Computer Networks 74 (2014) 114–140

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Providing service assurance in mobile opportunistic networks

Bhanu Kaushik [a,*], Honggang Zhang [b], Xinyu Yang [c], Xinwen Fu [a], Benyuan Liu [a], Jie Wang [a]

[a] Department of Computer Science, University of Massachusetts, Lowell, MA 01854, USA
[b] Department of Computer and Information Science, Fordham University, Bronx, NY 10458, USA
[c] Department of Computer Science and Technology, Xi'an Jiaotong University, PR China

ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 1 July 2014
Accepted 2 July 2014
Available online 26 September 2014

Keywords:
Auction
Ad-hoc network
Collaborative data sharing
Mobile data offloading
Service assurance
Wireless network

ABSTRACT

Concomitant to the growing popularity of Internet enabled mobile devices such as smartphones, tablets, PDAs, portable media players etc., however, are the concerns about availability of Internet access points for these devices. Network traffic originating from these devices has marked a multi-fold increase over the past few years. This increase in network traffic has in turn resulted in increased content availability and maintainability cost to the cellular service providers. Major challenges faced by mobile Internet users are limited hardware resources (3G or LTE) or exhaustion of carrier enforced data plans. Thus, users often either overpay for service availability such as (3G or LTE) or suffer incapability of accessing Internet services. In this paper, we argue that the ad-hoc network comprising of spatio-temporally co-existing users, identified as "Familiar Strangers" could be harnessed for viral dissemination of mobile application data. We present the architecture of a collaborative data sharing framework which comprises of two services, namely *SmartParcel* and *CollabAssure*. "*SmartParcel*" allows users to share mobile application data with their spatio-temporally co-existing peers. This service allows a user to receive application specific data from its neighboring nodes instead of cloud infrastructure. This reduces the network overhead generated by a large number of devices and thus, reducing content maintainability and dissemination costs at the server side. This system, however, suffers from the "*tragedy of commons*" problem, to overcome which we present the design of *CollabAssure*". "*CollabAssure*" is an auction based, ad-hoc market model, assuring service by giving users incentives to "sublet" their surplus data plans to the users without Internet access. *CollabAssure* service allows users to participate in ad hoc auctions with their spatio-temporally co-existing neighbors as buyers or sellers of the data bandwidth. This in turn reduces under utilization overhead of the overpaying mobile data users. Users with limited or no data plans also benefit from *CollabAssure* service by receiving services from ad-hoc peers. We perform trace based simulations by varying data refresh rates, allowed server connections, probability of user participation and analyze the data availability at different times of the day. Our simulation results advocate a higher Internet data service is ensured by using our proposed data sharing framework.

1. Introduction

The availability of a huge number of diverse applications is one of the major reasons why consumers favor mobile devices [1]. There are about 6.2 billion users around

* Corresponding author. Tel.: +1 978 944 6802.
E-mail addresses: bkaushik@cs.uml.edu (B. Kaushik), honggang@storm.cis.fordham.edu (H. Zhang), yxyphd@mail.xjtu.edu.cn (X. Yang), xinwenfu@cs.uml.edu (X. Fu), bliu@cs.uml.edu (B. Liu), wang@cs.uml.edu (J. Wang).

http://dx.doi.org/10.1016/j.comnet.2014.07.018
1389-1286/

the globe [2,3] and the proliferation of mobile Internet usage among consumers has cast the spotlight on the data traffic that originates from these devices. There has been a rapid growth in network traffic, i.e., 100 petabytes/month in 2007 to 700 petabytes/month in 2012 [3], mainly due to the use of mobile applications on the Internet.

The demand for higher data rates in wireless networks to support these applications has triggered the design and development of new data-minded cellular standards, such as WiMAX (802.16e), 3GPPs, HSPA, and LTE standards. In addition, Wi-Fi mesh networks are being developed to provide nomadic high-rate data services in a more distributed manner [4]. The emergence of these new mobile and wireless networks provides major opportunities to expand traditional mobile Internet-based applications. However, the best way to increase the system capacity of a wireless link is by moving the transmitter and receiver closer together, which obtains the dual benefits of higher-quality links and greater spatial reuse. The rise of the mobile user base has been accompanied by service disruption; thus, in a network with nomadic users, the deployment of further infrastructure, typically in the form of micro-cells, hot spots, distributed antennae, or relays, is crucial for providing a better service. Thus, satisfying the growth in user needs is a burden for cellular service providers.

To meet the growing needs of the Internet user base, cellular network providers offer wide coverage, thereby enabling ubiquitous wireless data access services. However, this service is expensive and cellular service providers only allow users to subscribe to a fixed data limit, which they often exhaust before the end of billing cycle or underutilize due to the overall available limits at the end of the billing cycle. Alternatively, users may choose "pay-per-use" schemes, where they pay significantly higher prices for the services used. In these scenarios, users either experience overpayment for higher service availability or are rendered incapable of accessing Internet services on occasions. Due to these issues and constraints, the overall mobile data user base can be roughly divided into two groups at any given moment in time: those with Internet access capabilities and those with no Internet access capability, as shown in Fig. 1. Note that some devices are connected to the Internet via 3G/LTE services, whereas others may be connected via Wi-Fi. The other major challenges faced by mobile Internet users include the unavailability of hardware (3G or LTE), unavailability of access points, service outages, and network and server overloads. These challenges result in the unavailability of application data to users and high service maintenance costs for both the service providers and hosting servers.

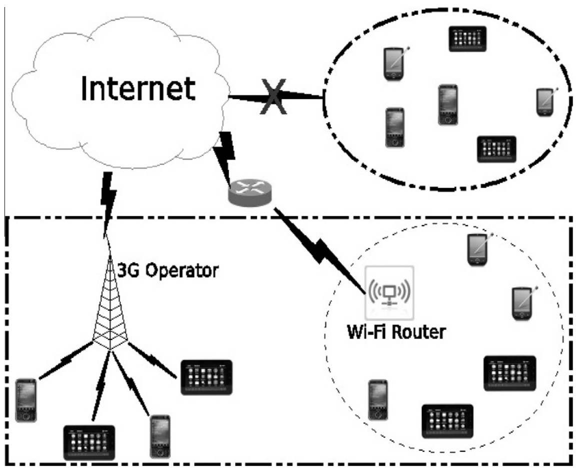

Fig. 1. Diversity of mobile Internet users.

These issues have been addressed by researchers in industry and academia. For example, a previous study [5] proposed the architecture of a macro-femto strategy for macrocell offloading. In this femtocell environment, the data traffic flows over the air interface to the femtocell (which is connected to the user's broadband connection), and then over the Internet to the operator's core network and/or to other Internet destinations [6]. In this setting, when a subscriber enters the coverage area of the femtocell, the users equipment associates with it automatically and traffic that previously flowed between the macrocell and the users equipment now flows through the femtocell and the subscriber's broadband connection. The major drawback of this strategy is that data offloading occurs primarily indoors (homes or offices) and it cannot be scaled.

In an alternative strategy, Wi-Fi is used mainly for offloading the overburdened cellular network traffic. Indeed, due to degradation of cellular services in overloaded areas, an increasing number of users are already using Wi-Fi to access Internet services to obtain a better experience. From the service provider's perspective, Wi-Fi is attractive because it allows data traffic to be shifted from expensive licensed bands to free unlicensed bands (2.4 GHz and 5 GHz). Studies have shown that expanding networks using Wi-Fi is significantly less expensive than a network rollout. The architecture of a large-scale data offloading scheme was presented in [7] and [8]. In addition, [9] and [10] addressed this issue by using the Wi-Fi proximity of users to provide data only to *Influential Nodes (nodes with the highest out-degree in a social graph)* or by scanning Wi-Fi routers, which then transfer data to other nodes in close proximity to achieve maximal coverage in a social graph. Although promising, these approaches require substantial changes to state-of-the-art software and hardware technologies, and they do not consider the heterogeneity of application data. Hence, there is a critical need for an infrastructure for data sharing and content availability, and spatio-temporal coexisting neighbors appear to be the perfect choice.

If we consider a typical scenario, such as *"reading the newspaper on the subway,"* many users tend to read newspapers on their mobile devices while they commute to their final destinations. However, the users without 3G or LTE hardware and data plans are unable to achieve this task in a subway setting because there is a lack of access points. In addition, the 3G/LTE data users have to buy a high data bandwidth in order to access multimedia data from the news servers, which they do not fully utilize by the end of the monthly billing cycle. In this scenario, our proposed framework allows these users to exchange their application (news) data with each other via ad hoc interfaces. This