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

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By

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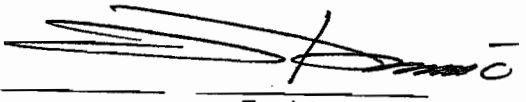

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"To my dearest mother and father -
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# Abstract

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, 24th - 25th November, 2004.

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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 (M²USIC 2007), Petaling Jaya, Malaysia, 19th -20th 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

The contents of the thesis is for internal user only

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