Wi-Fi Assist: Enhancing Vehicular Wi-Fi Connectivity with an Infrastructure-driven Approach

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ABSTRACT

Vehicles access the Internet via cellular networks, instead of Wi-Fi networks. This choice has been mostly justified by the ubiquitous coverage of cellular networks: Wi-Fi coverage has been shown to be inadequate in the past, even in urban areas.

We argue that providing Internet connectivity to vehicles via Wi-Fi is worth a revisit. Motivated by improvements in Wi-Fi network coverage in recent years, we propose Wi-Fi Assist, an add-on to current Wi-Fi infrastructures which differs from existing solutions in two key ways: (1) it is heavily infrastructure-driven; and (2) defines an interface for low-latency cooperation between different WLAN service sets, managed by different service providers.

1 INTRODUCTION

In practice, vehicles access the Internet via cellular networks, instead of Wi-Fi networks. Car manufacturers - e.g. BMW and Toyota - equip vehicles with cellular radios to provide Internet access [1, 2]. Wi-Fi can deliver better throughput than cellular (3G [9], LTE [8]), at lower energy and monetary costs, and reduce the increasing strain on cellular network capacity via traffic offloading [5]. Nonetheless, the choice falls on cellular networks due to their ubiquitous coverage. Cellular base stations cover large areas (<1 km to 10s of km) and their deployment is carefully planned by mobile carriers. This keeps the number of handoffs low, and allows for ‘make-before-break’ handoffs while under the service of the same carrier. To a vehicle, this translates into continuous Internet connectivity, with few interruptions. In contrast, the coverage of Wi-Fi APs is narrower (10s of m), WLAN service sets are typically small - e.g. <5 APs - and their deployment is often unplanned. As a result, in-car Internet connectivity over Wi-Fi is highly susceptible to interruptions, even in urban areas. Measurement studies in urban areas show that vehicular Wi-Fi sessions may experience Internet connectivity disruptions up to 42% of non-overlapping 1 second segments, with a median length of 5 consecutive segments [9]. Other studies report median periods with no Internet connectivity up to 30 seconds [6, 10].

In this short position paper, we argue that using Wi-Fi for vehicular Internet is worth studying, for three reasons. First, the aforementioned measurement studies were conducted in the late 2000s/early 2010s. Wi-Fi coverage in urban areas is likely to have improved significantly by now. Second, these studies only consider Internet connectivity via ‘open’ Wi-Fi hotspots [6, 10] or hotspots serviced by a particular provider [9]. This limitation is likely to hide a lot of connectivity opportunities. Finally, most research on vehicular Wi-Fi vehicular connectivity focuses on client-centric approaches to reduce Wi-Fi connection setup time, overlooking the benefits of infrastructure-side support. Solutions such as IEEE 802.11i [3] and IEEE 802.11r [4] do include infrastructure-side support, but are mostly tuned for ‘walking speed’ scenarios [15] and can only be applied within a single WLAN service set. The infrastructure has a wider view over the whole wireless system, both temporally and spatially (e.g., quality of Wi-Fi signal overtime/at multiple locations). We believe that ISPs, which have some form of control over most APs in urban scenarios, can enhance vehicular Internet service by (1) preemptively configuring an appropriate set of APs in the vehicles’ path; and (2) opening a set of cross-provider interfaces, allowing configuration state to flow in-between APs managed by different administrative domains. This can be enabled by the recently proposed concept of Network Service Support [12], which in turn relies on Software Defined Networking (SDN), Network Function Virtualization (NFV) and Cloudlets.

2 MOTIVATION

We obtain a preliminary profile of urban Wi-Fi coverage for vehicular scenarios using data from the SenseMyCity project [13]. This dataset contains mobility traces collected from smartphones of 100s of crowdsourcing volunteers in the city of Porto, Portugal. More specifically, we use its Wi-Fi scan dataset, which contains ~57 million entries of Wi-Fi scans, from a total 295.000 different APs. The data includes both pedestrian and vehicular traces: as a conservative approach to isolate vehicular traces, we discard those with median speeds lower than 5.6 m/s (∼20 km/h).

Fig. 1 shows that Wi-Fi coverage is pervasive along the main roads: the 50 × 50 meter cells which overlap the thicker lines in the roadmap report more than 20 different visible APs (more specifically, unique MAC addresses). Moreover, additional data in Table 1 shows that most networks (identified by ESSID) are composed by a small number of APs (1 to 4), motivating the need for cooperation between networks managed by different WLAN service sets. There are cases

| # of APs per auth. | # of APs per ESSID |
|-------------------|------------------|
| WPA2 | 48102 |
| Open | 21827 |
| Other | 7599 |
| 1-4 | 41988 |
| 5-9 | 684 |
| 10-49 | 150 |
| 50+ | 21 |
of ESSID which aggregate a large number of APs - e.g. the ‘Fon’ network with ~ 13k different APs, or ‘MEO-WiFi’ with ~ 6k APs\(^1\) - however, we cannot derive their degree of support for roaming optimizations from the data. Regarding authentication, the most common type is ‘WPA2 Personal’. This is followed by ‘open’ APs, mostly part of large networks such as ‘Fon’ or ‘MEO-WiFi’, on which users authenticate via a login/password combo. This shows there are benefits in exploring ways of enabling APs protected by ‘WPA2-Personal’ authentication, which is effectively removing > 50% of connectivity opportunities for vehicles.

3 PROPOSAL: WI-FI ASSIST

We propose an add-on to current Wi-Fi infrastructures - Wi-Fi Assist - which aims at a general reduction of Wi-Fi connection setup time to any Wi-Fi networks found by moving vehicles. If coupled with wide adoption by ISPs, this could improve both Wi-Fi connectivity and throughput in vehicular scenarios, previously shown to be at odds with each other due to DHCP delays in Wi-Fi connection setup [16].

3.1 Overview

Despite its early stage, Wi-Fi Assist’s design differs from existing solutions in two key ways: (1) it is heavily infrastructure-driven; and (2) defines an interface for low-latency cooperation between different WLAN service sets, managed by different service providers.

Infrastructure-driven design: Wi-Fi Assist aims at transferring work from the client to the infrastructure side, so as to shrink non-connectivity periods as much as possible. Non-connectivity periods have 3 main causes: (1) lack of Wi-Fi signal coverage; (2) failure to connect to a Wi-Fi network; and (3) Wi-Fi connection setup. While (1) is a ‘deal-breaker’, Fig 1 shows that it may be a rare event. Wi-Fi Assist mitigates (2) and (3) by preemptively establishing association/authentication state and encryption keys at Wi-Fi APs located along the vehicle’s trajectory. Ideally, after a bootstrapping step, the mobile client should only deal with transmitting and receiving data frames, which are eventually handled by Wi-Fi APs within the vehicle’s range. To accomplish this, Wi-Fi Assist servers keep track of a vehicle’s trajectory, predict the possible future ramifications of the current trajectory and use data aggregated from multiple participant APs to decide which are better suited to handle a particular vehicle (steps 1, 2, 3 and 5 in Fig. 2).

Cross-provider interface: In order to expand the space of APs which can handle a vehicle’s communication session, Wi-Fi Assist must be able to request the establishment of association/authentication state in APs belonging to different WLAN service sets, often managed by different providers (steps 4 and 5 in Fig. 2).

3.2 Challenges & Initial Design Options

Wi-Fi Assist’s realization involves the following challenges:

Latency minimization: Wi-Fi Assist adds new interfaces and system operations, and thus new potential sources of latency, which must be minimized: (1) communication with Wi-Fi Assist servers; (2) Wi-Fi Assist computations; and (3) AP configuration operations. One option is to distribute and coordinate Wi-Fi Assist servers across cloudlets [12, 14] managed by the participating ISPs and positioned near the configurable APs. The instantiation of Wi-Fi Assist servers could be facilitated through NFV. Latency of configurations internal to ISPs can be minimized by the pre-establishment of forwarding rules using SDN capabilities.

Maintaining transport sessions: As seen in Fig. 2, a vehicle must maintain a transport session while ‘hopping’ over different APs, included in different WLAN service sets. An interesting option proposed by [7] is the use of Multipath TCP (MPTCP) [11] for TCP transport, which allows for multiple sub-flows within a the same TCP session, between different source IP/port pairs and a single server.

Security: Wi-Fi Assist poses several security challenges along 3 axes: access control, accountability and resource protection:

• Access control: Credentials used by vehicles to access the scheduled Wi-Fi APs along their path should not be abused by other entities. Furthermore, usage of ISP configuration interfaces by Wi-Fi Assist should require strict authentication policies, which must be fast to minimize latency. A token-based authentication system (e.g. Kerberos) is an interesting solution.

• Accountability: ISPs providing configuration interfaces must be able to track/control traffic usage by Wi-Fi Assist instances, for billing purposes.

• Resource protection: A malicious party - either a Wi-Fi Assist instance, provider or vehicle - must not compromise the security of data traffic nor the integrity of the network infrastructure.

\(^1\)Data not shown in this document.
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