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Vehicular WiFi offloading: Challenges and solutions

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ABSTRACT

WiFi offloading is envisioned as a promising solution to the mobile data explosion problem in cellular networks. WiFi offloading for moving vehicles, however, poses unique characteristics and challenges, due to high mobility, fluctuating mobile channels, etc. In this paper, we focus on the problem of WiFi offloading in vehicular communication environments. Specifically, we discuss the challenges and identify the research issues related to drive-thru Internet access and effectiveness of vehicular WiFi offloading. Moreover, we review the state-of-the-art offloading solutions, in which advanced vehicular communications can be employed. We also shed some lights on the path for future research on this topic.

1. Introduction

In recent years, the demand for high-speed mobile Internet services has increased dramatically. People expect to connect to the Internet anytime, anywhere, even in their own cars. With advanced Internet connectivity on the move, drivers or passengers are allowed to personalize their in-vehicle experiences, making travels safer and more comfortable. A recent survey reveals that Internet access is predicted to become a standard feature of future motor vehicles [1], and excitingly, Internet-integrated vehicles have hit the road lately. Extending Internet connectivity to the in-vehicle environment, therefore, might be the next frontier for the mobile revolution. Not surprisingly, cellular-based access technologies, such as 3G and Long Term Evolution (LTE), play a vital role in providing reliable and ubiquitous Internet access to vehicles, as the cellular infrastructure is well planned and widely available. However, the cellular network nowadays is straining to meet the current mobile data demand, and on the other hand, the explosive growth of mobile data traffic is no end in sight, resulting in an increasingly severe overload problem. It is reported that the connected mobile devices will become more than the world's population in 2013, and the global mobile data will increase by 13 times in 2017, which will exceed one hundred exabytes [2]. Therefore, simply using cellular infrastructure for vehicle Internet access may worsen the overload problem, and degrade the service performance of both non-vehicle and vehicle users.[1]

As a popular wireless broadband access technology, WiFi, operating on the unlicensed spectrum, offers the "last-hundred-meter" backhaul connection to private or public Internet users. The advantages of WiFi access are summarized in Table 1. Recent research has demonstrated the feasibility of WiFi for outdoor Internet access at vehicular speeds [3]. The built-in WiFi radio or WiFi-enabled mobile devices on board can access the Internet when vehicles are moving in the coverage of WiFi hotspots, which is often referred to as the drive-thru Internet access [4]. This kind of access solution is workable to offer a cost-effective data pipe for vehicle users [5], and with the increasing deployment of the urban-scale WiFi network (e.g., Google WiFi in the city of Mountain View), there would be a rapid growth in vehicular Internet connectivity.

WiFi is recognized as one of the primary offloading technologies [8]. By delivering data originally targeted for cellular networks by WiFi, which is referred to as WiFi offloading, the congestion of cellular networks can be alleviated. WiFi offloading has been extensively studied for stationary or slow moving users[2] [9,8,10,11]. It is shown that around 65% of the cellular traffic can be offloaded by merely using the most straightforward way of simply switching the IP connection from the cellular network to WiFi when the WiFi connectivity is available (*on-the-spot offloading*). In addition, significant amount (above 80%) of data can be offloaded by delaying the data application [9] (*delayed offloading*). For moving vehicle users, one natural question needs to be answered: how much data can be offloaded? WiFi offloading in vehicular communication environments (or *vehicular WiFi offloading*) refers to delivering the data traffic generated by the vehicles or vehicle users via opportunistic WiFi networks, i.e., the drive-thru Internet access. However, due to high dynamics of vehicular communication environments, e.g.,

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[1] We will interchangeably use the terms "vehicle" and "vehicle user" in this article.

[2] We refer to these users as non-vehicle users.

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Table 1
The advantages of WiFi access.

Advantage	Description
Widely deployed Infrastructure	WiFi hotspots are widely deployed in many urban areas. It is shown that WiFi access is available 53% of the time while walking around popular sites in some large cities [6].
Low cost	WiFi access is often free of charge or inexpensive. For example, KT Corporation in South Korea offers WiFi services with $10 a month for unlimited data usage [7].
High availability of user devices	Most of current mobile devices, such as smart phones, tablets, and laptops are equipped with WiFi interfaces.
Efficient data transmission	Currently WiFi technologies (IEEE 802.11 b/g) can provide data rates of up to 54 Mbps. There are new technologies under development or test, e.g., IEEE 802.11 ac/ad, which can provide data transfer at several Gbps.

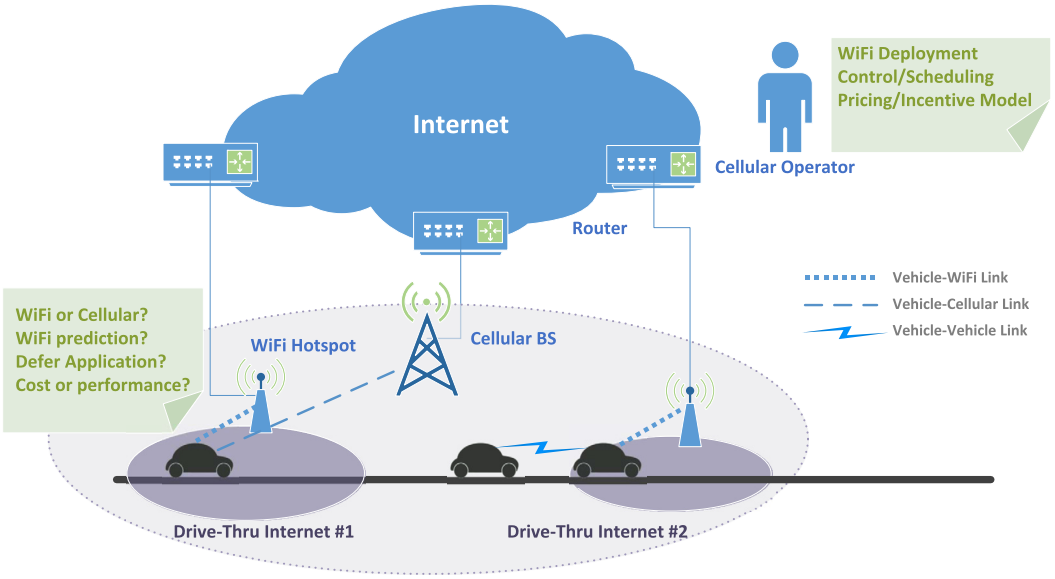

Fig. 1. WiFi offloading in vehicular communication environments.

the highly dynamic network topology due to high vehicle mobility, fast fluctuating wireless channels, etc., the effectiveness of WiFi offloading for vehicle users requires careful studies. The overview of vehicular WiFi offloading is shown in Fig. 1. We elaborate the unique features and challenges of vehicular WiFi offloading from the following three aspects.

Drive-thru access: Mobility plays both a challenge and a distinguishing role in vehicular WiFi offloading. For each drive-thru, vehicle users can only obtain a relatively small data volume due to the short connection duration with the WiFi hotspot; while vehicle users may experience multiple drive-thrus in a short time period due to high mobility. This short and intermittent connectivity will have great impacts on offloading schemes, such as a WiFi offloading performance prediction and mechanisms to delay some applications, which we will discuss later. Fluctuating channels may lead to high and bursty losses, resulting in disruptions to connectivity. Thus, proper handoff schemes and transport protocols are needed to reduce the disruptions and adapt to the wireless losses.

Cellular operators: To ease congestion of cellular networks, cellular operators may adopt certain commercial strategies to encourage data offloading, such as by stimulating vehicle users to transmit their data through WiFi networks. Thus, incentive models, such as variable service prices or reward mechanisms, should be investigated. Moreover, cellular operators may deploy their own commercial or non-commercial WiFi networks to offload mobile data, e.g., the WiFi hotspots operated by AT&T [12]. How to determine the WiFi deployment strategy to attain optimal offloading performance is another research challenge.

Vehicle users: The WiFi offloading potential can be predicted, as the mobility pattern of vehicles can be predicted from the historic drive information, driver preferences, etc. Based on this prediction, with the knowledge of usage cost of cellular and WiFi services, it is possible for vehicle users to determine when to use WiFi or cellular networks upon a service request emerging, and minimize the usage cost. It is a challenging task to understand the cost-effectiveness of WiFi offloading from the vehicle users' perspective.

In this paper, we focus on the problem of WiFi offloading in vehicular communication environments. We discuss the challenges and identify the research issues related to this problem. Moreover, we review the state-of-the-art offloading solutions, providing rapid access to research results scattered over many papers. We also try to shed some lights on the path for future research on this topic. The remainder of the paper is organized as follows. Section 2 surveys the existing research works on mobile data WiFi offloading for non-vehicle users. Section 3 discusses the challenges and existing/potential solutions in drive-thru Internet access and WiFi offloading in vehicular communication environments. Section 4 discusses further research issues and provides concluding remarks.

2. Mobile data offloading through WiFi networks

Mobile data offloading through WiFi access networks has been extensively studied. Due to the low-cost and high availability of WiFi access, offloading mobile data through WiFi is quite straightforward. However, the limited coverage of WiFi access points (APs), user mobility, and the dynamics of communication environments pose difficulties for analyzing and optimizing the offloading performance. In this section, we review the literature in WiFi offloading