Optimised Localisation (OpLoc) For Community Networks

Wahidah Md. Shah

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Declaration

I declare that the work in this thesis has not been submitted for a degree at any other university, and that the work is entirely my own.

Signature

Wahidah Md. Shah

Abstract

In recent years, there has been a tremendous increase in the amount of video-based content distributed across the Internet; with this growth forecast to continue. A range of distribution approaches have been developed in response to this demand, including Peer-to-Peer (P2P) and Content Distribution Network (CDN). These technologies are now vital to deliver content across the Internet, in order to keep pace with user expectations and the ever growing number of video-on-demand and video streaming services now on offer.

In spite of this growth in video-based services; Internet access in many parts of the world remains a challenge. This phenomenon is known as the 'digital divide', which expresses the connectivity gap between those with and without high quality access to the Internet. In response to this issue, community groups have built their own infrastructures (which we refer to as 'Community Networks' within this thesis), using technologies such as 'Wireless Mesh Networks', which involves combining wireless networking technology and ad-hoc routing protocols in order to create self-managing networks that can deliver Internet access to residents. Ordinarily these networks will have good network connectivity within the community, but may share a limited connection to the wider Internet.

The use of video delivery technologies, such as P2P, within these Community Networks introduces some key challenges. The shared connection to the wider Internet may reduce the probability of successfully connecting clients with remote clients and potentially creates network bottlenecks at the backhaul connection. The use of P2P localisation strategies, which would encourage clients to connect with local clients, could also result in issues with the availability of content.

This thesis proposes OpLoc, a system designed to strike a balance between saving bandwidth and preserving the live playback of P2P content within resource-constrained networks. OpLoc achieves this using two key mechanisms; dynamic localisation, which helps network providers determine the optimal level of localisation, depending on the physical network limitations and a local hook-in technique that is designed to preserve the continuity of live playback within resource-constrained networks, whilst also balancing the bandwidth requirements associated with P2P distribution.

OpLoc is evaluated through a variety of experiments using a testing framework. This testing framework allows for experimentation within controlled conditions, in order to provide reproducible and consistent results within larger networks (that would otherwise be difficult to study using real implementations). This evaluation shows how OpLoc is able to adapt to the network conditions; reducing bandwidth whilst preserving live playback in a resource-constrained network environment.

Preface

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original and my own work. The material has not been submitted, either in whole or part, for a degree at this or any other university.

Excepts of this thesis have been published in conference proceedings.

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(Wahidah Md. Shah)

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List of Abbreviations

ADSL	Asymmetric Digital Subscriber Line
ALM	Application Level Multicast
AP	Access Point
ARPANET	Advanced Research Project Agency Network
AS	Autonomous System
AODV	Ad hoc On-Demand Distance Vector
BASS	BitTorrent Assisted Streaming System
BEST	BitTorrent Extensions for Streaming
BiToS	BitTorrent Streaming
CBN	Community Broadband Network
CDN	Content Distribution Network
CN	Community Network
DAW	Distance-Availability Weighted
DHT	Distributed Hash Table
DNS	Dynamic Resolution Protocol
DPI	Deep Packet Inspection
DSL	Digital Subscriber Line
FCFS	First Come First Serve

IGMP	Internet Group Message Protocol
IP	Internet Protocol
ISP	Internet Service Provider
LAN	Local Area Network
LRSWRX	Least Recently Shared With Requesting Expired Chunk
LTM	Location-aware Topology Matching
LRF	Local Rarest-First
MAC	Media Access Control
NICE	Internet Cooperative Environment
NLI	Network Localisation Index
OpLoc	Optimised Locality
P2P	Peer-to-Peer
PIM	Protocol Independent Multicast
Prism	Portal Infrastructure for Streaming Media
QoE	Quality of Service
RPSL	Random Public and Strict Local
RTT	Round Trip Time
TCP	Transport Control Protocol
TTL	Time-To-Live
TFT	Tit-for-Tat
UTAPS	Underlying Topology-aware Peer Selection
VM	Virtual Machine
VoD	Video on Demand

VRNS	Variable Random Neighbour-Selection
WMN	Wireless Mesh Networks
WWW	World Wide Web

Chapter 1

Introduction

1.1 Growth in Video Distribution

Over the last 10 years the Internet has had to support a significant growth in the distribution of video content, with this trend forecast to continue. Cisco, in its recent Visual Networking Index (VNI) 2012-2017 [21], highlights Internet video as representing 57% of consumer Internet traffic in 2012 and forecasts that this will reach 69% by 2017. The delivery of Internet video to TV also doubled in 2012, and is expected to increase 5-fold by 2017. The sum of all forms of video including P2P is predicted to be 80-90% of global consumer traffic by 2017.

The origins of video distribution via the Internet date back to 1993, with the introduction of the Mosaic web browser that was capable of rendering various types of media including text, audio, images and video. As computing hardware increased in capability this opened up the possibility of an increasingly time-dependent set of media being presented, but this also highlighted the limitations of the Internet as a best-effort distribution infrastructure. This meant that video was typically delivered as a static, non-streaming digital asset downloaded from a media server and stored locally on a user's computer for playback.

Enhancements in last 20 years in network capacity and mechanisms to support video distribution across the Internet have resulted in the widespread availability of live-streaming video services. Services such as YouTube [112], online TV offered by PPLive [79], the BBC iPlayer [6] and video communication by Skype [93] all highlight the new possibilities of the Internet. Multimedia video over the Internet has become a dominant application and combined with ubiquitous network access and mobile devices now makes the potential for anywhere, anytime video services. Traffic from wireless devices is forecast to exceed the traffic from wired devices by 2017 [21]. These statistics all point towards an increasing demand that will be placed on the Internet as a platform for the reliable and cost effective distribution of video content.

1.2 Supporting Growth in Video Distribution

The growth in video distribution has been partly driven by networking advancements, multimedia compression and encoding optimisations but clearly through an increasing demand from users. The content available continues to improve in terms of resolution and overall video quality, and the signs are that this trend will continue as we move from Standard Definition (SD) to High Definition (HD) video through to 3D and Super High Vision content. These step-changes in video quality all place additional burden on a underlying infrastructure to support their distribution. As the Internet is fundamentally a best-effort delivery platform, one of the established approaches for delivering video is to use a Content Distribution Network (known as a CDN). A CDN consists of a number of dedicated CDN servers that are deployed at strategic locations within the Internet, which are responsible for storing copies of popular content from the original source. When users request content from the original source they are transparently re-directed to a geographically closer CDN server that has a copy of the media asset. This approach reduces the burden on the original server and also shortens the network delivery path. However, the cost of implementing a CDN is high due to the number of edge servers required. Moreover, as CDNs are based on a client-server architecture there is an inherent limit in the serving capability of the system.

Peer-to-Peer (known as P2P) has emerged as an alternative mechanism for delivering video. During the last 10 years it has been shown to be capable of distributing large amounts of content, including video material. Studies have shown that a significant proportion of Internet traffic has been found to be P2P-based, with P2P representing more than 50% of Europe traffic in 2008 [88]. In 2005, [75] CacheLogic analysed the data streams of Internet backbones and ISPs, and found that 61.4% of P2P traffic was video-based. P2P is particularly attractive as it represents a scalable solution without the need for additional server support, as is in the case with CDNs - with a P2P solution each device (known as a 'peer') involved in the communication is capable of acting as both a server and client; thus receiving content and sharing it with others.

1.3 Community Networks

Whilst modern technology has brought us closer to the notion of ubiquitous access to the Internet, there is still a significant gap between the access levels available in different parts of the world. Within the UK, this gap is particularly evident when comparing the access levels available in urban areas against those found in rural communities, who have very limited or often no access at all to the Internet. This phenomenon is commonly referred to as the 'digital divide', which expresses the connectivity gap between these groups of users.

In order to try and bridge this divide, many rural communities have been empowered to build, install and then operate their own networks. Community Broadband Network (CBN) is one example of an independent broadband operator that provides telecommunication infrastructures to rural sites in the UK. CBN launched in January 2004 [25] with the aim of encouraging and supporting communities in establishing their own networks. These community-based networks (henceforth abbreviated as CNs within this thesis) provide villages, neighbourhoods and local businesses access to the Internet in addition to providing local networking services. CNs benefit the community and neighbourhood in several ways. Users in a community network are able to share and communicate locally at lower cost, providing faster access and consuming less network traffic. In addition, the community may also host their own forums, servers and manage their networks based on their own particular needs.

Community Networks are commonly built using wireless technology - this can be achieved at relatively low cost without requiring significant investments in infrastructure. One particular technology used is Wireless Mesh Networks (WMNs) which allow users to communicate with each other locally through a variety of access points, or mesh nodes. A more detailed description of CNs and WMNs is presented in section 2.5.

1.4 Motivations

Whilst the demand for high quality content continues apace, the ability to deliver this across parts of the Internet remain a particular challenge. Those on the fringe of the network - such as users of a Community Network, are often unable to reliably access streamed media simply because of the resource limitations and external network capacity that is available to them. Technologies such as P2P should, in theory, be able to help; the concept of P2P would mean that users requesting media items could have them provided by other users in the same community - without relying on external network access and hence reducing the costs of distribution. The fundamental design of P2P allows clients that view video streaming to upload the same video to other clients at the same time. Thus, distributing video streaming with P2P can reduce the cost of having media servers in place. This also enables clients to actively contribute their resources such as storage space and bandwidth to the overall network. Allowing clients to re-distribute video to other clients makes the whole system scalable to support a large number of clients. In addition, if the existing download source fails or on when a nearer source is located, clients are able to change to a different source of video content.

Despite the numerous benefits of P2P, there are some key challenges. Firstly, the concept of locality is still not common in P2P deployments. Most P2P clients select remote peers without consideration of the underlying network, which increases the amount of cross-over traffic among different countries. Based on a research work published in 2012 [5], they claim that there is still no work on the locality in live video streaming over P2P networks. Moreover, when considering P2P within CNs for live streaming the problem is exacerbated. Such bandwidth restrictions reduce the probability of successful connections of local clients to other clients that are located outside of the local network. Frequent communication with the remote clients challenges the sustainability of the network and creates a network bottleneck at the backhaul connection. A simple localisation however does not well performed if peer has low capability as this limits number of successful connection. Thus, instead simple localisation, dynamic locality is introduces in order to counter a network with low peer capability.

Whilst the use of localisation can help there is a secondary issue that relates to the 'liveness' of streamed content; that happen when requested live contents are not available. Apart from localisation, an efficient mechanism is needed in order to ensure that the required live contents are available at the localised clients. The combination of localisation and the mechanism needs to balance the aims of bandwidth saving and the requirement of preserving the 'liveness' of streamed content.

1.5 Thesis Aims and Contributions

This thesis is concerned with the enhancements necessary for P2P systems to be capable of delivering live streaming within Community Network environments that have limited external connectivity. The thesis proposes a new dynamic localisation scheme and a mechanism to preserve the playback of live content whilst balancing the bandwidth requirements.

The specific aims and contributions of the thesis are as follows:

- **To study the properties of P2P systems and the impact of loca-**

lisation when delivering live streams. Existing studies have reported significant findings which show the research gap in providing efficient streaming delivery. These findings highlight a need to provide better peer selection algorithms, and also the introduction of localisation to reduce remote communication and bandwidth costs. Experiments were carried out through a series of simulations and an implementation in order to study the sharing behaviour among peers in P2P (presented in the Appendix). Discussion on the issues of the standard P2P and P2P streaming are also reported in Chapter 3.

- **To design a framework for efficient localisation within P2P technologies.**

  An optimised localisation mechanism encourages peers to favour local clients and at the same time, preserves the live playback. In live streaming, content is lively produce at the server and thus efficient mechanism must available in order to ensure live content availability and accessibility. With localisation in place, some pre-cautionary actions need to be taken to ensure required live content is available at the local clients. Otherwise, the live content cannot be downloaded and peers are unable to continue to play the streaming content. By having localisation that ideally favours the local clients, a mechanism in piece selection has to ensure live contents are available in the local clients. Thus, localisation needs to balance the aims - localising the clients and also in providing the required live content locally in order to preserve the live playback.

- **To engineer the optimised localisation framework onto CNs.** The design of the framework is built in a python testing framework, which run P2P live streaming within the CNs network. The localisation framework is targeting to select a sufficient amount of local clients and preserve the live playback by ensuring the live contents are available at the clients. The