 GB RAM. The low-relay-capability peer was set up by Android 4.2.2 smartphone, dual-core 1.2 GHz processor, 1 GB RAM which connects to the same AS network as the proposed router via Mobile Virtual Network Operator (MVNO) using the access line of NTT DOCOMO 3G whose download and upload speed tested by speed test website [66] at experimental place was 3.5/0.3 Mbps. An additional peer is arbitrarily provided in the different ISPs from the viewer peer, which continuously played the same TV program throughout the experiments. The ISP to which the viewer peer connect is SoftBank Broadband(AS17676) which is also placed in Japan.

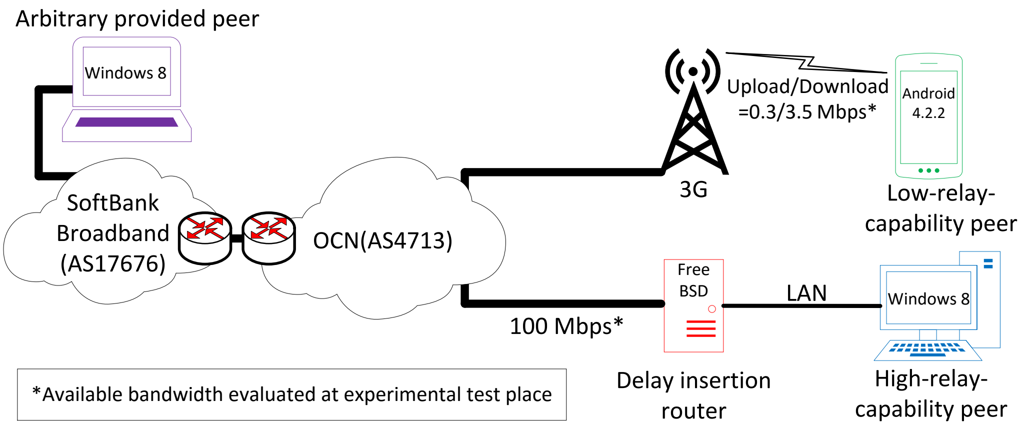


FIGURE 6.1: Experimental setup for LoRCAD scheme evaluation.

TABLE 6.1: Specifications of devices used in experiment.

	Delay Insertion Router	**High-relay-capability peer**	**Low-relay-capability peer**
Connection	OCN FTTH	LAN	3G HSPA
DL/UL speed (Mbps)	100/100	100/100	3/0.3
Operation System	FreeBSD 9.2	Windows 8.1	Android 4.2.2
CPU	Intel Core i7 3.5 GHz	Intel Celeron 1.2 GHz	ARM Cortex 1.2 GHz
RAM (GB)	8	2	1

At the delay insertion router, three schemes are deployed : LoRCAD, ATO, and No delay control. No delay control is the normal P2PTV system without any delay insertion. The delay insertion to P2P streaming packets is conducted in both the upload and the download links. LoRCAD, ATO and No delay control scheme are deployed into the P2PTV data packets from/to Windows PC and conducted the experiment for comparing traffic locality.

SopCast version 3.9.6 and PPLive version 3.6.5.0053 are used in this experiment and played the documentary program and animation program at the live channel respectively. The average bit rate of this video streams was 384 kbps in SopCast and 1 Mbps in PPLive. The time duration of each experiment was 60 minutes. The value of d_{unit} was set at 150 ms.

6.2 Relay Capability Estimation Evaluation

The effect of relay capability estimation on terminals of candidate neighbor peer node is evaluated in terms of relay capability estimated value and CPU utilization.

Environment & Methodology: Relay capability estimation performance and CPU utilization of peer nodes are evaluated simultaneously while responding to ping packets received from delay insertion router with varying ping parameters. The high-relay-capability peer and the low-relay-capability peer shown in Figure 6.1 are used as terminals to which relay capability should be estimated from the router. Specifications of these terminals and networks are the same as described in Section 6.1. In this section, they are served by Windows PC and Android smartphone respectively. Although the Windows PC is placed in a private network of the router and in a strict sense it is not the target terminal of relay capability estimation in LoRCAD, this terminal is used in order to measure CPU utilization during relay capability estimation in a simple experiment environment.

Data rate of ping is set at 5 Mbps and the length of ping packet L is varied from 700 to 1500 bytes. The value of time interval between each ping packet, T_{int}, is varied from 1.12 to 2.4 ms with maintaining 5 Mbps data rate of ping value. So, there are five pairs of (L[bytes], T_{int}[ms]) in this evaluation include (700, 1.12), (900, 1.44), (1100, 1.76), (1300, 2.08) and (1500, 2.40). Ping packets are sent to terminals for five minutes continuously.

The available bandwidth between the router and Windows PC was limited at 5, 10, 20, 50 and 100 Mbps by `dummynet`. Through preliminary experiments, CPU utilization of peer nodes did not reach 100% when they responded to ping whose data rate is 5 Mbps under the condition that the limited available bandwidth between the router and Windows PC and the condition of actual available traffic between the router and Android smartphone. Therefore, the value of RL_{cap} in this experiment is not limited by terminal capability, but will only depend on the smaller of the data rate of ping and available bandwidth between the router and the terminals.

Relay Capability Estimation Results: Figure 6.2 shows results of estimated relay capability at Windows PC and Android smartphone using 5 Mbps ping data rate. For Windows PC peer node, the result of relay capability estimation increases and close to the ping data rate value with the rise of parameters (L, T_{int}). For the estimation result of Android smartphone, it is similar to speed test result in upload direction which equals 0.3 Mbps for all conditions. From the result of relay capability estimation, it can be concluded that parameter (L, T_{int}) should as large as possible for increasing the effectiveness of estimation.

CPU Utilization Results: Figure 6.3 shows CPU utilization of terminals while responding to ping packets. During sending ping response packets, CPU utilization of both devices increases compared with the normal situation without any ping packet receiving or responding. CPU utilization of smartphone device is higher than Windows PC because of processor performance. The CPU utilization in Windows PC and smartphone slightly increase with the rising of parameters (L, T_{int}).

From results of relay capability estimation and CPU utilization at peer nodes, the large size of ping packet (L) and the large amount of interval between ping packet (T_{int}) give the high effectiveness of estimation while consuming CPU utilization. However, the increase of CPU utilization is tiny and still in acceptable value which will not affect the performance of peer nodes.

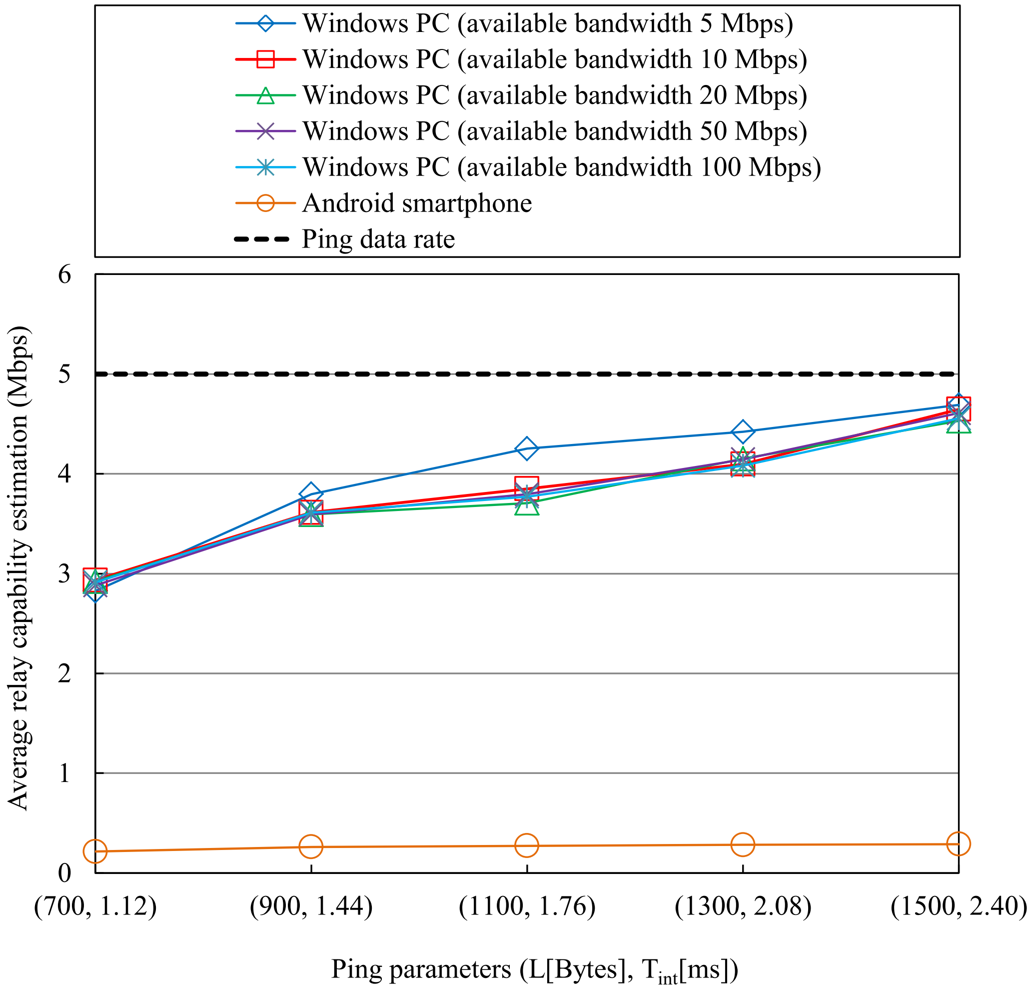


FIGURE 6.2: Estimated relay capability when using ping datarate 5 Mbps.

To evaluate the effectiveness of the proposed LoRCAD compared with normal P2PTV system and existing ATO scheme, traffic characteristics found in each scheme were evaluated. Regarding bandwidth estimation, this chapter sets $L = 1500$ byte and $T_{int} = 2.4$ ms by considering effectiveness of relay capability estimation and acceptable CPU utilization condition. Parameter N_{sent} is set at 64 through the result of preliminary experiments. Experiments to evaluate the performance of traffic localization in each scheme (LoRCAD, ATO, and No delay control) were conducted under the conditions as shown in Figure 6.1. In addition, there were only two peers,

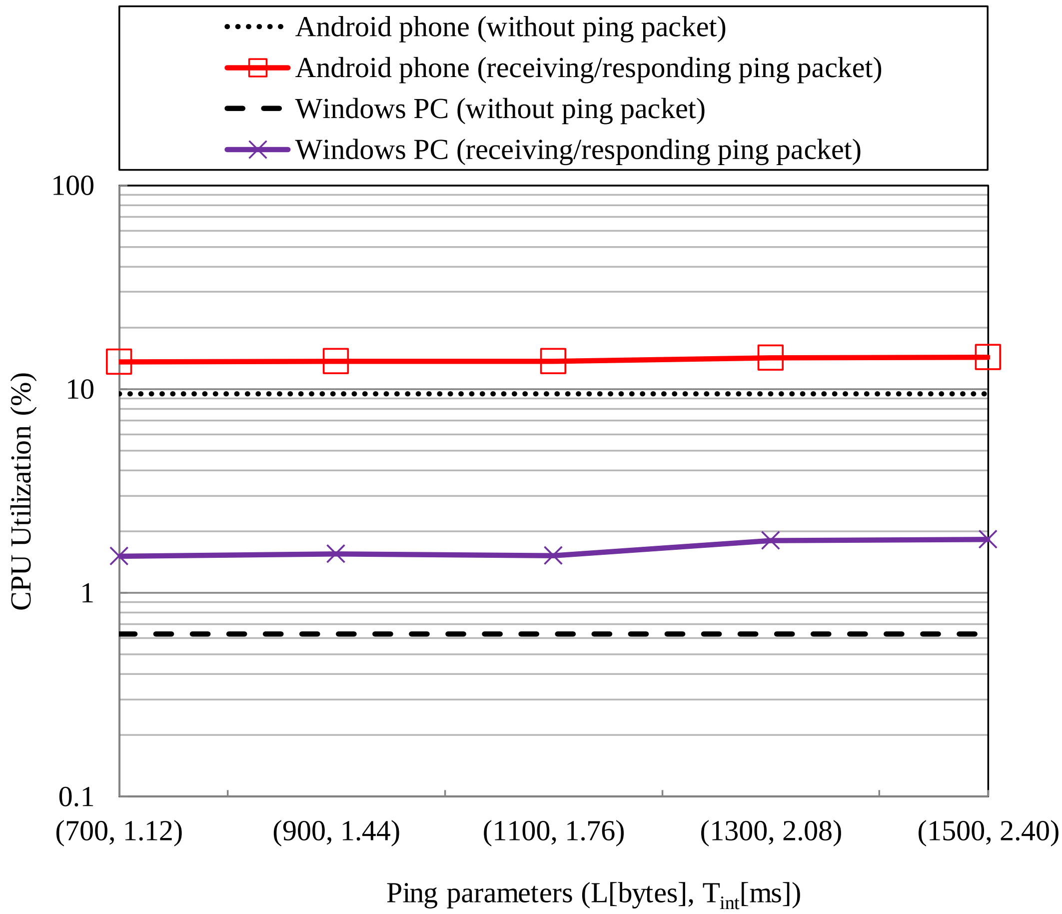


FIGURE 6.3: Effect of ping parameters on CPU utilization.

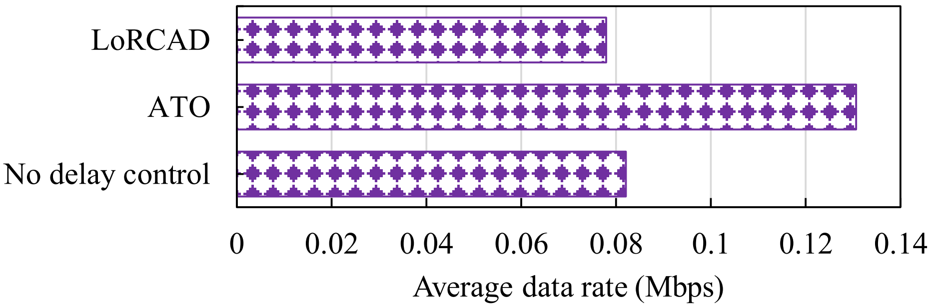
one low-relay-capability peer, and one high-relay-capability peer, which were viewing the same P2PTV program in the OCN network during evaluation.

6.3 Evaluation Results for the Case Where High-Relay-Capability Peer is a New Viewer Peer

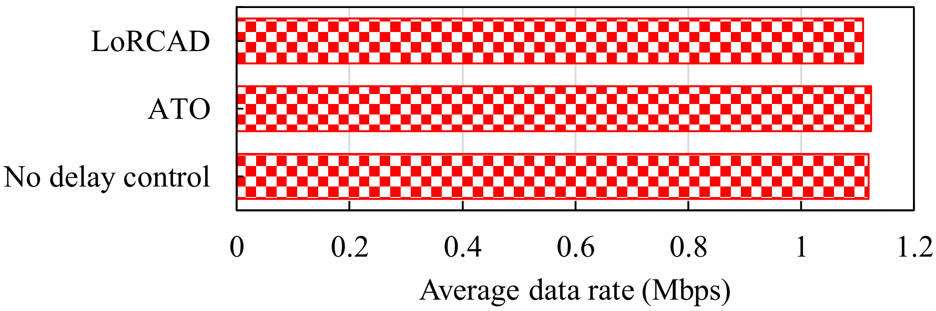
From experimental setup in Figure 6.1, the high-relay-capability peer (Windows PC) was set as the newly joining peer which downloaded traffic from the low-relay-capability source peer (Android smartphone) and other source peers. Data rate and CPU utilization at the low-relay-capability source peer were measured for evaluating bandwidth utilization and workload of peer's terminal. Furthermore, the downloaded traffic results of the high-relay-capability peer were set as the newly joining peer in both SopCast and PPLive application were presented and discussed as follow.

6.3.1 Upload and Download Data Rate at the Smartphone

The average data rate in both upload and download direction at the Android smartphone are shown in Figure 6.4 (a) and (b) respectively. The LoRCAD scheme can reduce upstream traffic around 17% of total available upload bandwidth at the Android smartphone (0.3 Mbps) and its upload data rate is the same level as the No delay control scheme because the LoRCAD router leads the Windows PC to avoid download traffic from the Android smartphone. On the other hand, the upload data rate of ATO scheme is the highest because the router tries to localize traffic and lead the Windows PC to download video data from the Android smartphone. The download data rate results when deploying LoRCAD, ATO, and No delay control scheme are quite similar to each other. From results of data rate evaluation, it can be concluded that LoRCAD scheme can help reducing the upload data rate at the low-relay-capability source peer because it avoids data being uploaded to the high-relay-capability destination peer regardless of AS hop distance.



(a) Upload direction



(b) Download direction

FIGURE 6.4: CPU utilization at the local low-relay-capability upstream peer while deployed traffic localization schemes.

6.3.2 CPU Utilization at the Smartphone

Under the condition of Figure 6.1, CPU utilization at the Android smartphone was measured. The result of CPU utilization at the Android smartphone is presented by the bar graph in Figure 6.5. The solid, diagonal and grid bar represent CPU utilization while deploy LoRCAD , ATO, and No delay control scheme into the delay insertion router respectively. The black dotted line represents CPU utilization of Android smartphone without any P2PTV traffic. The function of avoiding relay traffic from the low-relay-capability peer in LoRCAD scheme can reduce CPU load of Android smartphone close to the No delay control scheme. ATO scheme leads the Windows PC peer download video data from the Android smartphone in the internal AS network which increases workload at the smartphone and leads its CPU utilization highest among every scheme. Although the CPU utilization of LoRCAD is 5% lower than ATO scheme, there is no large difference in the CPU utilization between them. Reducing CPU utilization at the low-relay-capability peer would be the minor benefit of the LoRCAD scheme when compared to reducing upload bandwidth resource as presented in the previous subsection.

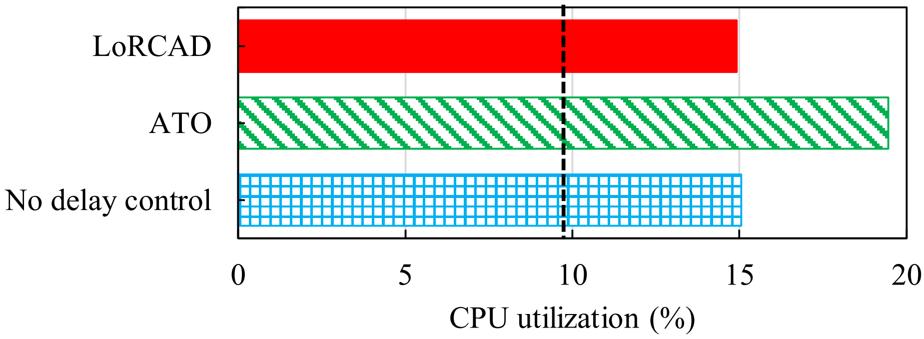


FIGURE 6.5: CPU utilization at the local low-relay-capability upstream peer while deployed traffic localization schemes.

6.3.3 Traffic Result at the PC for SopCast Application

From experimental setup in Figure 6.1, the high-relay-capability peer was set as the newly joining peer which downloaded P2PTV video data from the low-relay-capability source peer and other source peers. Figure 6.6 presents the cumulative amount of data received by the high-relay-capability viewer peer versus the AS hop distance of streaming packets while deploy each traffic localization technique (LoRCAD, ATO, and No delay control) into delay insertion router. The LoRCAD can lead the high-relay-capability viewer peer avoid downloading video data from the low-relay-capability peer and localize traffic by leading the high-relay-capability viewer peer to receive 63% of video data from peers in 1 AS hop distance networks. On the other hand, ATO scheme leads the high-relay-capability viewer peer downloads 36% of total data received from the low-relay-capability peer which placed in the same AS network. In No delay control scheme, there is most of the data received from the high distance AS networks.

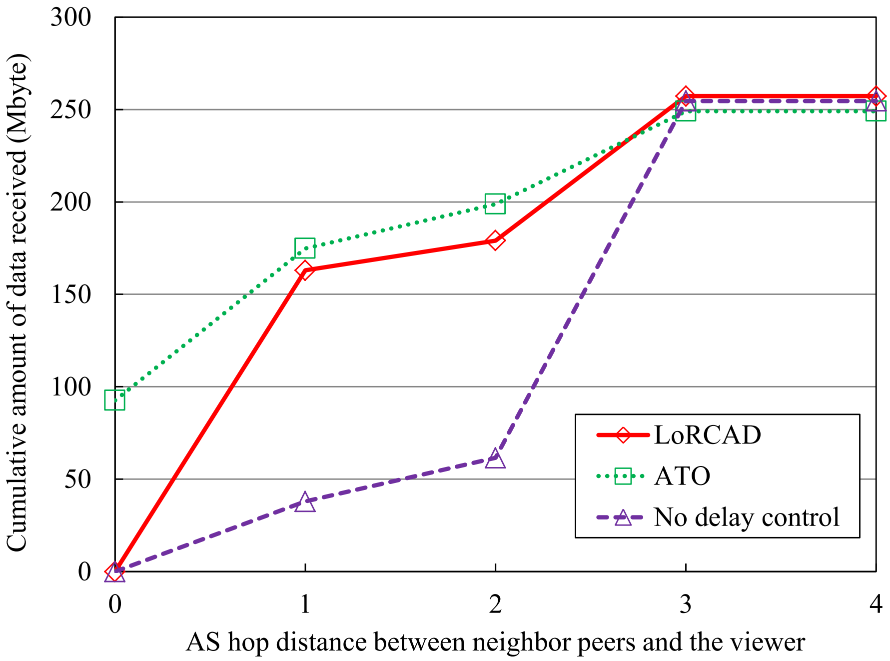
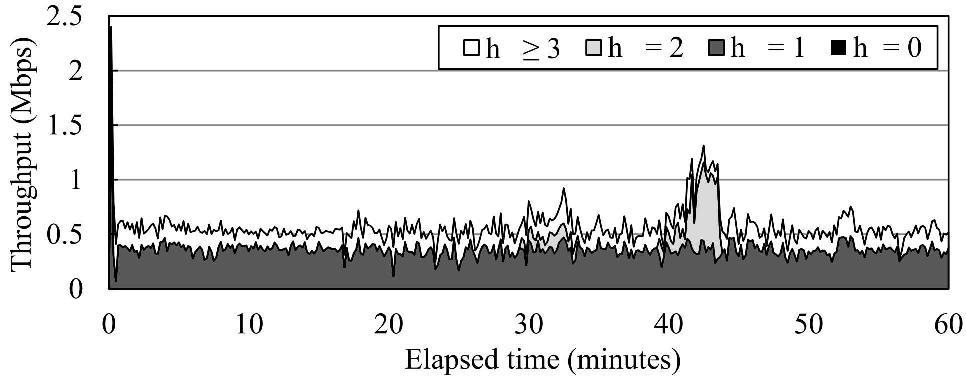
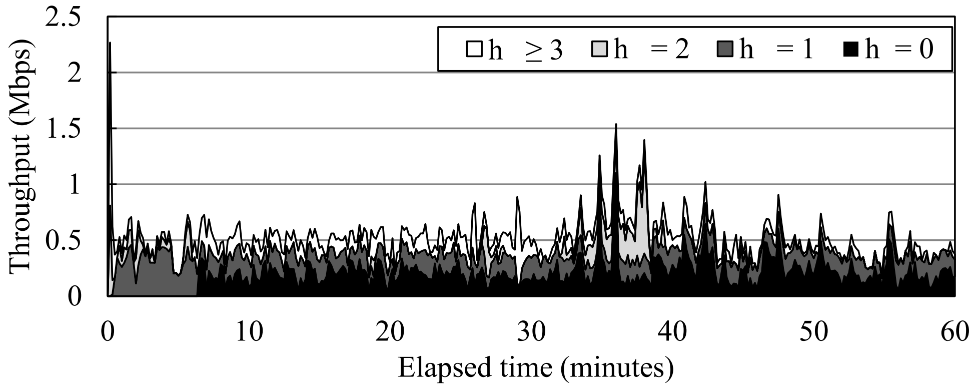


FIGURE 6.6: Cumulative amount of data received by the high-relay-capability peer in SopCast application.

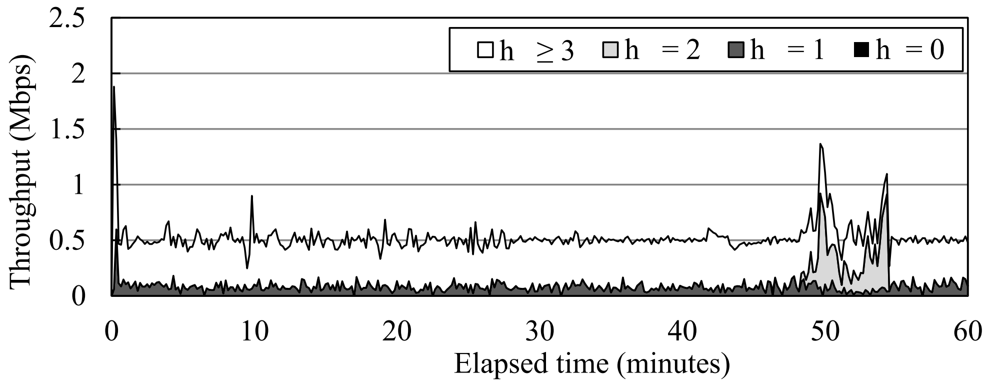
Figure 6.7 shows the throughput of each scheme over elapsed time. The graphs represent download throughput from the neighbor peers that are in each AS hop distance away from the viewer peer. In LoRCAD, there is no downloaded throughput from the low-relay-capability peer in the same AS network. However, the LoRCAD scheme can lead SopCast application to download most of throughput from 1 AS hop distance network. The ATO scheme leads SopCast application to download a part of throughput from the low-relay-capability peer in the same AS network throughout the evaluation. Without any traffic localization function in No delay control scheme, video data received from 2 and 3 AS hop distance network downloaded is the highest among all scheme.



(a) LoRCAD



(b) ATO



(c) No delay control

FIGURE 6.7: Download throughput for the high-relay-capability peer in SopCast application.

6.3.4 Traffic Result at the PC for PPLive Application

Figure 6.8 presents the cumulative amount of data received by the high-relay-capability viewer peer versus the AS hop distance in each scheme while viewing the PPLive program. As with the results for SopCast, the LoRCAD also can lead PPLive program to avoid downloading video data from the low-relay-capability peer which is located in the same AS network. For the ATO scheme, there is a part of data received from the low-relay-capability which is located in the same AS network. The result of ATO scheme indicates its traffic localization regardless of peer's relay capability. For the No delay control scheme, the ratio of data received from the high distance AS networks is the highest among all scheme because of its peer selection without any physical network awareness.

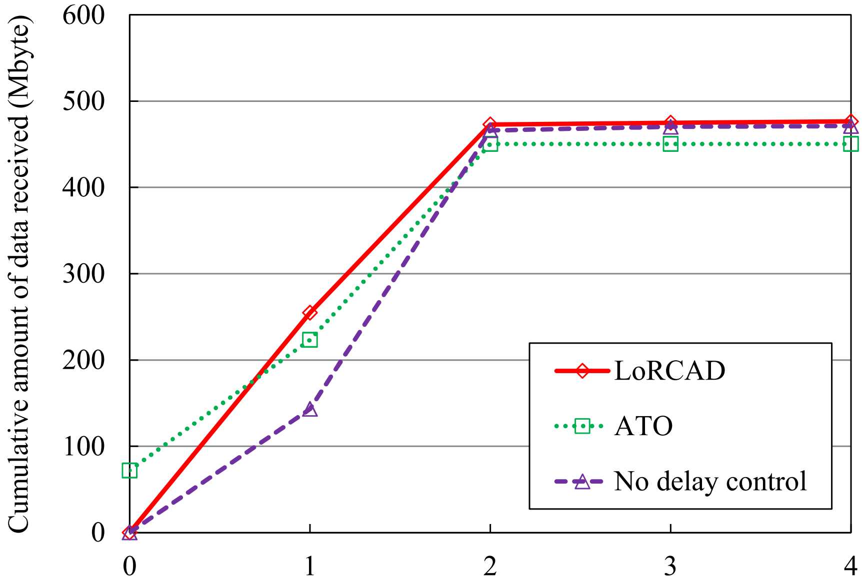
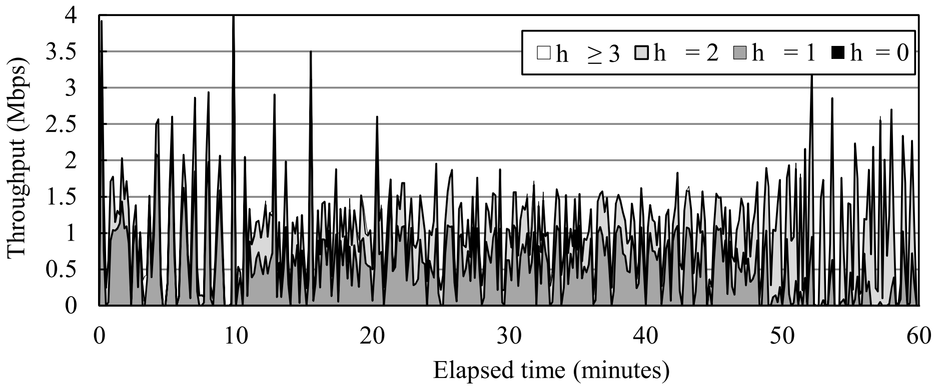
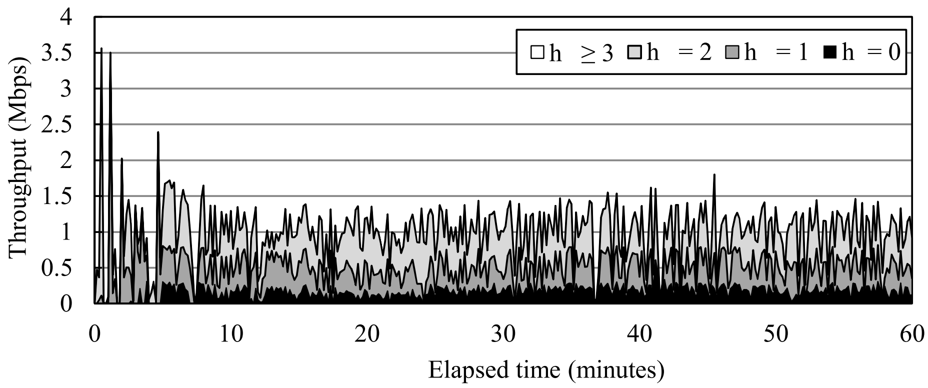


FIGURE 6.8: Cumulative amount of data received by the high-relay-capability peer in PPLive application.

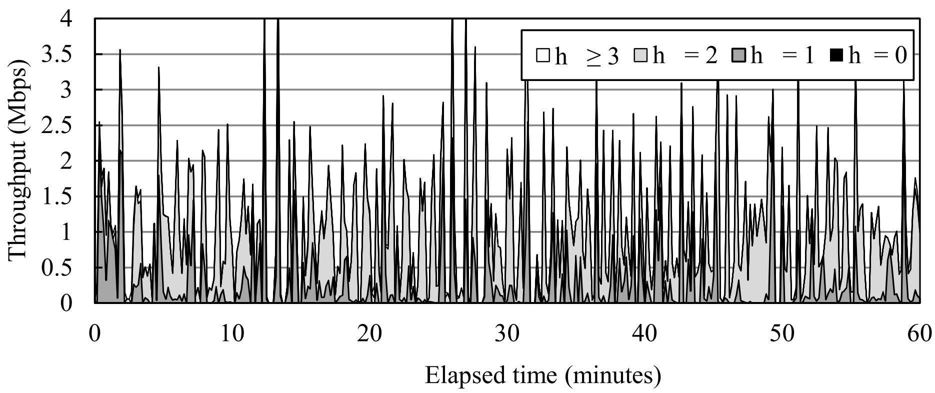
Figure 6.9 shows throughput over elapsed time from each scheme. Although there is no downloaded throughput from internal AS network in LoRCAD scheme, most of the data from one AS hop distance network which shows the ability of traffic localization in LoRCAD scheme. ATO scheme can localize traffic within the low distance AS networks. A part of their data is received from internal AS network



(a) LoRCAD



(b) ATO



(c) No delay control

Figure 6.9: Download throughput for the high-relay-capability peer in PPLive application.

and one AS hop distance network. Without any traffic localization function in the No delay control scheme, the video data is received from the high distance AS networks as shown in Figure 6.9 (c).

6.4 Evaluation Results for the Case Where Low-Relay-Capability Peer is a New Viewer Peer

Under the condition of Figure 6.1, statistical traffic was measured when the low-relay-capability peer and the high-relay-capability peer were set as the newly joining peer and the upstream source peer respectively. The experimental results of both SopCast and PPLive application are presented in this section.

6.4.1 Traffic Result for SopCast Application

The results of the video data amount which the low-relay-capability viewer peer receive from source neighbor peers when deploying each traffic localization technique into the delay insertion router while viewing SopCast program are shown in Figure 6.10. This graph shows the result of LoRCAD is quite close to those of ATO and No delay control. When deploy each scheme (LoRCAD, ATO and No delay control) into the delay insertion router, the low-relay-capability peer can normally download video data from the high-relay-capability peer. Figure 6.11 shows throughput of each scheme over elapsed time. LoRCAD scheme increases upload traffic from the high-relay-capability peer to the low-relay-capability peer in the same degree as ATO and No delay control scheme.

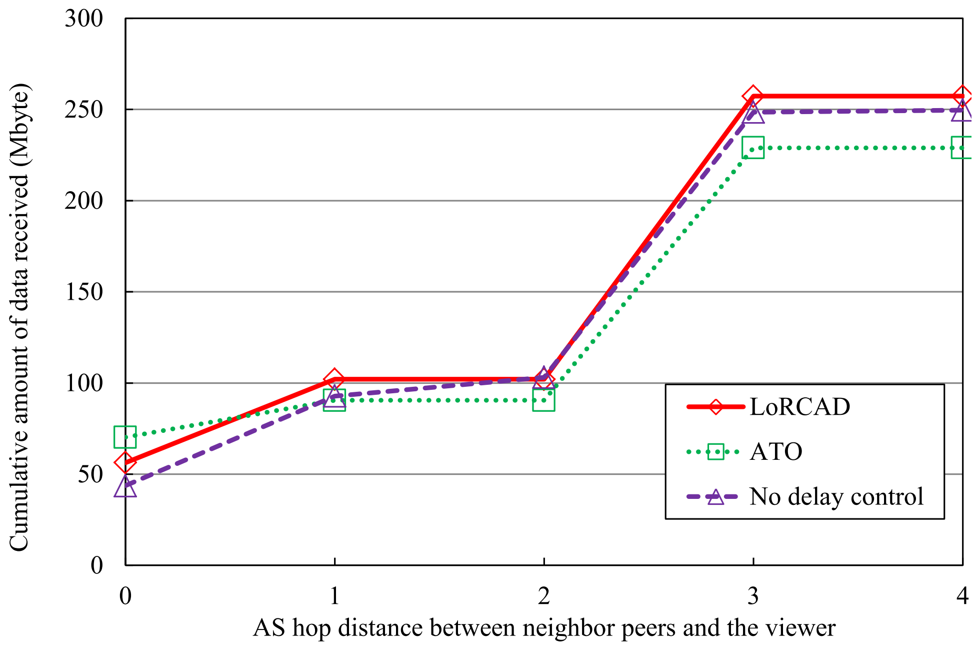
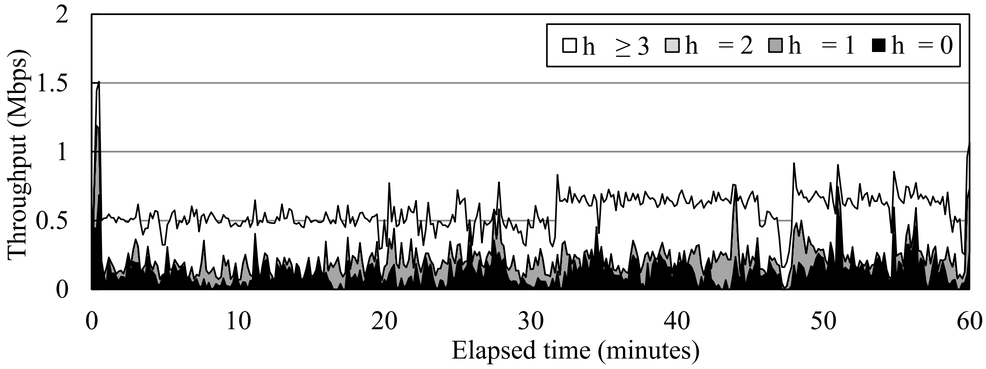
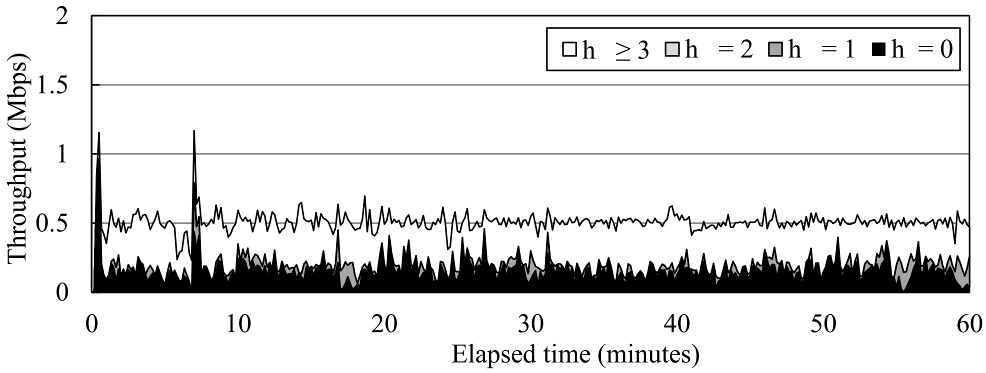


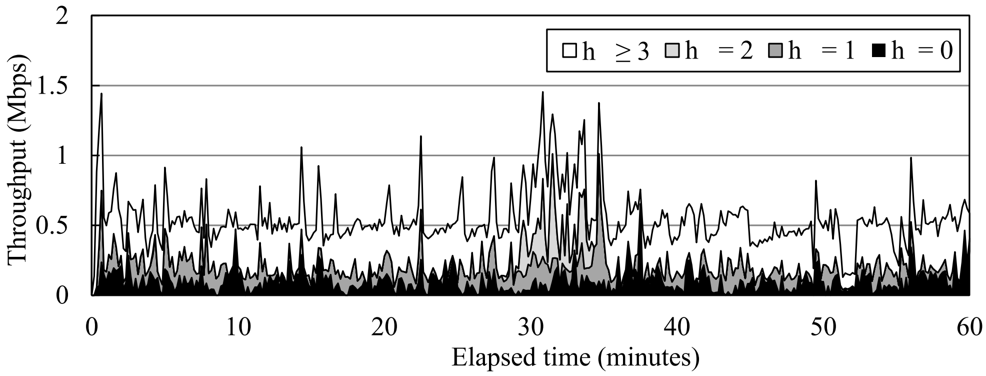
FIGURE 6.10: Cumulative amount of data received by the low-relay-capability peer in SopCast application.



(a) LoRCAD



(b) ATO



(c) No delay control

FIGURE 6.11: Download throughput for the low-relay-capability peer in SopCast application.

6.4.2 Traffic Result for PPLive Application

The cumulative amount of data received by low-relay-capability peer while viewing PPLive application is shown in Figure 6.12. Similar to results in SopCast application, LoRCAD scheme can relay video data to the low-relay-capability peer same as ATO and No delay control scheme. This can indicate the efficiency of relay capability estimation and video streaming direction detection function in LoRCAD. Throughput over elapsed time in each scheme are shown in Figure 6.13. In every scheme, there is a tiny part of download throughput from the high-relay-capability peer in the same AS network. The LoRCAD scheme allows the low-relay-capability new viewer peer in PPLive application to download video data from the high-relay-capability peer similar to ATO and No delay control scheme.

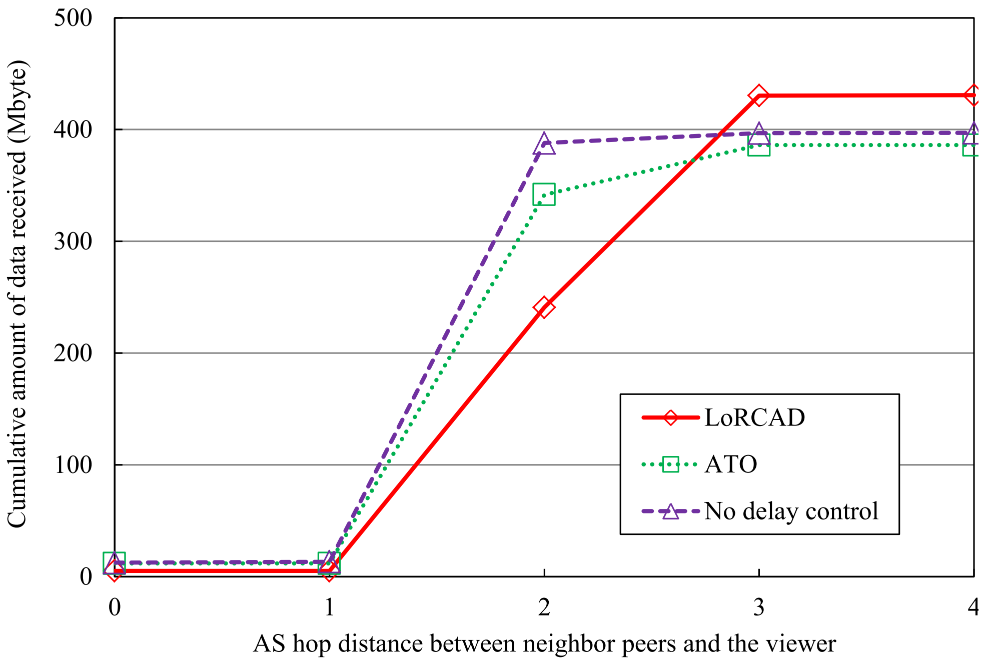
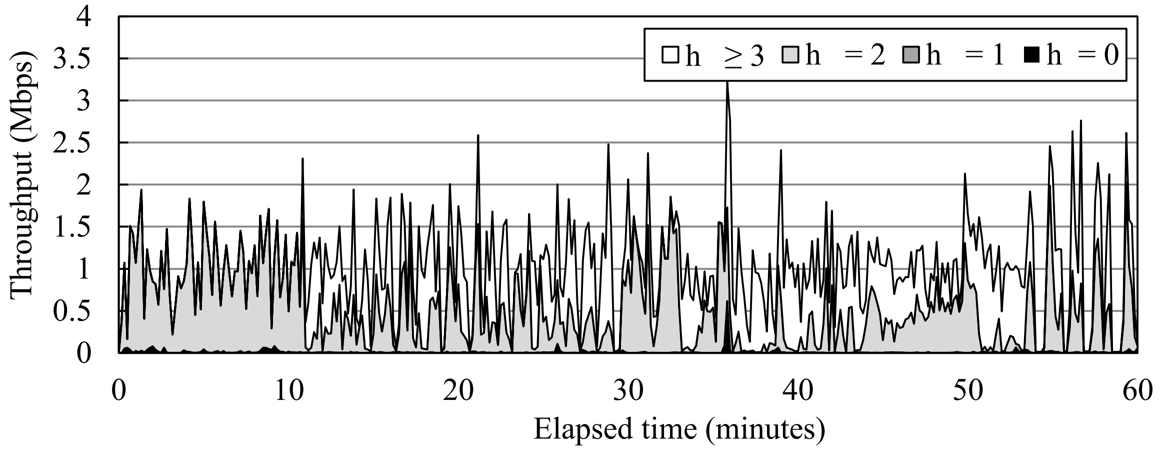
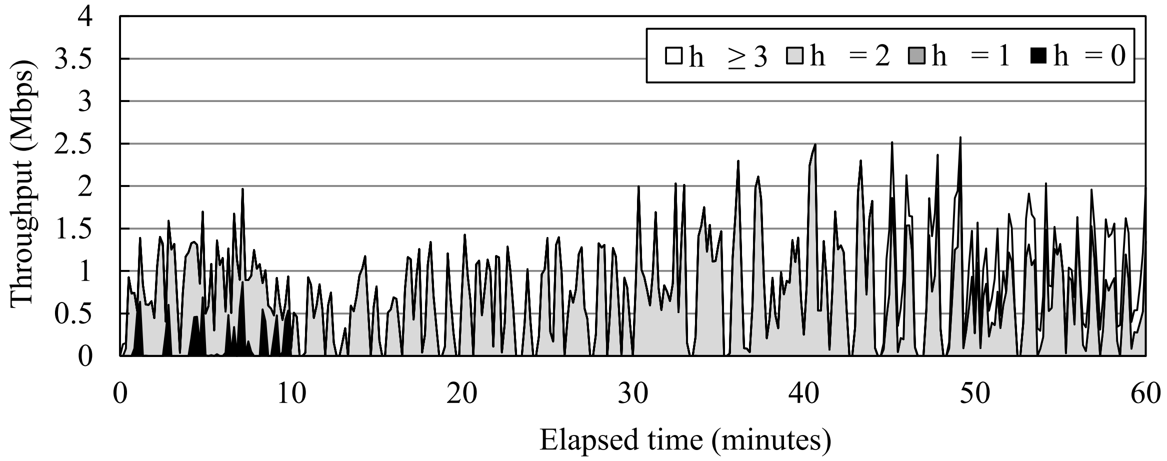


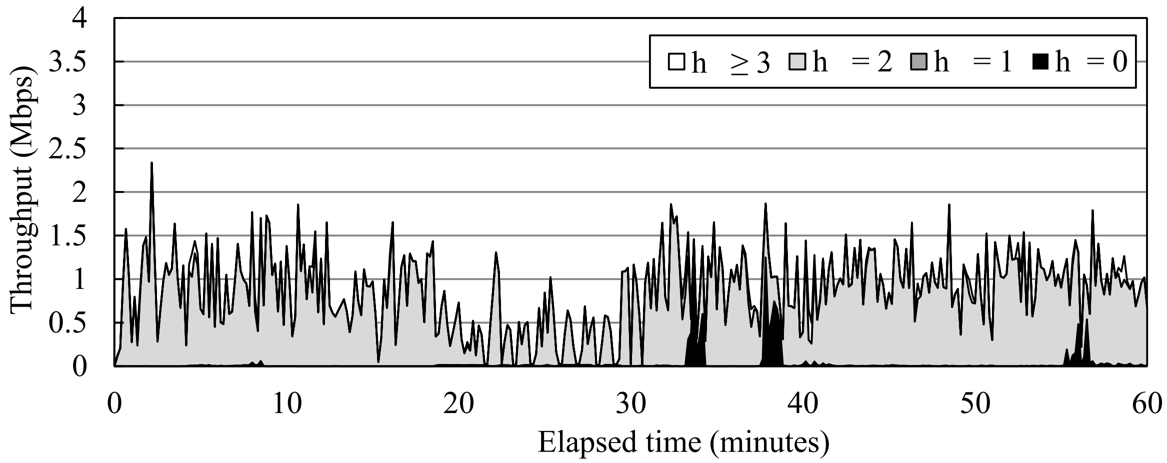
Figure 6.12: Cumulative amount of data received by the low-relay-capability peer in PPLive application.



(a) LoRCAD



(b) ATO



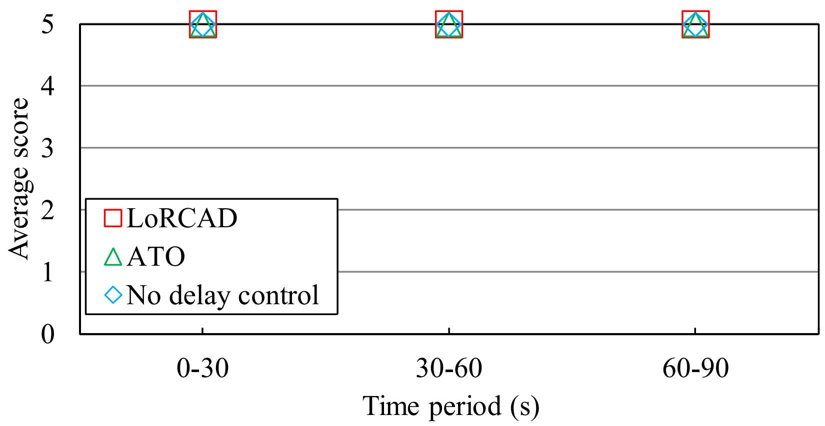
(c) No delay control

Figure 6.13: Download throughput for the low-relay-capability peer in PPLive application.

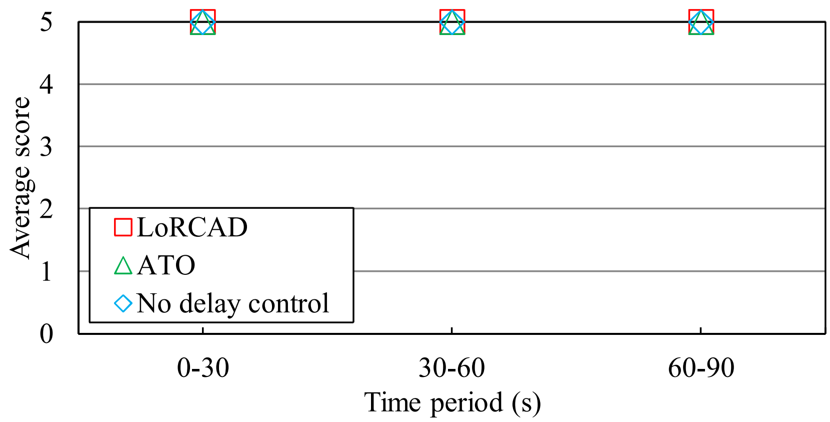
From results of traffic evaluation at the low-relay-capability peer in both SopCast and PPLive application, this can conclude that the proposed LoRCAD scheme can realize traffic localization while allowing upload traffic to the low-relay-capability peer.

6.5 Video Quality Evaluation

For the video quality evaluation in this chapter, DMOS was used to evaluate video quality downloaded similar to evaluation in Chapter 4. A video screen of 90 seconds duration was captured and separated them into 3 parts that were each 30 seconds. Ten subjects watched each part of captured video and evaluate degradation using the rating scale in Table 4.4. Figure 6.14 presents the results of video quality evaluation in the SopCast and PPLive applications when parameter d_{unit} was set at 150 ms. In ATO, the average rating score is close to the No delay control in every period same as results in Chapter 4. Moreover, in LoRCAD scheme, the effect of delay insertion did not appear although the new viewer cannot download video data from the low-relay-capability peer. From the result of video quality evaluation, it can be concluded that LoRCAD traffic localization scheme which avoids downloaded video data from the low-relay-capability neighbor peers can maintain video playing quality in the same degree as the ATO scheme and normal P2PTV system.



(a) SopCast application



(b) PPLive application

FIGURE 6.14: Rating of video quality in P2PTV applications from LoRCAD and existing schemes.

6.6 CPU Utilization & Scalability Evaluation for the Delay Insertion Router

Figure 6.15 shows CPU utilization of the delay insertion router during each traffic localization scheme (LoRCAD, ATO, and No delay control) runs by varying the number of viewers connecting to the router. Here, all the viewers simultaneously start playing the video. As shown in the graph, there is a linear relationship between the number of viewers connecting to the router and the CPU utilization in each scheme. The CPU utilization of LoRCAD and ATO increases compared to No delay control. The LoRCAD can maintain the CPU utilization close to that of ATO although the bandwidth estimation function is added. From linear formula of LoRCAD scheme, the scalability can estimate that the delay insertion router using LoRCAD can support 4166 users if the CPU utilization threshold is set at 80%.

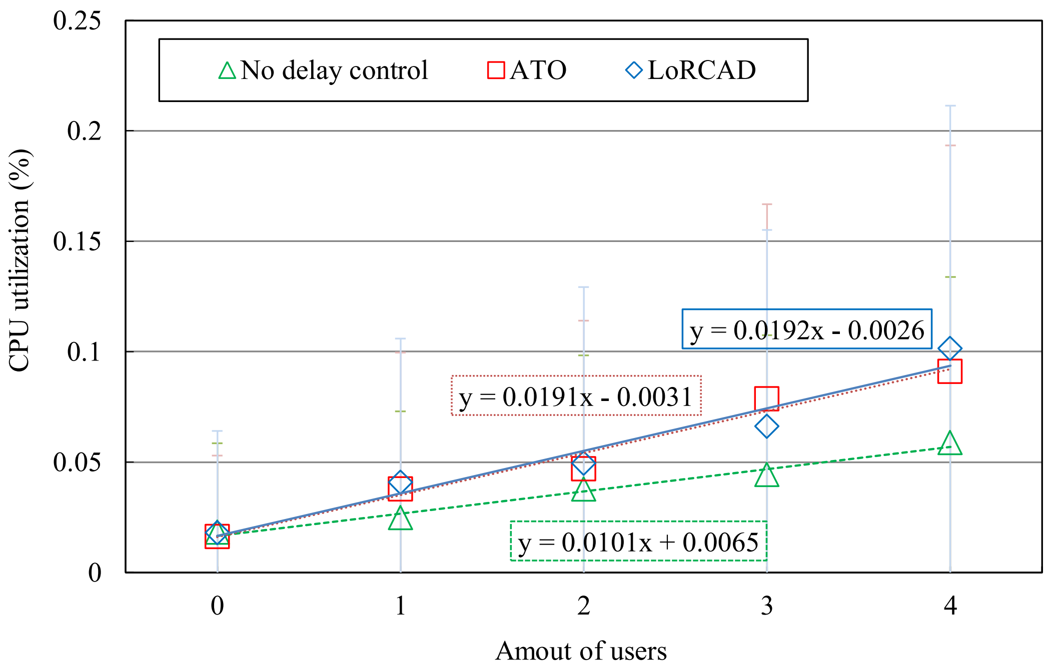


FIGURE 6.15: CPU utilization of delay insertion router with varying the number of viewers.

6.7 Conclusion

The development of delay insertion based P2PTV traffic localization scheme was presented, in which the ISP's edge routers insert an additional delay for P2P streaming packets depending on the relay capability, video streaming direction and AS hops distance between source and destination peers. The experimental results showed the proposed LoRCAD was able to avoid connecting to low-relay-capability peers when downloading P2PTV streaming data which achieves saving 17% of total upload bandwidth resource and 5% of CPU consumption at the low-relay-capability peers. The function of avoiding video data from the low-relay-capability peer without physical network distance consideration may reduce traffic localization ability of the LoRCAD scheme compared to the existing ATO scheme. However, the results also showed the proposed scheme achieved traffic localization compared to the case in which No delay control is performed. In addition, the proposed LoRCAD scheme can maintain video quality of P2PTV application at the same degree as the existing ATO scheme and as the case in which delay control is not performed. From ISP's perspective, the benefits of proposed LoRCAD scheme compared to ATO scheme is it can greatly reduce upload traffic from the low-relay-capability peers. Moreover, it does not exploit the behavior of specific P2PTV services and can be applied to new services without modification of the software at each peer or at the streaming server. Additionally, in terms of deployment, the adoption of this scheme only by ISPs that need to optimize upload traffic for the low available uplink bandwidth user and reduce inter-AS traffic is sufficient to achieve the benefit for the ISPs, and collaboration with other ISPs is not necessary.

Chapter 7

Conclusion and Future Work

This dissertation presented an improvement of delay-insertion-based P2PTV traffic localization to achieve the goal of localizing P2PTV traffic correspond to the physical network topology and optimizing available bandwidth for the low-relay-capability peer. There are two proposed traffic localization schemes which are the ATO scheme (considering precise network information) and the LoRCAD scheme (considering precise network information and relay capability). The proposed traffic localization schemes were implemented on gateway router without collaboration with P2PTV content providers or software modification on P2PTV application.

To realize precise network topology and diversity of peers' relay capability awareness in delay-insertion-based P2PTV traffic localization, the amount of delay was inserted into P2PTV packets proportional to AS hop distance for leading P2PTV application avoid making the connection with neighbor peers from the large AS hop distance networks. AS hop distance database was newly created by collecting AS-path considering the route history of border gateway protocol. For the peer's relay capability estimation, the proposed gateway router sent ICMP ping packets to candidate neighbor peers and then analyzed their echo packets. The direction of video streaming was detected by considering packet length and source/destination IP address of P2PTV traffic.

The methodology of proposed delay insertion method was described in detail in this dissertation. PC-based router operated under Linux OS was implemented as proposed gateway router which utilized `libcap`, `Geolite` database and `dummynet` for inspect traffic, defined candidate neighbor peer's AS network and inserted additional delay into P2PTV packets respectively.

In summary, this dissertation provides the following contributions:

- Though experiments using real networks, it is demonstrated that the proposed ATO and LoRCAD schemes can effectively realize traffic locality in terms of reducing normalized AS hop distance which is newly defined metric in this paper. This means they reduce inter-AS traffic compared to the normal P2PTV system with random or RTT-based neighbor peer selection.
- Compared to the existing delay insertion based scheme, the proposed ATO, and LoRCAD schemes can localize P2PTV traffic in AS level. P2PTV application was led to connect with neighbor peers from the same AS network or as low AS hop distance network as possible.
- The proposed LoRCAD scheme also considers relay capability of candidate neighbor peer. The proposed method can avoid downloading streaming data from the low-relay-capability candidate neighbor peers for reducing its available uplink bandwidth consumption and extra workload. In addition, this scheme allows every type of source peers to upload streaming data to the low-relay-capability peers. The low-relay-capability peer which has the limitation in terms of available bandwidth path or devices performance can receive video data without difficulties.
- Although the proposed ATO and LoRCAD schemes which insert the delay into P2PTV packets intentionally degrades RTT and may have an impact with QoS, this research investigated the degradation of video playing depending on the amount of inserted delay and clarified suitable delay value for maintaining QoS of P2PTV applications.
- In the LoRCAD scheme, a large number of ICMP packets are sent to candidate neighbor peers for the relay capability estimation and it may disturb the

performance of destination peer devices. However, this research clarified the appropriate range of parameters for maintaining effectiveness of relay capability estimation while avoiding the increase of CPU utilization at the candidate neighbor peers.

To outline the directions of future work, the P2PTV traffic filtering process which was skipped for reducing the scale of research is considering. This traffic localization scheme can more completely realize implementation in the Internet network. Various methods are considered for example the deep packet inspection, port number detection, and shaping device installation.

Appendix A

List of Publications

A.1 International Journal Papers

[J.1] C. Wechtaisong, K. Ikeda, H. Morino and T. Miyoshi , "Delay-Insertion-Based P2PTV Traffic Localization Using AS-Level Topology Information", *IEICE Transactions on Communications*, Vol.E98-B, No.11, pp. 2259-2268, Nov 2015.

A.2 International Conference Papers (Peer-reviewed)

[C.1] C. Wechtaisong and H. Morino, "Delay Insertion Based P2PTV Traffic Localization Considering Peer's Relaying Capability", *Proc. of the 22th AsiaPacific Conference on Communications (APCC)*, Aug 2016.

[C.2] C. Wechtaisong, K. Ikeda, T. Iijima and H. Morino, "Delay Insertion Based P2PTV Traffic Localization Considering Available Bandwidth of Logical Link", *Proc. of the 17th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, pp. 352-355, Aug 2015.

[C.3] C. Wechtaisong, H. Morino and T. Miyoshi, "Delay-insertion-based P2PTV traffic localization using AS-level topological information", *Proc. of the 10th Asia-Pacific Symposium on Information and Telecommunication Technologies (APSITT)*, pp. 1-3, Aug 2015.

A.3 Conference Papers (Not Peer-reviewed)

[T.1] C. Wechtaisong, K. Ikeda, T. Iijima and H. Morino, "Delay Insertion Based P2PTV Traffic Localization Considering Peer's Relaying Capability", *IEICE technical report (MoNA2015-22)*,Vol. 115, No. 311, pp. 1-6, Nov 2015.

[T.2] C. Wechtaisong, H. Morino and T. Miyoshi, "Performance Evaluation of Delay-Insertion-Based P2PTV Traffic Localization", *Proc. of the 2015 IEICE Society Conference (Communication Society)*, Sep 2015.

[T.3] C. Wechtaisong, H. Morino and T. Miyoshi, "Decentralized Traffic Localization in P2PTV using AS-hop Information", *Proc. of the Intensive Workshop Session, the 9th South East Asian Technological University Consortium Symposium (SEATUC)*, pp. 29-33,Vol. 5, July 2015.

[T.4] C. Wechtaisong, H. Morino and T. Miyoshi, "Delay insertion based P2PTV traffic localization using AS-level topology information", *IEICE technical report(IN2014-84)*, Vol. 114, No. 307, pp. 19-24, Nov 2014.

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