A Study on SDN-based Pragmatic Service Management for Network Applications

著者	Guillen Barja Luis Alberto
学位授与機関	Tohoku University
学位授与番号	11301甲第19357号
URL	http://hdl.handle.net/10097/00130247

氏名	GUILLEN BARJA LUIS ALBERTO（ギリエ バルハ ルイス アルベルト）
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論 文 審 査 委 員	（主査）東北大学教　授　菅沼　拓夫 東北大学教　授　加藤　寧　東北大学教　授　周　暁 東北大学准教授　阿部　亨　東北大学准教授　和泉　諭

論 文 内 容 の 要 旨

Chapter 1 Introduction

The integration of the cyber (i.e., networking, software, storage) and the physical (i.e., humans, hardware, and natural elements) space will enable the realization of Society 5.0. This new evolution in society seeks to solve social problems by using cutting-edge technologies (i.e., IoT, Big-data, AI, and robotics). The integration into a cyber-physical space, driven by business applications, will also change the way people interact with each other and with their surroundings. However, for this interaction, having efficient networking and communication technology is critical.

From among those business applications, Network Applications (NA)—i.e., programs that run on different end-systems and communicate over the Internet—have been the façade and the rationale of the Internet. Although in the early decades of Internet, applications such as email, file transfer or the World Wide Web (WWW) had a significant influence in society, in recent years Multimedia and Social applications enabled the change of user paradigm from simple consumers to producers, which influenced on how current and future Internet traffic will grow exponentially. It is foreseen that in a few years, about 80% will be video traffic not only from video services but also from other applications such as surveillance, gaming, or healthcare.

Services such as YouTube, Netflix, Amazon are vastly used worldwide daily; these Multimedia Applications are deployed in distributed Content Delivery Networks (CDN), which are overlay networks comprised of servers that store the content in nodes geographically dispersed so that they can deliver the service closer to the end-user. However, these services still run on top of best-effort services, and therefore, practical service management for multimedia applications is still needed.

In that regard, Software-defined Networking (SDN), which is an emerging network technology that it is changing the way networks are managed. SDN allows the decoupling of the control plane and the forwarding plane. The controller acts as the central entity that interacts with lower and higher-level applications, which allows a centralized, programmable, and flexible control. Therefore, the hypothesis in this study is that SDN can help in the service management for NA.

The main goal of this dissertation is to realize pragmatic service management for NA, based on two major foundations: The collaboration of components, and using SDN as the enabler of that collaboration. In particular, due to its influence in future traffic, Multimedia Applications were used as the use-case.

The target issues were addressed from two points of view, the perceived user satisfaction of the service (or Quality of Experience QoE) and the performance (or Quality of Service QoS) with particular focus on the network component.

Chapter 2 SDN-based Quality of Experience Management

QoE, which is defined as the perceived user satisfaction, has become an essential element to evaluate a service. In particular, for video streaming services, factors such as the video start delay, freezing events, quality shifts, or the media throughput (video quality) affect the most to the overall QoE. Currently, Dynamic Adaptive Streaming over HTTP (DASH) has become the de-facto standard for—stored and live—video content delivery. In DASH, media is cut into pieces, called segments, which can be requested over HTTP in different representations. Clients request a specific segment based on various parameters, such as the network status or the device specifications, in a continuous adaption cycle until all the segments of the video are played. However, since DASH does not define the implementation details, there are various criteria for performing the adaption. Therefore, since the adaption happens based on inaccurate information, and there is no control over the resource assignment, these are distributed unfairly among clients. Additionally, since HTTP uses TCP as the transport protocol, which was not designed to reduce delay, it becomes a performance bottleneck.

In this Chapter, the main issue addressed was the lack of collaboration of elements (i.e., network, transport, and user) to handle the resource assignment in DASH. Therefore, the main goal was to improve the QoE management for Multimedia Application using video streaming with DASH as the use-case. The proposal consists of an SDN-based QoE management for DASH with multi-element collaboration for quality adaption using HTTP/3, whose major change is the usage of QUIC as the underlying transport layer.

Based on the user profile, which contains the information from the service provider, we calculate a category to send the segments via an adequate end-to-end route. To test the feasibility and effectiveness, we used an emulated environment, and measure various QoE metrics (i.e., number of stalls, media throughput, and the number of quality shifts). Based on the obtained results, this chapter showed how the proposed approach could pragmatically improve the QoE.

Chapter 3 SDN-based Quality of Service Management

Multimedia Applications are usually deployed in distributed CDNs and hosted in Data Centers (DC), which provide highly reliable infrastructure. However, when a failure occurs, moving data within and outside the DC is costly, not only in terms of computation but also network bandwidth. Therefore, storage and network management are critical for QoS in Multimedia Applications. QoS, which is defined as the characteristics of service to satisfy stated and implied user requirements, has been crucial to ensuring the compliance of Service Layer Agreements (SLA).

In that regard, Distributed Storage Systems (DSS), which combines network and storage capabilities, offer storage persistence and availability. However, the network component is left to legacy technologies. For instance, routing control and programmability are limited, creating a load imbalance in the network and the service. Therefore, this Chapter addressed these problems and improved the QoS of Multimedia Applications by enhancing the performance of CDNs with DSS.

The proposal consists of an SDN-based control method for DSS, with features as on-demand inverse multiplexing, dynamic multipath routing, and a hybrid server-network load balancing to use the resources effectively.

The performance test was performed using an emulated environment in various contexts and parameters (e.g., completion time, cumulative network and service load, overall throughput), where the proposed approach showed a considerable improvement compared to others, concluding that it is possible to further improve the QoS in Multimedia Applications by a centralized SDN-based control method that enhances the performance of CDN with DSS.

Chapter 4 SDN-based Service Reliability Management

Service reliability of NA will not be possible without Network survivability, which is defined as the capability of a network to maintain the service continuity even in the presence of failures. Previous Chapters showed how SDN offers various benefits to QoS and QoE; however, the SDN controller becomes a single-point-of-failure. If a controller fails, even if it is functional, the device is not programmable. Moreover, in the case of a large-scale failure (e.g., disaster), a vast amount of devices is likely to fail (including controllers). Most of the current solutions (either legacy or SDN-based) only consider single or few devices/link failures, but large-scale multi-controller failures are still not adequately tackled. Therefore, the main goal of this Chapter was to improve the communication reliability immediately after a widespread failure in SDN so that it is possible to allow service continuity.

The proposal consists of a protection mechanism to mitigate the impact of large-scale failure on controller communication. We take advantage of the possible ways to connect to a controller (out-of-band and in-band) and find a trade-off between restoration and protection mechanisms. In particular, the protection mechanism consists of three stages: Controller Disconnection Avoidance, which calculates a given number of alternative paths to control-lines around the disaster using in-band connections. The next stage, Data Communication Protection, assigns a Risk Factor Index (RFI) to all links to alert higher-level mechanisms of the risk. Finally, once the predicted failure starts to occur, the last stage: Disaster Impact Monitoring, progressively updates the RFI every given interval.

The proposal was implemented and tested in a simulated environment, and the results showed that the proposed approach achieved a higher success rate at the data plane, considerably reduces the percentage of non-operational devices at the control plane with just a small fraction of the implementation cost compared to traditional approaches.

Chapter 5 Conclusions

In general, the main goal of this study was to realize pragmatic service management for NA, which was based on two major foundations: The collaboration of components, and the usage of SDN as the enabler of such collaboration. The target issues were addressed from the QoE and QoS point-of-view. In the first case (QoE), we discussed the lack of collaboration of elements to handle the resource assignment and shown that the QoE of Applications can be improved by the proposed method, which uses multi-level collaboration with SDN. In the second case (QoS), we addressed two features: service performance and reliability; by a hybrid load balancing control method, we could achieve higher performance, and by a three-stage SDN controller communication, we shower how to improve reliability, even in cases where multiple failures occur.

In the future, there are many directions in which this study might be extended. For instance, in Chapter 2, experimenting with multiple parallel segment delivery over HTTP/3 or using predictive segment request from content providers might be an exciting direction. In Chapter 3, using predictive path selection to optimize the route assignment, or using Network Function Virtualization (NFV) can further improve the application. Finally, in Chapter 4, investigating the impact of multiple failure models in heterogeneous network environments would enhance the adaption scheme.