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Enabling vehicular mobility in city-wide IEEE 802.11 networks through predictive handovers

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A B S T R A C T

The increasing number of IEEE 802.11 networks deployed worldwide gives mobile users the possibility of experiencing high-speed wireless access on the move. Moreover, the high density of these deployments in urban areas make IEEE 802.11 a suitable access technology for moving vehicles. However, in order to provide a seamless access to vehicles, the transition between Access Points (APs) must be quick and reliable. The main bottleneck of existing handover mechanisms is the long AP scanning process, which only provides a snapshot of the available networks at a given location, impacting the handover decision on moving vehicles. To overcome this limitation, we propose COPER, a context-based predictive handover mechanism that considers vehicle's trajectory, road topology, and network deployment information to decide the best handover location and candidate access points. We validate with real experiments in a city-wide 802.11 network and show that COPER can provide better average signal strength, data rate, and connected time than other existing handover approaches.

1. Introduction

In the recent years, the number of mobile users connected through 802.11 networks have significantly increased. At the same time, the increasing number of wireless network deployments open the way towards ubiquitous network connectivity. However, under vehicular mobility, the selection of the AP in providing the most sustainable network connectivity is a challenging task. In this context, the standard IEEE 802.11 handover comprises three phases: scanning, authentication and, association, and is inefficient in ensuring a seamless transition to the best AP. It is well known that the scanning process in which the Mobile Station (MS) probes nearby APs on each channel and waits for probe responses, is the major bottleneck [1–3]. This inefficiency is mainly caused (i) by the long delay in the handover and, (ii) by the lack of indication on short-term changing in the nearby APs' Received Signal Strengths (RSS). The first implies long disconnection periods, while the second leads to potentially inconsistent AP selection.

Many solutions have been proposed to mitigate these issues with some success, mostly by reducing the disconnection period during the handover. The future emergence of IEEE 802.11p/WAVE networks [4], which have been specifically designed for vehicular communications, opens the way towards seamless handovers. One of the major modifications proposed in this standard is the suppression of the authentication and association phase, and the transmission of Wireless Access in Vehicular Environments (WAVE) beacons containing the service transmission characteristics over a dedicated channel. However, this standard still provides no guidance as to how AP selection may be optimized.

As a result, in current and future 802.11 deployments, the inconsistency of the AP selection remains an open issue. Currently, the majority of the proposed handover optimization only rely on the instantaneous sensing of the RSS. However, this metric only provides a snapshot of the current state of the network and does not provide any trend for its evolution, which is critical in the context of vehicular communications. Gustafsson and Jonsson [5] distinguish session continuity as one of the mobility management enhancement that are necessary to achieve the Always Best Connected (ABC) paradigm. The MS needs to augment its knowledge on nearby networks and vehicle's mobility such that it can anticipate their evolution. This anticipation allows the MS to avoid abrupt connection disruption due to inappropriate AP selection and to provide a seamless connection to the AP.

In this paper, we propose COPER, a COntext-aware Predictive handovER technique conceived with the aim of optimizing vehicular communications through a metropolitan IEEE 802.11 hotspot network. The AP selection process of COPER uses a prediction of

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MS connectivity over the near future such that the roaming decision is performed at the most appropriate location. In this case, a prior knowledge of the route taken by the vehicle would allow computing optimal handover locations. However, most of the time, people drive on previously known routes, thus, do not need to be assisted by any embedded system. As a result, there is no way to know the destination, nor the route the driver plans to take in advance. In fact, this information is not reliable since the driver may change the route on impulse. Consequently, COPER includes a direction detection module that provides a short-term prediction of the direction of the vehicle. In order to perform the direction detection and the AP selection, COPER uses the knowledge of the road topology, the APs' locations and their modeled RSS, all stored in a Context DataBase (CDB).

The remainder of this paper is organized as follows. In Section 2 we present related work. Section 3 describes the different modules composing COPER and the CDB construction. The results of the evaluation study are presented in Section 4. Section 5 proposes a discussion on the possible enhancements of COPER. Finally, in Section 6 we conclude the paper.

2. Related works

During vehicular mobility, an MS connected through 802.11 networks faces frequent handovers and must select the next AP and associate within the shortest delay. Prior studies on the standard IEEE 802.11 handover mechanism [1–3] identified the scanning phase as the most costly in time. Indeed, during scanning, the MS probes nearby APs and waits for responses on all available channels. Scanning implies a disconnection period because the MS cannot exchange frames with the current AP while listening on other channels. Several approaches have been proposed to reduce or even eliminate the impact of the scanning phase during handover. Montavont et al. [6] proposed an optimization to this process by performing short interleaved scanning phases with on-going data communication. In SyncScan [7], Ramani and Savage investigated a modification of the infrastructure where the APs synchronously broadcast beacon frames on the same channel so that the MS just needs to switch the channel and wait for a short period to retrieve the available APs. Another solution consists in relocating the scanning to a second interface. The experiments conducted by Ramachandran et al. [8] and Brik et al. [9] show that such a solution can provide a significant gain in terms of the time that the MS is associated. In our prior work [10], we evaluated the impact of adding a second radio and showed that the MS can reach up to 98% of layer 2 connection time. Even though the impact of scanning on handover duration can be significantly reduced, it still suffers from providing inaccurate results. Indeed, scanning is an instantaneous sensing of the network that does not always reflect reality. Because of beacon loss, scanning can miss an available AP, especially in dense deployments, like those discuses in [11,12]. To overcome this issue, a solution is to use repeated multiple scans, split into short interleaved scanning phases as described in [6]. However, this approach is not applicable to vehicular communications, as the sensed values become rapidly obsolete because of the relatively high velocity.

In order to provide a dynamic knowledge of nearby APs, Mhatre and Papagiannaki [13] propose performing RSS predictions based on smoothed RSS trends. A similar approach is proposed by Sadiq et al. [14]. Nevertheless, this kind of prediction can only be performed over a very short period, since it does not consider any information on the vehicle's motion. For instance, the MS will not be able to predict a sudden signal decrease when the vehicle leaves the line of sight of the AP.

In the literature, multiple 802.11p network architectures for Vehicle-to-Infrastructure (V2I) communications have been proposed, including multiple handover mechanisms. The network architecture described in [15] consists of IEEE 802.11f Inter Access Point Protocol (IAPP) compatible RoadSide Units (RSU) interconnected by a set of layer 2 switches connected to a gateway router. This makes, the network appear as a single distribution system and mobility management is handled at the layer 2, avoiding the use of Internet Protocol (IP) mobility protocol such as Mobile IPv6 (MIPv6) or Proxy Mobile IPv6 (PMIPv6). The handover is triggered when the On-Board Unit (OBU) sends an IEEE 802.11 disassociation message to the current RSU. The RSU, then, communicates the OBU address to the next RSU by forwarding the packets addressed to OBU. The major drawback of this approach is that it is designed to work in a highway environment where the next RSU selection is trivial. Note that in an urban scenario, the AP selection process may not be as trivial as in the highway scenario. An extended version of this approach presented in [16], is intended to work in an urban environment. The authors propose forwarding data packets to all the candidate RSUs. When an RSU detects that the OBU has entered in its coverage range, it is selected as the next RSU and sends a Move–Notify message to the remaining RSUs. However such an approach implies significant packet overhead.

In order to allow the MS to anticipate the short-term evolution of the network, it is critical to provide information about the vehicle's mobility. Based on the fact that people usually drive on previously known routes, Deshpande et al. [17] propose replacing the scanning with an AP selection using historical information. While driving, the MS learns and caches information about nearby APs (ESSID, BSSID, channel) by frequently sensing during inactive periods. This information is, then, used to script the handover location in advance such that the MS is always connected to the best candidate AP. Another approach is proposed by Kwak et al. [18], who suggest including the trajectory of the vehicle and neighbor information in order to select APs along the vehicle's path and predict an optimal handover location. This approach was investigated by Montavont and Noel [19], who propose an augmented version of the Mobile IPv6 (MIP6) architecture with a new component, a GPS server which is periodically updated with the location of the MS. Based on the evolution of the MS location and prior knowledge of AP locations, channels, BSSIDs and IPv6 prefixes, the GPS server triggers handover to the closest AP when the MS is about to leave the coverage range of the current AP by sending a handover indication packet to the MS. In [20] and [21] the authors use large datasets gathering mobility history of cellular network users [20] and large indoor 802.11 network [21]. Zhang et al. [20] propose a cloud-based mobility prediction system that consists in detecting periodicity in the mobility pattern using the Kullback–Leibler divergence (KLD) as the metric and evaluate social interplay in order to identify some pairs of calls that will be co-located. In [21] Abu-Ghazaleh and Alfa model the mobility behavior of users in a 802.11 network as Markov Renewal Processe (MRP). This model intends to predict handovers and the sojourn duration of a user based on the current location and the prior location of the user immediately before the transition into the current location. In the same way, De Rango et al. [22] proposed an efficient prediction-based bandwidth allocation scheme using the Mobile ReSerVation Protocol (MRSVP) and an analysis of users' mobility to ensure quality-of-service (QoS). These approaches propose long-term predictions that allow the MS to ensure service continuity in case the selected AP is unavailable (switch off or not able to provide enough bandwidth). In our previous contribution (MROAD) [23], the AP selection process uses prior knowledge of the route of the vehicle and the location of the APs along the road. The RSSs of the APs are modeled offline using the CORNER signal propagation model [24]. Based on this information, MROAD can predict the best handover location. This allows the MS to trigger the handover using its location as the single input.