

Load Specification and Load Generation for Multimedia Traffic Loads in Computer Networks

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Editorial

The number of users in contemporary computer and communication networks is steadily increasing – in some of the existing networks (such as the Internet and various mobile networks) this growth is even exponential. However, not only the number of network users is growing but also the amount of traffic, as it is introduced into the network by single users, is increasing very quickly. Thus, there exists an increased probability for the occurrence of significant network bottlenecks as a consequence of overall network traffic growth in case of an inadequate network dimensioning. In particular, if applications that generate so called continuous media streams (such as voice traffic or video streams) are used, the resulting requirements with respect to transmission and switching capacities of the underlying networks can become very demanding; and this may also be true for the requirements with respect to the quality of the offered network services (QoS).

Therefore, analyzing and predicting the performance of computer networks for realistic user-behavior and for realistic traffic scenarios, respectively, becomes increasingly relevant. Moreover, quite often performance predictions are required for high load and over-load situations. So, there is a significant demand for methods to characterize and formally describe loads in computer networks as well as a need for (hardware- or software-based) load generators being able to produce, in a realistic manner, various kinds of traffic loads (from e-mails or files to be transmitted to the transfer of video frames as elements of a video stream).

This thesis – representing the PhD thesis of Mrs. Jing Cong – has been motivated primarily by the lack of concepts, architectural models, and tools supporting load generation at arbitrarily chosen service interfaces in networks. The author has elaborated a variety of results which are theoretically founded but, at the same time, are also very relevant for practical use in such areas as characterization, specification, transformation, and generation of load. In particular, the thesis comprises: a specification technique which is generally applicable to formally describe load at arbitrary service interfaces within a given protocol hierarchy; load models specified by a way of example for various multimedia traffic loads; an innovative architectural model for a unified load generator combined with load transformation; a prototype implementation of a load generator (UniLoG – Unified Load Generator) based on the proposed architectural model; conceptual approaches for a distributed generation of loads in networks; and, last but not least, a large variety of case studies. The case studies, in particular, strongly underline, on one hand, the practical relevance of the solution methods and approaches presented in this thesis but also, on the other hand, they clearly demonstrate the very broad spectrum of applicability of load generators for the purpose of performance evaluation, QoS management, and in the area of traffic engineering for complex computer networks. Thus, this innovative research report should be a valuable source of information to researchers, developers, network managers, and students with strong interest in performance engineering and traffic engineering of networks.

Abstract

The integration of communication services, the variety of different types of load sources, and the rapid growth of network dimensions lead to complex traffic loads in communication and computer networks to date. In particular, these complex traffic loads may cause transmission congestion which would induce the unsatisfactory provisioning of Quality of Service (QoS) for multimedia applications. In this instance, it is very important to investigate efficient network mechanisms and to establish appropriate protocols to optimize the network performance. Understanding of the characteristics of network loads in the real world is a precondition to investigate the reasons why the performance, the architecture, and the QoS of the applications will be significantly influenced by some specific traffic scenarios.

This thesis focuses on establishing a unified methodology for load generating at different interfaces in the protocol hierarchy of communication and computer networks. The unified load generator is based on a formal load specification technique established by us which enables one to describe the user behaviors at different interfaces with an optional degree of detail, and constitutes a framework of load modeling for different applications provided in networks.

At the beginning of this thesis, we introduce some basic concepts relating to load modeling and load generation. Based on the concept of loads, a new framework for load generating, which combines the load generation and the load transformation processes existing in real networks, is presented. The application of the load transformers may significantly simplify the secondary load generation, and enables one to study the impact of the secondary loads on some concurrent distributed applications of interest.

As one of the main topics of this thesis, a formal load specification technique, based on earlier research results, is extended and established. On one hand, the formal load specification technique provides a clean separation between specifying the elementary user behavior and specifying the set of request types at a chosen interface; on the other hand, it enables us to specify the reactions of the service systems. Therefore, a dynamic load generation process that is close to the real scenarios can be supported.

After introducing the formal load specification technique, an architecture for a unified load generator (*UniLoG*) is presented and some crucial implementation issues are discussed. The unified load generator is dependent neither on a specific interface nor on a specific network application; thus, the basic requirement on unification is fulfilled. A prototype of the UniLoG load generator has been implemented by us. A user-friendly GUI is provided to support the load modeling and the parameterization of the load models. Concrete traffic loads can be created in existing networks by using an appropriate adapter component.

A variety of experiments are conducted to prove the correctness of the components of the UniLoG prototype. Another series of experiments investigate the influence of the background loads, which are generated by using the prototype of UniLoG, on the level of QoS for streaming media applications. All these experiments show that the UniLoG load generator is a valid and flexible tool for generating artificial traffic loads in communication and computer networks.

Furthermore, proposals of how to extend the UniLoG load generator for distributed load generation are presented.

Kurzfassung

Wegen des verstärkten Einsatzes multimedialer Anwendungen (z.B. Videokonferenzen, Bildtelefon und Anwendungen des E-Learning) sowie des schnellen Wachstums der Anzahl von Benutzern sind – trotz der beeindruckenden Geschwindigkeitssteigerungen bei den Übertragungs- und Vermittlungstechniken – Leistungsengpässe in heutigen Rechnernetzen dennoch häufig vorhanden. Zur Vermeidung der Leistungsengpässe und zur Deckung des erheblichen Kommunikationsbedarfs multimedialer Anwendungen ist es heutzutage äußerst wichtig, die hochdynamischen Verkehrsflüsse zu prognostizieren und diese Verkehrsprognosen bei der Netzplanung und -dimensionierung zu berücksichtigen. Um Leistungs- und Verhaltensanalysen von Kommunikationssystemen durchführen zu können (wie z.B. Bewertung der Leistungsfähigkeit eines Netzes, Durchführung der QoS-Studien bei variabler Netzbelastung) ist eine hinreichend realistische Lastgenerierung unverzichtbar.

Diese Dissertation widmet sich einem verallgemeinerten, auf einer formalen Lastbeschreibungstechnik basierenden Ansatz zur Lastgenerierung. Mittels dieses Ansatzes lassen sich abstrakte Lasten (Auftragssequenzen) für verschiedenartige Dienstschnittstellen eines dienstintegrierten Netzes spezifizieren und zur Generierung synthetischer, multimedialer Verkehrslasten heranziehen.

Am Anfang dieser Dissertation stellen wir einige Grundkonzepte in Bezug auf Lastmodellierung und Lastgenerierung vor. Basierend auf dem Konzept der Last wird eine neue Architektur für einen möglichst universell einsetzbaren Lastgenerator erstellt, mit der ein Lastgenerator unter Nutzung sogenannter Lasttransformatoren konstruiert wird. Die Anwendung der Lasttransformatoren kann die Erzeugung der Sekundärlast erheblich vereinfachen und ermöglicht, die Auswirkung der Sekundärlasten auf einige ausgewählte Anwendungen zu studieren.

Als ein Hauptteil dieser Dissertation wird, aufsetzend auf frühere Resultate, eine neue Technik zur formalen Beschreibung von Verkehrslasten im Hinblick auf eine Lastgenerierung in Echtzeit entwickelt. Einerseits kann diese formale Lastbeschreibungstechnik die von Benutzern erzeugte Last an unterschiedlichen Systemschnittstellen bei variabel wählbarem Detaillierungsgrad präzise spezifizieren. Andererseits wird die realitätsnahe dynamische Lastgenerierung durch die Berücksichtigung der Reaktion von Bediensystemen unterstützt.

Nachdem die formale Lastspezifikationstechnik vorgestellt worden ist, wird eine Architektur für einen verallgemeinerten Lastgenerator erstellt, die auf die formale Lastbeschreibungstechnik aufsetzt. Ein erster Prototyp für den verallgemeinerten Lastgenerator (nämlich *UniLoG*) ist bereits von uns realisiert worden. Dieser Prototyp unterstützt die Funktionen der formalen Beschreibung von Lasten durch eine grafische Benutzungsoberfläche. Konkrete Lasten können als Konsequenz der Übergabe von abstrakten Aufträgen mittels einer passenden Adapter-Komponente generiert werden.

Im Rahmen von Fallstudien unter Nutzung des UniLoG-Lastgenerierungswerkzeuges zeigt diese Dissertation auch auf, dass sich zum einen mit dem entwickelten Lastgenerierungskonzept die Echtzeitanforderungen bei der Erzeugung realistischer Lasten in der Tat erfüllen lassen und dass die angestrebten Verhaltensanalysen von Netzen mit deutlich reduziertem Aufwand gegenüber konventionellen Ansätzen erzielt werden können.

Ausserdem wird ein Konzept zur verteilten Lastgenerierung aufsetzend auf der zentralisierten Lastgenerierung erstellt.

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