SCALEABLE AND SMOOTH TCP-FRIENDLY RECEIVER-BASED LAYERED MULTICAST PROTOCOL

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"To my dearest mother and father -
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Abstract

In the presence of heterogeneity and scalability, i.e. the case when delivering real-time television content over the Internet, receiver-based layered multicast communication is the most efficient way to deliver real-time video data to a large number of receivers. *TCP-friendly Receiver-based Layered Multicast Protocol* (TRLMP) is a protocol that supports layered multicast real-time video delivery, while maintaining the fair sharing of the network resources. However, there is room for improvement on the current TRLMPs. Some of the current TRLMPs and their techniques are not efficient in supporting the delivery of real-time video data on the Internet, in particular when the number of receivers is very large. The current TRLMPs' techniques do not allow the receivers to: 1) estimate *Round Trip Time* (RTT) in a scalable manner; and 2) achieve a steady reception rate because of volatile loss rate estimation. These problems result in stability and scalability problems for TRLMPs. In this thesis, we propose a new TRLMP called *Scalable, Smooth and TCP-friendly Receiver-Based Layered Multicast Protocol* (SS-TRLMP) to address the problems of the current TRLMP.

Similar to other TRLMPs, SS-TRLMP relies on a TCP-equation model to control congestion and fair behaviour of the protocol. However, the equation model requires RTT data, which is problematic to estimate when the number of receivers is too large. In order to address this problem, we proposed the *Scalable RTT Estimation Technique* (SRTT) for layered multicast communication. The technique models *Transmission Control Protocol* (TCP) behaviour more accurately than the current RTT estimation techniques. Moreover, the technique is simple and can be easily implemented in the current Internet infrastructure.

Stability is one of the requirements of real-time video applications. However, even with the current loss rate smoothing techniques, TRLMPs behaviour is highly volatile. Moreover, in layered multicast communication there is no synchronisation of packets between multicast layers, which causes misinterpretation of loss events at receivers. We address these problems with packet re-ordering at the receiver and the *2-Step Loss Filtering Technique*. Packet reordering technique enables the TRLMP to estimate accurate loss rate similar to TCP, and 2STEPS provides better stability and responsiveness than the current techniques.

Finally, by combining the techniques of the current TRLMPs and the proposed techniques, we designed SS-TRLMP. The proposed SS-TRLMP has the following properties: TCP fairness, scalability and stability.

Abstrak

Dengan kehadiran heteroginiti dan skalibiliti dalam komunikasi Internet, iaitu dalam kes penghantaran kandungan televisyen melalui Internet, komunikasi *receiver-based layered multicast* adalam merupakan kaedah yang paling efisyen untuk penghantaran data video kepada penerima sangat ramai. *TCP-friendly Receiver-based Layered Multicast Protocol* (TRLMP) adalah protokol yang menyokong penghantaran video dalam masa-nyata dan pada masa yang sama mengekalkan penggunaan sumber rangkaian secara adil dan saksama. Namun begitu masih terdapat ruang untuk penambahbaikan terhadap TRLMP. Sebahagian TRLMP sekarang dan teknik-tekniknya tidak efisyen dalam menyokong penghantaran data video secara masa-nyata di Internet, terutamanya bila jumlah penerima adalah sangat ramai. Teknik-teknik dalam TRLMP sekarang tidak dapat: 1) menganggar *Round Trip Time* (RTT); dan 2) mencapai kadar penerimaan yang stabil kerana anggaran kadar kehilangan paket yang tidak stabil dalam teknik sekarang. Masalah-masalah ini menyebabkan TRLMP menjadi tidak stabil dan tidak skala bila menghantar data video masa-nyata kepada jumlah penerima yang sangat ramai. Dalam tesis ini satu protokol baru telah dicadang bagi mengatasi masalah tersebut. Protokol ini dinamakan sebagai *Scalable, Smooth and TCP-friendly Receiver-Based Layered Multicast Protocol* (SS-TRLMP).

Seperti mana TRLMP lain, protokol ini bergantung kepada model persamaan *Transmission Control Protocol* (TCP) untuk mengawal keadilan dan kesaksamaan penggunaan sumber rangkaian dan tingkahlaku protokol. Namun begitu persamaan ini memerlukan penganggaran RTT. Penganggaran RTT adalah sukar untuk dilakukan bila jumlah penerima terlalu besar. Untuk mengatasi masalah ini, *Scalable RTT Estimation Technique* (SRTT) telah dicadangkan. Teknik ini memodelkan tingkahlaku TCP secara lebih tepat berbanding teknik-teknik lain. Tambahan pula teknik ini adalah ringkas dan mudah untuk dilaksanakan dalam infrastuktur Internet sekarang.

Kestabilan adalah salah satu keperluan penting bagi aplikasi video masa-nyata. Namun begitu walaupun dengan dengan menggunakan teknik penstabil sekarang, anggaran kadar kehilangan paket TRLMP masih lagi tidak stabil. Tambahan pula dalam komunikasi *multicast* berlapisan tidak ada penyelarasan paket antara lapisan *multicast* yang berbeza. Ini mengakibatkan salah interpretasi berkenaan urutan paket oleh penerima. Masalah-masalah ini dapat diatasi dengan kaedah penyusunan semula urutan

paket oleh penerima dan *2-Step Loss Filtering Technique*. Teknik penyusunan semula urutan paket membolehkan TRLMP menganggar kadar kehilangan paket sebagaimana pengiraan kehilangan paket dalam TCP. Manakala 2STEPS membolehkan protokol mencapai kesatabilan dan tindakbalas yang lebih baik berbanding teknik-teknik sekarang.

Akhir sekali, dengan menggabungkan teknik-teknik yang telah dicadangkan dengan teknik-teknik TRLMP masa kini protokol SS-TRLMP telah direkabentuk. SS-TRLMP mempunyai ciri-ciri saksama kepada TCP, skalabiliti dan stabiliti.

Declarations

Some parts of the work presented in this thesis have been published in the following articles and poster presentations:

Osman Ghazali & Suhaidi Hassan, Implementation of a TCP-Friendly Layered Multicast Protocol on NS-2 Simulator, in the Proceedings of the IEEE NS-2 Workshop, Serdang, Malaysia, 24^{th} - 25^{th} November, 2004.

Osman Ghazali & Suhaidi Hassan, An Assessment of Current Layered Multicast Techniques for Real-Time Video, in the Proceedings of the International Computer Symposium (ICS 2004), Taipei, 15^{th} - 17^{th} December, 2004.

Osman Ghazali & Suhaidi Hassan, A Comparative Study of Loss Rate Estimation Techniques in a Layered Multicast Protocol, in the Proceedings of the 2nd ECTI Annual International Conference (ECTI-CON 2005), Pattaya, Thailand, 12^{th} - 13^{th} May, 2005.

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Osman Ghazali, Suhaidi Hassan, Mohd Azam Abdul Rahman Evaluation of Round Trip Time for Layered Multicast Protocol, in the Proceedings of MMU International Symposium on Information and Communications Technologies (M^2USIC 2007), Petaling Jaya, Malaysia, 19^{th} -20^{th} November, 2007.

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List of Abbreviations

1STEP	1 Step Loss Filtering Technique
2STEPS	2-Step Loss Filtering Technique
α	Rate factor
ALI	Average Loss Interval Algorithm
BL	Base Layer
CBR	Constant Bit Rate
CoV	Coefficient of variation
DORTT	Double One-way Transmission-time Round Trip Time Estimation Technique
DVMRP	Distance Vector Multicast Routing Protocol
EL	Enhancement layer
ERA	Explicit Rate Adjustment Protocol
FIFO	First In First Out
FLID-DL	Fair Layered Increase/Decrease with Dynamic Layering
FRTT	Fixed Round Trip Time Estimation Technique
FRTTQD	Fixed Round Trip Time Estimation Technique with Queuing Delay
FTP	File Transfer Protocol
HALM	Hybrid Adaptation Layered Multicast
HLMP	Hybrid Layered Multicast Protocol
HRTT	Hierarchical Round Trip Time
HTTP	Hypertext Transfer Protocol
IETF	International Engineering Task Force
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IPV4	Internet Protocol Version 4
IPV6	Internet Protocol Version 6
LAN	Local Area Network
LB	Lower Boundary
LBNL	Lawrence Berkeley National Laboratory
LER	Loss Event Rate
LMP	Layered Multicast Protocol

MRTT	Multicast Round Trip Time
ns-2	Network Simulator Version 2
ORTT	One-way Transmission-time Round Trip Time
OTcl	Object-oriented Tool Command Language
OTT	One-way Transmission Time
PGMCC	Pragmatic Multicast Congestion Control
PIM-SM	Protocol Independent Multicast Sparse Mode
PLM	Packet-pair Receive-driven Layered Multicast
PLR	Packet Loss Rate
PRT	Packet Reordering Technique
QoS	Quality of Service
R1	End host closest router
R2	R1 immediate router
RED	Random Early Detection
RFC	Request for Comment
RLMP	Receiver-based Layered Multicast Protocol
RNG	Random Number Generator
RRTT	Round RTT
RTP	Real-time Transport Protocol
RTT	Round Trip Time
SMCC	Smooth Multi-rate Multicast Congestion Control
SMTP	Simple Mail Transfer Protocol
SRTT	Scaleable Round Trip Time
SS-TRLMP	Scaleable and Smooth TCP-friendly Receiver-based Layered Multicast protocol
TCP	Transmission Control Protocol
TFCCP	TCP-Friendly Congestion Control Protocols
TFLMP	TCP-friendly Layered Multicast Protocol
TFLMP-1STEP	TCP-friendly Layered Multicast Protocol with Packet Reordering Technique and 1 Step Loss Filtering Technique
TFLMP-2STEPS	TCP-friendly Layered Multicast Protocol with Packet Reordering Technique and 2-Step Loss Filtering Technique

TFLMP-ALI	TCP-friendly Layered Multicast Protocol with Average Loss Interval Algorithm
TFLMP-DORTT	TCP-friendly Layered Multicast Protocol with Double One-way Transmission-time Round Trip Time Estimation Technique
TFLMP-FRTT	TCP-friendly Layered Multicast Protocol with Fixed Round Trip Time Estimation Technique
TFLMP-FRTTQD	TCP-friendly Layered Multicast Protocol with Fixed Round Trip Time Estimation Technique with Queuing Delay
TFLMP-MM16	TCP-friendly Layered Multicast Protocol with Min-max Algorithm and 16 Windows History
TFLMP-MM8	TCP-friendly Layered Multicast Protocol with Min-max Algorithm and 8 Windows History
TFLMP-RRTT	TCP-friendly Layered Multicast Protocol with Round Trip Time
TFLMP-SRTT	TCP-friendly Layered Multicast Protocol with Scaleable Round Trip Time
TFMCC	TCP-friendly Multicast Congestion Control
TFRC	TCP-friendly Rate Control
TUCCP	TCP-Friendly Unicast Congestion Control Protocol
TLMP	TCP-friendly Layered Multicast Protocol
TRLMP	TCP-friendly Receiver-based Layered Multicast Protocol
TSMCCP	TCP-friendly Single-layer Multicast Congestion Control Protocols
UB	Upper Boundary
UDP	User Datagram Protocol
USC/ISI	Information Science Institute, University of Southern California
VDO	ViDeOnline
VINT	Virtual Internet Test Bed project
VMCC	Vegas Multirate Congestion Control
WEBRC	Wave and Equation Based Rate Control

Chapter 1

Introduction

Nowadays, the Internet is one of the most important and popular communication mediums. Since its introduction to the public, the Internet very quickly emerged as a new platform for digital communications, businesses and entertainment. For example, currently there are many telephony service providers that are using the Internet as their main communication channel [1], many business transactions are concluded through the Internet [1, 2], many people are communicating via email everyday [3], many people are playing Internet games [4, 5], and many people from all over the world are enjoying media streaming via the Internet [6].

In recent years, video transmission over the Internet has gained popularity both from users and the research community. Many varieties of video-based applications were introduced, among others including online cinema [7-9], instant news broadcasts [7], movies-on-demand [10], live broadcasts [11], and video conferencing [11]. These applications deliver video content to large numbers of clients or receivers across the Internet. Any host connected to the Internet can become a client, receive the video signal, and enjoy online Internet video.

Figure 1.1 shows the overview of video streaming architecture over the Internet. The server or sender is at the left, while the client or receiver is at the bottom right. At the sender side, the sender can stream either live video or stored video to its clients. A video coder encodes raw bit-streams of the video (either live or stored video) into compressed

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