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Service level agreements (SLAs) parameter negotiation between heterogeneous 4G wireless network operators

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A B S T R A C T

We are currently witnessing a growing interest of network operators to migrate their existing 2G/3G networks to 4G technologies such as long-term evolution (LTE) to enhance the user experience and service opportunities in terms of providing multi-megabit bandwidth, more efficient use of radio networks, latency reduction, and improved mobility. Along with this, there is a strong deployment of packet data networks such as those based on IEEE 802.11 and 802.16 standards. Mobile devices are having increased capabilities to access many of these wireless networks types at the same time. Reinforcing quality of service (QoS) in 4G wireless networks will be a major challenge because of varying bit rates, channel characteristics, bandwidth allocation and global roaming support among heterogeneous wireless networks. As a mobile user moves across access networks, to the issue of mapping resource reservations between different networks to maintain QoS behavior becomes crucial. To support global roaming and interoperability across heterogeneous wireless networks, it is important for wireless network operators to negotiate service level agreement (SLA) contracts relevant to the QoS requirements. Wireless IP traffic modeling (in terms of providing assured QoS) is still immature because the majority of the existing work is merely based on the characterization of wireless IP traffic without investigating the behavior of queueing systems for such traffic. To overcome such limitations, we investigate SLA parameter negotiation among heterogeneous wireless network operators by focusing on traffic engineering and QoS together for 4G wireless networks. We present a novel mechanism that achieves service continuity through SLA parameter negotiation by using a translation matrix, which maps QoS parameters between different access networks. The SLA matrix composition is modeled analytically based on the G/M/1 queueing system. We evaluate the model using two different scheduling schemes and we derive closed form expressions for different QoS parameters for performance metrics such as packet delay and packet loss rate. We also develop a discrete event simulator and conduct a series of simulation experiments in order to understand the QoS behavior of corresponding traffic classes.

1. Introduction

Third-/fourth-generation (3G/4G) systems have been designed to provide high-speed data services and support multimedia applications over mobile personal communication networks [1]. Universal mobile telecommunication system (UMTS) has been the predominant standard for third-generation mobile telecommunication. Developed by 3GPP, UMTS has evolved

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from the current Global System for Mobile Communications (GSM) [2]. Similarly CDMA2000 which is based on code division multiple access (CDMA) is the second major standard for 3G and was developed by 3GPP2 [3]. Currently, there is a growing interest of wireless network operators to migrate their existing 2G/3G networks to 4G technologies such as LTE [4,5]. To construct an effective 4G network for provisioning future mobile services in the presence of asymmetric multimedia packet data traffic, variable data rates, packet sizes and delay, and quality of service (QoS) becomes a critical issue. Along with this QoS issue, there is a strong deployment of different packet data networks such as those based on IEEE 802.11 (wireless local area networks) and 802.16 (broadband wireless access). Mobile devices continue to have increased capability to access many of these wireless networks types. As a mobile user moves between access networks, the mapping of QoS requirements to resource reservations between different networks becomes an important issue. Currently, there is no single unified reservation mechanism in 3G/4G because there is a range of new deployments and operators that are migrating their current mobile networks to different standards. To support global roaming and interoperability across heterogeneous wireless networks, it is important for wireless network operators to negotiate SLA contracts that satisfy the QoS requirements.

The area of quality of service (QoS) has matured rapidly over the past decade. Today there are three main QoS frameworks that can provide service differentiation and support for sensitive applications namely, IntServ [6], DiffServ [7] and MPLS [8]. IntServ and DiffServ can be regarded as mechanisms for translations and descriptions of queuing and scheduling disciplines whereas MPLS relies on underlying mechanisms to provide the requested behavior. All the three frameworks rely on fundamental techniques for separating traffic classes and treating these classes independently through queuing and scheduling disciplines. The different classes have set boundaries on certain traffic parameters such as average and peak bandwidth and delay and the combination of queuing and scheduling disciplines are engineered to meet these requirements. It is therefore vital for QoS frameworks that, modeling of traffic behavior through different domains be accurate, so that resources can be assigned as accurately as possible.

During the past decade, researchers have made significant efforts to understand the nature of Internet traffic and it has been proven that Internet traffic exhibits self-similar properties. The first study, which stimulated research on self-similar traffic, was based on measurements of Ethernet traffic at Bellcore [9]. Subsequently, the self-similar feature has been discovered in many other types of Internet traffic including studies on transmission control protocol (TCP) [10,11], WWW traffic [12], VBR video [13] and signaling system No 7 [14]. Further studies into the characteristics of Internet traffic have discovered and investigated various properties such as self-similarity [15], long-range dependence [16] and scaling behavior at small time-scale [17]. The Refs. [18,19] provide two extensive bibliographies on self-similarity and long-range dependence research covering both theoretical and applied papers on the subject.

With the increasing demand of Internet connectivity and the flexibility and wide deployment of IP technologies, we have witnessed a paradigm shift toward IP-based solutions for wireless networking [20]. Several wireless IP architectures have been proposed [21–27] based on IP QoS models such as IntServ, DiffServ, and MPLS. 3GPP has also introduced a new domain called IP multimedia subsystem (IMS) for UMTS to deliver innovative and cost-effective services such as IP telephony, media streaming, and multiparty gaming by providing IP connectivity to every mobile device [28]. IMS is also included in the new flat IP architecture of LTE. As a result, in recent years, researchers have focused on understanding the nature of wireless IP traffic and it has been convincingly demonstrated by numerous high-quality studies [29–32] that multimedia traffic carried by 3G/4G wireless networks also exhibit self-similarity and long-range dependence (LRD), the traffic attributes which classical tele-traffic theory based on Poisson models fail to capture. Much of the current understanding of wireless IP traffic modeling is based on the simplistic Poisson model, which can yield misleading results and hence poor wireless network planning. Since the properties and behavior of self-similar traffic is very different from traditional Poisson or Markovian traffic, several issues need to be addressed in modeling wireless IP traffic to provide end-to-end QoS to a variety of heterogeneous applications. Moreover, unfortunately, the area of wireless IP traffic modeling in terms of providing assured QoS is still immature because most efforts in this area to date have focused primarily on the characterization of wireless IP traffic without investigating the behavior of queueing systems under such traffic conditions.

In our recent work [33] on SLAs between heterogeneous wireless DiffServ domains, we have found that there is a need for a better understanding of traffic behavior on queuing systems in order to develop efficient traffic differentiation techniques and accurate service level agreements (SLA). In this work, we focus on translation matrices, which are used by mobile terminals as they move across different wireless QoS domains (access domains). Wireless access domains are resource constricted and optimization of resource usage is of utmost importance from a purely commercial perspective since resources are expensive. Being able to accurately derive these matrices will reduce resource consumption.

2. Related work

Current works are focusing on a wide range of issues related to IP/wireless traffic modeling along with its application to 3G/4G networks. Typical areas of investigation include mobility management, QoS, interoperability, and service level agreements (SLAs). Consequently, we highlight only related efforts in these areas below.

2.1. Prior work on self-similar traffic modeling in fixed IP and wireless IP networks

During the past decade, substantial work has been done on Internet traffic modeling based on queueing theory in the presence of self-similar traffic [34–43]. We highlight few and most relevant of them. In [34], it was shown that, with