# Exploiting Hotspot-2.0 for Traffic Offloading in Mobile Networks

Wenchao Xu, Haibo Zhou, Yuanguo Bi, Nan Cheng, Xuemin (Sherman) Shen, Lakshmi Thanayankizil, and Fan Bai

## Abstract

WiFi networks can offload data traffic from congested cellular networks in a cost-effective way. However, it is difficult to perform WiFi offloading in mobile environments due to the complicated and time consuming access procedure of WiFi networks. In this article, we first investigate mobile traffic offloading by leveraging the HS-2.0 technique, which greatly simplifies the access procedure and provides a novel signaling diagram to enable automatic association and seamless roaming for mobile users. We then compare the legacy HS-1.0 with HS-2.0, and study the impacts of HS-2.0 on mobile traffic offloading by considering the pedestrian case and the drive-thru Internet case, respectively. We develop an HS-2.0 traffic offloading prototype and provide useful results through empirical measurements. Finally, we show the research issues for HS-2.0 mobile traffic offloading.

## Introduction

Due to the popularity of smart devices and applications, the amount of mobile traffic has been increasing dramatically. It is predicted that monthly global mobile traffic will exceed 49 exabytes by 2021, which is almost six times more than the current number [1]. To meet the overwhelming traffic requirements, traditional network upgrades include acquiring more spectrums, deploying small cells and evolving new technologies (e.g., from WCDMA to LTE), which are costly and time-consuming. Mobile traffic offloading, which offloads mobile traffic from cellular networks to cost-effective wireless networks, appears as a handy-to-deploy and economic approach.

WiFi is envisioned as the most promising mobile traffic offloading solution with well known advantages, such as low cost, high throughput and universal compatibility [2]. In spite of the extremely high popularity of WiFi, there are still some flaws and weaknesses that limit the utilization of WiFi networks and require further improvements. First, except for enterprise WiFi networks, most WiFi networks do not provide roaming service. A complicated and time-consuming access procedure is required when WiFi clients are switching from one access point (AP) to another. The management of user authentication credentials is problematic since it may involve manual inputs, web interactions or email/message verifications, and so on. Secondly, users are not aware of the service ability or the security level of the network prior to association. The limited information contained in the service set identifier (SSID) and probe/response beacons is inadequate for users to choose a proper AP that can satisfy their quality of service (QoS) requirements. Even the most fundamental information of whether the AP has Internet connectivity is unknown before association. Moreover, since no accounting information is conveyed, it is not easy to explore various business opportunities for mobile network operators (MNOs).

To address the above issues, Hotspot-2.0 (HS-2.0) was proposed to simplify the access procedure and enhance the interworking ability of WiFi networks, and thus has attracted wide attention and support from industrial manufacturers to open source communities. The HS-2.0 technology greatly facilitates capitalizing current WiFi networks for industrial deployment, as it provides seamless and secure connectivity like cellular networks, and makes WiFi networks more suitable for traffic offloading in mobile scenarios. On one hand, the automatic network access allows mobile users to handover from one hotspot to another smoothly; on the other hand, the user account information can be managed by remote servers, which satisfies the commercialization requirements of MNOs. To verify the feasibility of HS-2.0 on mobile traffic offloading, in [3, 4] it is shown that HS-2.0 enables passpoint devices to follow a more effective policy by utilizing the newly added elements in the beacon frames. Compared to legacy hotspot selection schemes, the trace-driven simulation shows that HS-2.0 can increase network capacity by 15 percent and save 13 percent energy. In terms of the control plane, Lavrukhin *et al*. in [5] analyzed the overhead of the HS-2.0 query protocol and showed the importance of the proper deployment of the HS-2.0 APs.

Unfortunately, the topic of employing HS-2.0 in mobile traffic offloading has not been well studied to date. For example, the feasibility of HS-2.0 traffic offloading has not been well examined, especially in real mobile conditions. The benefits of automatic association and the ability of seamless roaming on offloading performance also need further investigation. Such a lack of understanding on the key issues of HS-2.0 enabled mobile traffic offloading thus motivates our work.

In this article, we introduce the HS-2.0 technology, and show its advantages for mobile traffic offloading. We present the HS-2.0 offloading system architecture and discuss several key research issues. We study HS-2.0 enabled mobile traffic

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offloading in both a pedestrian case and a drive-through Internet case. We set up the test platform and conducted a ground test. The test results and corresponding analysis indicate the feasibility and prospect of HS-2.0 enabled mobile traffic offloading, from which we can provide the following information:

- HS-2.0 can provide adequate information for users with limited mobility, which can be used to choose an eligible and secure hotspot with required QoS.
- The automatic access scheme of HS-2.0 can provide feasible WiFi offloading performance for high mobility users, such as vehicles in drive-through Internet scenarios.
- HS-2.0 traffic offloading requires research attention to address several key issues involving handover protocol, QoS mapping, and so on.

The remainder of this article is organized as follows. In the following section, we present the HS-2.0 technology status. Then we introduce the HS-2.0 traffic offloading system architecture and demonstrate the improvements from HS-1.0 to HS-2.0. Following that, we study two research cases of HS-2.0 and show corresponding experiments. Then we discuss the HS-2.0 traffic offloading research issues. The final section concludes the article.

## HS-2.0 Technology Status

In this section, we present the current status of HS-2.0, including HS-2.0 progress and the efforts needed to facilitate mobile traffic offloading using HS-2.0.

### HS-2.0 Progress

HS-2.0 aims to enhance the interworking ability of WiFi networks [6], and provides seamless roaming when users move through different hotspots or switch between cellular and WiFi networks. The HS-2.0 specification is based on the IEEE 802.11u standard, which is an amendment to the original beacon/probe scheme of the 802.11 standard. To expedite the application of HS-2.0, the WiFi Alliance launched the WiFi passpoint certification to cooperate with manufacturers and vendors. HS-2.0-compatible devices are certified as 'passpoint devices'. Also, the Next Generation Hotspot (NGH) Program initiated by the Wireless Broadband Alliance (WBA) is now utilizing HS-2.0 and passpoint devices to provide commercial solutions for end users and business customers.

**Specification and Framework:** In May 2012, the WiFi Alliance released the first HS-2.0 specification. The second edition was then released in February 2015 [6], which improves the credential management and proposes the Online Sign Up (OSU) protocol to make the WiFi network more suitable for roaming situations. Currently, the second release of HS-2.0 is being tested by WBA on automatic OSU and policy management.

**Industrial Solutions:** The passpoint certification is credited by the WiFi Alliance to HS-2.0-compatible devices. There are more than 1600 passpoint certified devices to date [6], including computers and accessories, phones, and APs. For mobile client devices, Apple has supported HS-2.0 since iOS 7 on the iPhone 5; more and more Android phones are also certified by passpoint, e.g., HTC,

The open source community has contributed to the development of HS-2.0. One example is the hostapd (host access point daemon), which is designed to enable 802.11 wireless cards to function as an AP for the Linux and FreeBSD platforms.

Samsung smart phones. In addition, at the Microsoft Build Developer Conference in May 2015, Microsoft announced that Windows 10 supports HS-2.0. For APs, Cisco and Ruckus Wireless proposed end-to-end solutions for WiFi passpoint devices. Huawei and NetGear also released several AP products supporting HS-2.0.

**Open Source Support:** The open source community has contributed to the development of HS-2.0. One example is the hostapd (host access point daemon), which is designed to enable 802.11 wireless cards to function as an AP for the Linux and FreeBSD platforms. Since the release of version 2.2 in June 2014, HS-2.0 (release 2) has been supported by hostapd. The hostapd program runs in user space, which drives several types of wireless cards to serve as an AP. According to our empirical test, most common Linux systems, e.g., OpenWRT and Ubuntu, are compatible to run hostapd to build HS-2.0 hotspots.

### HS-2.0 To Be Developed

To further facilitate the practice of applying HS-2.0 in mobile traffic offloading, more efforts are needed from both industry and academia.

**Industrial Progress:** Although there are a considerable number of passpoint devices, the deployment of the HS-2.0 network is not yet catching up to the expectations from users and MNOs. One reason is that there is a lack of a feasible method to upgrade current hotspots to HS-2.0. Initiators of HS-2.0 are expected to provide low-cost upgrade schemes to encourage MNOs and other service providers to incorporate HS-2.0 into their infrastructures and expedite the popularization of HS-2.0.

**Academic Research:** Academia has not paid enough attention to HS-2.0 related research. Since the access diagram of WiFi networks has been changed greatly by HS-2.0, it is expected that more measurement tests should be conducted in traffic offloading experiments using HS-2.0, for example, deploying HS-2.0 hotspots in the drive-thru Internet. The feasibility and performance of HS-2.0 mobile traffic offloading needs further investigation. To this end, we discuss traffic offloading using HS-2.0 in the following section.

## HS-2.0 Enabled Traffic Offloading System Architecture

HS-2.0 introduces the control plane to traditional WiFi networks, which can facilitate automatic network discovery, selection and association for mobile users. Moreover, the authentication, authorization, and accounting (AAA) server adopted in HS-2.0 enables the remote management of WiFi networks. In Fig. 1, the system architecture of the HS-2.0 offloading system is illustrated, including the control plane and the data plane. The control plane refers to the communication that manages the connection setup, monitoring and maintenance. For roadside access networks, the control

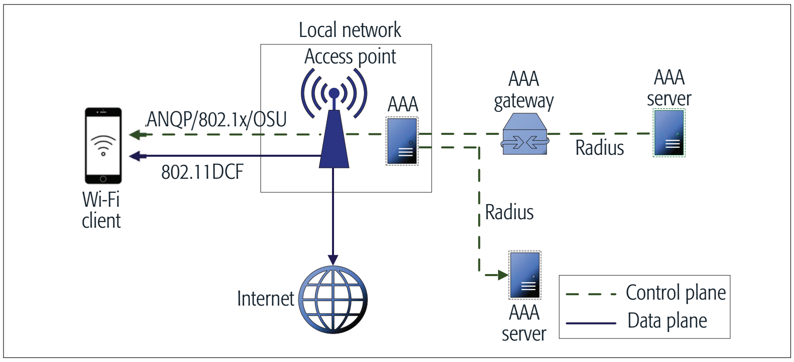


FIGURE 1. System architecture of HS-2.0 for WiFi networks.

plane is responsible for setting up the connection between the vehicle and the hotspot, providing AAA functions and dynamic network resource reservation. The data plane refers to the communication for the user data transmission. The HS-2.0 control plane does not couple with the data plane transmission, so it can be integrated in different WiFi standards.

## Control Plane

The control plane is adopted in HS-2.0 to provision access management and network resource control. First, compared to the legacy standard, important information such as the AP capability, roaming consortium, and supported query protocol, are added into the basic beacon and probe response frames [7]. The clients can further query more information, for example, using the Access Network Query Protocol (ANQP), by which the WiFi clients can obtain the network information more precisely and thus improve the effectiveness of network selection and association. Furthermore, HS-2.0 specifies that the IEEE 802.1X protocol is employed in the authentication method to provide users secure connection. The latest released HS-2.0 also provisions OSU ability which can enable users to automatically select a proper plan with reasonable costs from service providers. This kind of management framework makes WiFi networks as easy and secure as cellular networks. In the control plane, HS 2.0 mainly carries out the functions of network detection, and secure connection setup with OSU capability. Network detection aims to provide a network search procedure for automatic association, and a secure connection is setup via the authentication procedure with the AAA server. In addition, the OSU provides a dynamic network resource reservation mechanism. In the following, these functions are described in detail.

**Network Detection:** Traditionally, there are two ways for the clients to detect a WiFi network. In the passive approach, the clients listen to the beacon frames periodically (typically per 102.4 ms) broadcasted by the nearby APs which are identified by the specified service set identifier (SSID). In the active approach, the clients broadcast probe request frames to seek the information of the target AP. The APs that satisfy the requested parameters will reply the probe response frame to that client. The information that a client device can get through these two approaches includes SSID name, supported rates, operating channel, extended service set identifier (ESSID) and physical layer related information, and basic security parameters, and so on. Generally such information is not sufficient for clients to find a proper AP to associate to. First, the clients have limited information about the backhaul network connected to the AP, for example, Internet accessibility, the security level, and QoS mapping support. Second, according to the default AP selection policy, the HS-1.0 WiFi clients always choose the AP with the largest received signal strength indicator (RSSI) among all available nearby APs. Such an AP selection policy might result in improper association, for example, association to APs without Internet connectivity, or causing unbalanced load distribution and low utilization of available APs [8].

In order to overcome these problems, HS-2.0 no longer relies on the SSID solely to identify a WiFi network [6]. Prior to AP association, the WiFi clients can obtain more information such as the network access identifier (NAI) and the operator information via multiple ways. First, new information elements are added into the beacon and probe frames, so that the client devices can obtain more information about the surrounding WiFi networks by listening to beacon frames or requesting probe response frames. Our measurement results show that these elements can be traced in the "tagged parameters" via wireshark software. Among those new added information elements, some key parameters and their purpose are listed in Table 1. In addition, a new query protocol called ANQP is specified for the clients to obtain further information about the AP or the backhaul network services. Some of the important elements are also listed in Table 1.

Using the experiment below as an example, the interworking subfield in the extended capabilities parameter is set to 1, which means that the AP is compatible with the 802.11u protocol. And the advertisement protocol parameter indicates that the supported query protocol is ANQP and the query response length limit is 127 bytes. A real HS-2.0 WiFi access procedure traced in our ground test is shown as follows. First, the client device parses the beacon frame and the probe response frames received from the HS-2.0 AP, which showed that the interworking ability and the ANQP protocol is supported. The client device then queries the authentication information by sending an ANQP query request to the AP. The query list includes the NAI realm list, domain name list and WAN metrics, and so on. The HS-2.0 AP then replies the ANQP response list, including the requested NAI realm name, supported Extensible Authentication Protocol (EAP) method, the domain name and WAN metrics, and so on. The client devices check the information and find that they are compatible with its credential and realm configuration, and then start the AP association and the network authentication procedure. The AP then forwards the credential to the AAA server, which then replies the authentication result to the AP to allow the client to access the network.

**Security and Online Sign Up:** HS-2.0 devices are required to support WPA2-802.1X with various EAP methods, for example, EAP-TLS, EAP-TTLS, to enable wireless communication as secure as the enterprise WiFi [9]. In addition to security requirements, HS-2.0 adopts the OSU scheme for users who do not have the credentials for the current HS-2.0 network but are willing to subscribe

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with the network service provider. After choosing a proper service plan, the OSU scheme will return the necessary credentials to the clients, which can be used to access the target HS-2.0 network. This dynamic subscription can attract more clients and thus improve the utilization of WiFi networks.

### Data Plane

The data plane of the HS-2.0 network is independent of the control plane. The backhaul Internet connection and the remote management connection can be separated to simplify the network deployment and improve roaming capability. The data plane parameters can be queried by ANQP for clients, including both the downlink and the uplink bandwidth and load in real time. During the connection stage, the data plane statistics can be sent to the AAA server for service accounting.

HS-2.0 disables the low-efficiency P2P device management mode and wireless distributed system, which is used to form an extended service set (ESS) and enable local roaming in traditional WiFi networks.

| Parameters | Sub-field | Purpose |
|---|---|---|
| Extended capabilities | Interworking | Indicates if this WiFi network can interwork with other networks. |
| | QoS traffic capability | Indicates if the WiFi network can support QoS mapping between WiFi and external networks. |
| Interworking advertisement protocol | Access network type | Indicates if the network is private or public, is connected to the Internet. |
| | Advertisement protocol ID | Indicate the query protocol ID and the response length limit. |
| Roaming consortium | N/A | Indicate the roaming consortium whose credential can also authenticate with the current AP. |
| ANQP element | WAN metrics | Information about Internet connecting, downlink and uplink speed/load, etc. |
| | NAI realm data | Information about NAI realm name and authentication method. |
| | Domain name | Domain information about the operators. |

TABLE 1. Important information elements in beacon, probe and ANQP frames in HS-2.0.

## HS-2.0 Enabled Traffic Offloading: Case Study

HS-2.0 enables automatic access to WiFi networks, which greatly simplifies the association procedure and enables seamless roaming for WiFi clients. HS-2.0 can improve WiFi offloading in terms of automatic access and handoff, cost management, secure connection, and so on. In this section, two potential HS-2.0 enabled traffic offloading cases, that is, the pedestrian case and drive-thru Internet case, are studied. The characteristics of these two cases are summarized in Table 2.

### Pedestrian Case

In the pedestrian case illustrated in Fig. 2a, the mobility level of users is generally low. Most of the time, they are quasi-static, that is, staying in the room or wandering in a store or street. As WiFi networks become more and more popular, it is common that every user can detect multiple surrounding APs. If a user can associate to more than one AP, it can dynamically choose the AP that can provide better network performance. For example, in [10] the authors consider the bandwidth limitation on both wireless and back-end link to control the association of each user to achieve load balancing. In [8] the authors use the link latency to formulate a game theoretical approach to balance the load of APs. HS-2.0 makes such research ideas feasible in real network operation. Compared to HS-1.0, HS-2.0 users can ignore the APs that do not satisfy the association requirement via the improved beacon frames and the ANQP protocol query results, for example, link status like bandwidth or load information, and so on.

The key research issues for the HS-2.0 application in the pedestrian case are presented as follows. First, it is important to verify how much control information can be conveyed via HS-2.0 for pedestrians. The specification can be studied and practical tests can be conducted to investigate the actual information elements and related usages, and how this information could help improve offloading performance. Regarding that there exist various AP switching algorithms, it is now practical to build a real test platform to offer convincing verifications. Furthermore, it is interesting to explore the multi-homing strategy for HS-2.0 devices. Based on the information elements offered from HS-2.0, it is possible to enable multiple connections for a user to enhance the QoS level as well as to improve the utilization of access resources [11].

### Drive-Thru Internet Case

In the drive-thru Internet case, the APs deployed along the roadside are used to offload traffic from cellular networks for vehicle clients. The automatic access and remote authentication ability provided by HS-2.0 makes the application practical. Also, the remote accounting capability can solve the issue of service pricing and will facilitate feasible business models of drive-thru Internet traffic offloading. In [12] the authors set up the drive-thru test environment to measure both the uplink and downlink throughput of UDP and TCP traffic for an 802.11b network.

| Scenario | Characteristic | Test and analysis | Objective |
|---|---|---|---|
| Pedestrian | Quasi-static; unpredictable mobility; access overhead tolerant. | How much control information can be obtained via HS-2.0? | Association control for QoS optimization |
| Drive-through Internet | Highly dynamic; predictable mobility; require low access latency. | How fast the control information can be exchanged via HS-2.0? | Quick access and longer product phase for drive-through throughput |

TABLE 2. HS-2.0 traffic offloading scenarios.

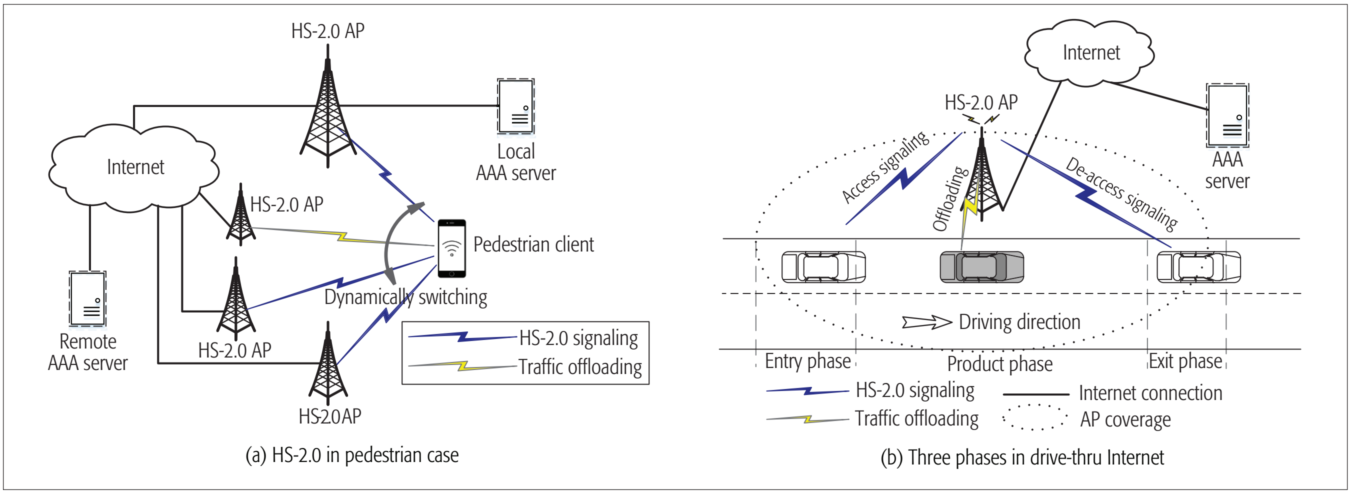


FIGURE 2. HS-2.0 enabled traffic offloading cases.

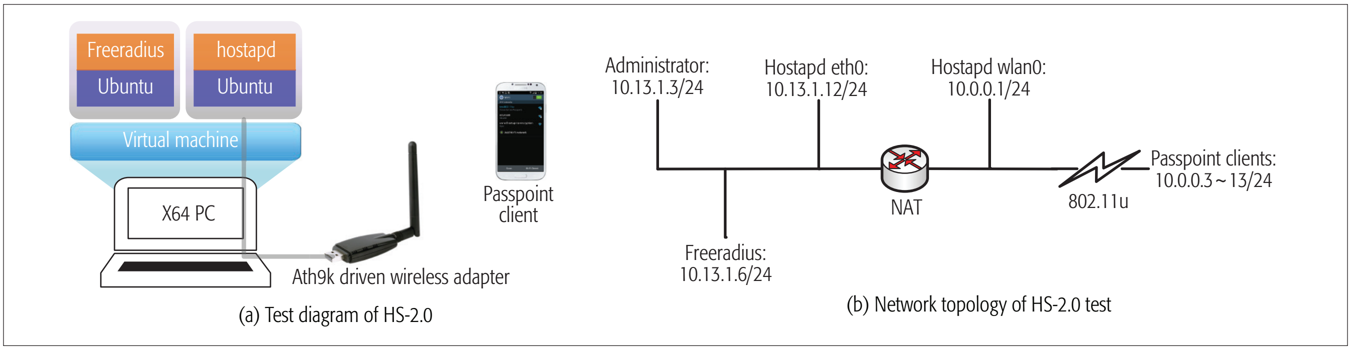


FIGURE 3. HS-2.0 test diagram and network topology.

The author divided the drive-thru Internet duration into three phases as illustrated in Fig. 2b, which are the entry phase, the product phase and the exit phase.

**The Entry Phase:** In this phase, the vehicle clients are approaching the coverage area of a hotspot. The clients should finish the whole access procedure, including network detection and query, AP selection/authentication and association. In addition, the network layer parameters should be set up properly like IP address assignment, routing table setup, and so on.

**The Product Phase:** During this phase, the signal level of the WiFi network is strong and the connection is stable, and the network throughput can be achieved above a certain level. Traffic is offloaded from cellular networks to the HS-2.0 WiFi networks.

**The Exit Phase:** In this phase, the vehicle is leaving the WiFi coverage area, and the radio signal becomes weak. Therefore, the link rate declines to a low level until the connection fails.

The pioneering work in [12] provided a measurement-based conclusion for further protocol design in the drive-thru Internet. However, the author adopted the open association scheme and did not consider the overhead of the network access procedure. In the exit phase, the vehicle clients rely on the signal strength or the link rate to judge if the connection is still usable or not. In [13] the authors formulated the drive-thru downlink traffic as a Markov reward process to analyze the link throughput. It has not considered the association overhead to the AP and the IP assignment procedure, which is mandatory to set up an effective Internet connection. In the HS-2.0 drive-thru Internet, the following issues should be investigated to maximize the utility of network resources. First, a field test of HS-2.0 for drive-thru Internet throughput should be conducted to verify the feasibility of using HS-2.0 WiFi for moving vehicles. The duration of the effective product phase should be evaluated when HS-2.0 automatic association and authentication are adopted. Second, the behaviors of vehicle users during the access procedure can be modeled and analyzed to improve the probability of successful access in short duration, and thus extend the product phase to improve network throughput. Furthermore, the handover protocol between two consecutive HS-2.0 networks should be investigated. For example, during the exit phase, rather than wait until the connection fails, the vehicle client can make the decision on whether to maintain the current link connection even at low transmission rate or switch to another AP by obtaining the necessary information from the beacon frame and query result, for example, the throughput and the load level of the candidate APs.

## System Experiment: Preliminary Evaluation

By using open source software and commercial off-the-shelf (COTS) wireless adapters, we have developed an HS-2.0 WiFi offloading prototype and obtained preliminary measurement results in a real drive-thru Internet experiment. The measurement results provide verification of the feasibility of applying HS-2.0 in mobile traffic offloading. The system architecture and test parameters are shown in Fig. 3a. Integrated with the passpoint function, the Samsung Galaxy S4 phone is used as the HS-2.0 client in our test. To set up the HS-2.0 AP, we adopt the FreeRadius software to run as the AAA server and the hostapd daemon as the AP controller. FreeRadius and the hostapd daemon run on two separate Ubuntu hosts on the Vmware work station, which is installed on a X64 server. The Atheros USB wireless adapter is plugged into the Ubuntu OS via the virtual port and thus can be driven by the hostapd daemon. The network topology is illustrated in Fig. 3b. The network address translator (NAT) is set up between the wireless and wired networks to serve as the network gateway. The AAA server and the AP controller are running on different hosts to emulate the situation that the authentication is apart from the local AP controller.

### Pedestrian Case

We have reproduced the entire network discover and selection procedure in the laboratory environment to demonstrate the HS-2.0 application in the pedestrian case. By reading the trace of the packets sniffed at the AP side, the parameters for dynamic AP switching are examined. First, the client parses the received beacon/probe frames and checks the parameter of the "Interworking" field in the fourth octet of the "Extended Capabilities" Tag. If the parameter is set to "1" then the target AP supports HS-2.0. The client can then further find out if the target AP provides Internet access by checking the "Interworking" Tag. Then the client can further query the authentication information to find out if the target AP is suitable to associate. The link status, that is, data rate and load level for both uplink and downlink connection, can be obtained via the query protocol that is specified in the "Advertisement Protocol" Tag, for example, ANQP, that the link information can be queried in the "WAN Metrics" Tag. Based on the information, the clients can switch to a proper AP, and dynamically switch from one to another to have better service quality. The measurement results provide important metrics for the design of the AP switch algorithm and handover protocol to optimize network performance for pedestrian users.

### Drive-Thru Internet Case

We also test the application of HS-2.0 in the drive-thru Internet case to verify the feasibility of HS-2.0 in a high mobility case. The test is conducted in the suburban area of Waterloo, Ontario, Canada, where no other WiFi signal is detected. The HS-2.0 AP is placed on the roadside while the client device is held by a passenger in the car and no external antenna is installed. The AP is set to work at channel 6, mode 802.11g. The radio power is set to 20 dBm. Vehicle speed is around 40 km/h. The Arduino and the GPS shield testbed are used to record the position of the vehicle during the test. The iperf software is installed both on the hostapd server and the client device to measure the uplink UDP throughput every 0.5 seconds. Along with the GPS data, the measurement of the HS-2.0 drive-thru Internet throughput is shown in Fig. 4, where the vehicle was driving from left to right.

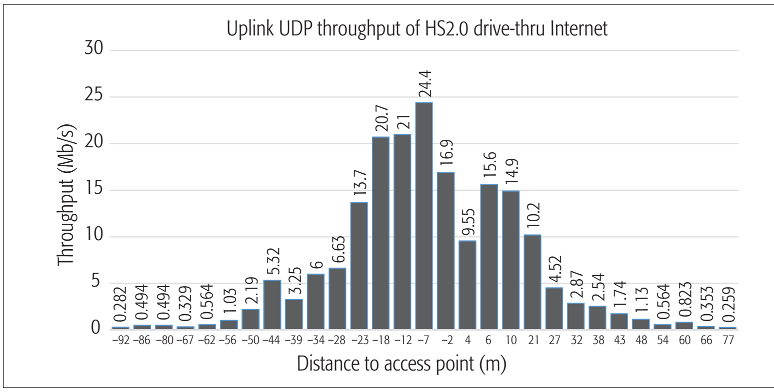


FIGURE 4. HS-2.0 drive-thru Internet measurement results.

In our test, HS-2.0 functions, that is, automatic association, authentication and IP address assignment, took place during the entry phase. The measurement results show that HS-2.0 is quite suitable for the drive-thru Internet case since the overhead of HS-2.0 signaling has barely reduced the product phase, when considerable throughput is achieved around 100 meters. The measurements also gives us the confidence that the HS-2.0 drive-thru Internet can offload more vehicular traffic if an external antenna can be installed or advanced WiFi protocol, that is, 802.11n or 802.11ac can be applied. The overhead of the access procedure is not significant since the entry phase is fairly short, and the event that the access procedure has not finished is quite rare in real tests.

## Research Issues

In this section, the research issues for HS-2.0 mobile traffic offloading, such as the handover protocol, QoS mapping, offloading strategy, are discussed.

**HS-2.0 Handover Protocol:** In the mobile environment, users often switch from one AP to another. The handover between two consecutive APs can affect the network experience and traffic offloading performance greatly. A shorter handover duration and lower packet loss probability can provide users with seamless AP switching and high utilization of the network resources. To achieve the requirements of the HS-2.0 system for mobile traffic offloading, the handover protocol needs to be developed carefully.

**HS-2.0 Traffic Offloading with Multiple Connections:** HS-2.0 can provide load level and bandwidth information of the potential APs around users. Such information can be used to set up multiple data pipes to offload the traffic for users [11, 14, 15]. The offloading strategy, for example, how to allocate the generated traffic for each data pipe, and to maximize the offloading performance while reducing the communication costs, can be made according to the network information provided by HS-2.0.

**HS-2.0 QoS Mapping for Traffic Offloading:** Video/voice streaming are becoming more and more popular. To better support such an application for WiFi networks, for example, voice over WiFi (VoWiFi), it is important to map the QoS parameters, for example, frame priority, from the wireless side to the backhaul connection to grantee the quality of user experience. HS-2.0 provides the QoS mapping capability. However, the relat-

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ed QoS mapping schemes and performance evaluation has not yet been investigated.

**Incentive-Based HS-2.0 Traffic Offloading:** The remote AAA server can obtain the user activity via HS-2.0 APs, while HS-2.0 users can also acquire the cost information of the corresponding services via the OSU scheme, domain information, and so on. Thus it is possible to apply incentive schemes, such as game theory/pricing policy, to encourage users to share network resources to improve HS-2.0 traffic offloading performance and the utilization of network resources.

## Conclusion

In this article, we have investigated HS-2.0 enabled mobile traffic offloading, which can expedite WiFi data offloading more efficiently and cost-effectively. The architecture of HS-2.0 enabled traffic offloading has been introduced, including the control plane and the data plane. We have investigated the current status of HS-2.0 and studied the pedestrian case and the drive-thru Internet case to demonstrate the importance of HS-2.0 for mobile traffic offloading. The ground measurement tests have been conducted to demonstrate that HS-2.0 is suitable for mobile traffic offloading and has great research potential and industry practice expectations.

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