INSTITUT FÜR INFORMATIK

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Masterarbeit

MEADcast Evaluation & Linux Kernel Implementation of the Router

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Hiermit versichere ich, dass ich die vorliegende Masterarbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

München, den 7. Juli 2077

. . . .
(Unterschrift des Kandidaten)

Abstract

Hier steht eine kurze Zusammenfassung der Arbeit. Sie darf auf gar keinen Fall länger als eine Seite sein, ca. eine drittel bis eine halbe Seite ist optimal.

Contents

1 Introduction

1.1 Motivation

Over the last two decades, the number of people with access to the internet has continuously increased at a rate of 5%, resulting in a current total of over 5 billion individual internet users [ITU23]. Furthermore, the unrelenting demand for data has led to an average growth in total bandwidth usage of 30% over the past five years. This development was further accelerated by the COVID-19 pandemic, as the increased reliance on remote work, online education, and digital entertainment surged the bandwidth consumption [Car21]. These growth rates are expected to remain high in the future. Especially Multimedia content like Video Streams, Conferences, and Online Games depict a major portion of the global internet traffic. Video traffic is accountable for more than half of the bandwidth consumed in 2020 [Car21]. Network Operators and Service Providers need to comply with the continuously rising demand.

Already in the late 1980s, Deering and Cheriton proposed a multicast extension to the IP protocol, to facilitate efficient multipoint communication (*1:m, m:n*)[DC90; Dee89]. Multicast offers the advantage, to greatly reduce the occupied bandwidth by condensing identical traffic into a single stream, targeted towards multiple recipients [Cai+02]. Routers may replicate packets of that stream at points where the paths towards the receivers diverge. Many of today's internet services, particularly those with high bandwidth demands, may benefit significantly from multicast delivery [RES06; TD18]. Besides technical benefits, the adoption of multicast communication could reduce the emissions caused by Communication Technology (CT). Several studies assert that networks are accountable for a major portion of today's CT emissions [AE15]. Furthermore, they forecast strongly increasing energy consumption by networks until 2030. Multicast communication has the potential to lower energy consumption and therefore emissions by promoting more efficient use of network resources and potentially reducing the need for additional infrastructure.

1.2 Challenges of Multicast

The application of IP-Multicast has yielded mixed results. Practically all of today's devices support IP-Multicast [RES06]. Furthermore, it is utilized on a local scale, and various protocols like RIPv2 [Mal98], OSPF [Moy98] and mDNS [CK13] rely on multicast.

However, more than thirty years since the initial proposal of IP-Multicast, its global deployment and usage still lags far behind expectations [Dio+00; RES06]. Despite the potential advantages of Multicast, the majority of internet traffic continues to rely on point-to-point communication, known as *unicast*. There are several reasons for the limited usage of IP-Multicast.

Feasibility   Besides the aforementioned advantages, IP-Multicast entails various technical obstacles. In comparison to unicast, it suffers from an increased technical complexity, requiring the interaction of various protocols on multiple network layers [RES06; Dio+00]. Furthermore, multipoint communication in general interferes with the application of today's widespread security mechanisms like encryption [RH03]. IP-Multicast is based on a fixed class D address space [Dee89], which bears an insufficient number of addresses [DT19] and a complex routing procedure [Dio+00; RES06]. Global IP-Multicast availability is limited because successful packet delivery necessitates all routers along the path to support multicast. However, this scenario is unlikely since many commercial routers come preconfigured with IP-Multicast disabled [Aru19]. Moreover, the following paragraph describes, why Network Operators are probably not willing to enable it.

Desirability   So far, Network Operators and ISPs have shown limited efforts to deploy Multicast within their Administrative Domains [Dio+00; RES06]. The additional technical complexity of Multicast requires more extensive management efforts. Moreover, due to the complex routing, infrastructure upgrades may be necessary. ISPs seem to assess this as an unsuitable investment, despite its potential for significant bandwidth savings [Dio+00]. Charging for multicast services is also non-trivial compared to existing unicast billing [RES06]. IP-Multicast hampers Network Operators' ability to anticipate network load, and amplification attacks may become more likely to occur [Dio+00]. As long as there is no growing pressure on ISPs to extend their service offering, increasing multicast deployment is doubtful. Multicast delivery has no direct impact on receivers, so customers are unlikely to apply the required pressure. Moreover, statistics illustrate that more than half of the internet traffic volume is HTTP-based [Clo23], which is not well suited for multipoint communication. Additionally, web browsers, the most widely utilized HTTP clients, are not designed for IP-multicast usage.

1.3 Goal and Contribution

The current state of the internet put forth various unicast-based alternatives, aimed at addressing the absence of a globally usable multicast protocol. One such alternative, known as MEADcast, offers the capability for 1:n sender-based IPv6 multipoint communication over the internet [TD18; DT19]. Key features of MEADcast include the preservation of receiver privacy, technology-agnostic destinations, and zero network support requirements.

   As proposed by Danciu and Tran, the primary goal of this thesis is to conduct a real-world evaluation of MEADcast, utilizing a Linux Kernel implementation of the required router software [DT19]. This step represents a logical progression following previous investigations of MEADcast, which were based on network simulations [TD18] and Software-defined networking (SDN) [Ngu19]. The evaluation will focus on the following aspects:

Feasibility Study   The first part of the evaluation will assess the feasibility of deploying MEADcast in a real network. This aims to identify potential limitations and structural issues of the current protocol specification. Further investigation will examine the practicality of using MEADcast on the internet, taking into consideration concerns related to IPv6 extension header processing.

Performance Evaluation   A comparative performance analysis will be conducted to evaluate MEADcast in comparison to both IP unicast and multicast. This assessment will provide insights into the efficiency and effectiveness of MEADcast as a multipoint communication solution.

Scenario identification   Building on the results of the previous evaluation steps, this phase involves identifying scenarios, application categories, and characteristics that justify the utilization of MEADcast. Thereby, it can be determined where MEADcast may offer advantages and excel in real-world applications.

1.4 Procedure and Structure

To assure the achievement of the previously defined goals this thesis pursues the following procedure. This approach ensures a cohesive narrative, with each chapter building upon the knowledge acquired in the previous sections.

Chapter 1   The introductory chapter depicts the motivation for investigating multipoint communication, highlights the current challenges of IP-Multicast, and articulates the goal of this thesis.

Chapter 2   Moving forward, this chapter establishes the theoretical foundation for subsequent investigations, by examining several multicast protocols, including IP-Multicast, Xcast, and MEADcast. Additionally, the chapter provides a brief overview of Kernel development fundamentals, laying the groundwork for the router implementation.

Chapter 3   With a clear understanding of the relevant protocols and fundamentals, Chapter 3 begins with the selection of metrics to measure the achievement of the thesis' objectives. Subsequently, experiments are designed, aimed to capture these metrics. This chapter finishes by outlining the testbed requirements derived from the experiments and presents the corresponding design.

Chapter 4   This chapter provides technical insights into the Kernel implementation of the router software and details the specifications of the testbed. Hereby, the chapter serves as the basis for the practical experiments.

Chapter 5   Following the conduction of our experiments, Chapter 5 presents the obtained results. These findings are critically evaluated with respect to the thesis' overarching goal, providing valuable insights into the feasibility and performance of MEADcast. This opens the door to identify scenarios and applications the protocol is well suited for.

Chapter 6   The closing chapter summarizes the findings and draws conclusions from this research. Additionally, it outlines potential avenues for further work and exploration in this field.

2 Background Work

2.1 Multicast

Multicast is a technique of sending data one-to-many or many-to-many. Related technologies are unicast, broadcast and anycast.

2.1.1 IP Multicast

- Separate address space
- IGMP / MLD
- Intra-Domain Routing: DVMRP, MOSPF, PIM dense/spare
- Inter-Domain Routing: MBGP, MSDP

2.1.2 Multicast over Unicast

- Xcast family (Xcast, Xcast+, GXcast, Xcast6 Treemap (island))
- MEADcast
- Bier

Xcast

Traditional multicast scales well with large multicast groups but have issues with a high number of distinct groups. Xcast is a mutlicast protocol with complementary scaling properties compared to the traditional approach [Boi+07]. The protocol is designed with the key idea of supporting huge numbers of small multicast sessions. Xcast achieves this by explicitly encoding the receiver addresses in each packet, instead of using a multicast addresses [Boi+07].

3 Design

3.1 Metrics

3.2 Experiments

3.3 Testbed

4 Implementation

4.1 Router

4.2 Testbed

5 Evaluation

6 Summary

6.1 Conclusion

6.2 Further Work

List of Figures

Acronyms

CT Communication Technology. 1

SDN Software-defined networking. 2

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