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Mobile Internet access over intermittent network connectivity

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ABSTRACT

Mobile Internet access is the key technology to enable vehicular infotainment applications such as downloading of maps and multimedia contents. Mobile Internet access through roadside APs has emerged as an alternative to cellular networks due to its high bandwidth and low cost. However, due to the sparse deployment of roadside APs, connectivity disruption might take place when vehicles travel between APs. In addition, the IP address will also change as the vehicle changes its attachment to the network. This creates problems to existing IP applications as they are not designed to handle connectivity disruption and change of address. Furthermore, as a vehicle travels at high speed, its contact with a roadside AP will be brief. It is necessary to effectively utilize such brief contacts. In this paper, we propose a MObile Network Access framework (MONA) to address these issues. MONA protects application connections from connectivity disruptions by introducing a Terminal Local Proxy (TLP) which splits application connections such that connectivity disruptions are transparent to the applications. By enabling cooperative relaying, MONA exploits opportunistic contacts for additional data transfer. Through simulation and numerical analysis, MONA is shown to be able to exploit both direct and indirect contact opportunities and delivers more than existing PCMP scheme. This shows MONA is a viable approach and it can serve as a complementing technology to various existing techniques and contribute to the development of a more complete solution for mobile Internet access.

1. Introduction

It is envisioned that vehicular networking will foster many attractive applications for future transportation systems (Karagiannis et al., 2011). Among these applications, vehicular Internet access is the key technology to enable mobile infotainment services such as downloading of traffic information, maps, touristic information as well as bulk multimedia. Despite the large coverage of cellular networks such as 3G and Long Term Evolution (LTE) in urban area, considering the potentially high node density on the roads and the volume of the data transfer, it would not be scalable or cost efficient for cellular networks alone to handle vehicle-to-infrastructure Internet access. With the advent of Dedicated Short Range Communication (DSRC) and 802.11 technologies, mobile Internet access through high throughput roadside Access Points (APs) appears to be a promising solution to handle bulk data transfer for mobile vehicles. These roadside APs can provide broadband connectivity at low cost and serve as a complementing technology for vehicular Internet access.

However, due to the highly mobile nature of vehicular networks and the large urban area that vehicles might traverse, there are also several research challenges to enable mobile Internet access through roadside APs:

1. *Intermittent connectivity*: Intermittent connectivity takes two forms. The first is the connectivity between moving vehicles and roadside APs. With the large urban area, it is not practical to deploy enough APs to cover the entire city. Then there are often gaps between the coverage of two APs as each roadside AP has limited coverage. Thus, the connectivity experienced by vehicles passing by will likely to be intermittent. This could break application connections if the two APs are far apart. On the other hand, when cooperative downloading is enabled, i.e. vehicles closer to the roadside APs relay traffic for nodes further away, the connectivity among vehicles can also be intermittent due to different movement patterns of vehicles.
2. *Brief contact opportunity*: The coverage of individual AP is usually limited. Since vehicles on the roads usually travel at high speed, they only have a few seconds to communicate with the roadside APs depending on the vehicle speed (Ott and Kutscher, 2004). This limits the amount of data exchange between the moving vehicles and the roadside AP during each contact.
3. *Change of address*: As the coverage of the roadside AP is limited, when a vehicle roams from one roadside AP to another, it will acquire a different IP address. As a result, data packets will be

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routed to the old address at the previous AP and will not reach the new address.

These issues have great impact on the mobile applications. Intermittent connectivity could break data connections if the connectivity disruption between a vehicle and the roadside AP is long enough. In addition, with cooperative downloading taken into consideration, the intermittent connectivity among vehicles could prevent the establishment of end-to-end path between a helper vehicle carrying data and the intended recipient, undermining the performance of cooperative relays. Simple solutions such as software auto-reconnection or even manual reconnection are not practical. Although applications can attempt to reconnect to Internet servers periodically, they will likely miss the contact because the contacts between the vehicle and the APs are opportunistic and very brief. On the other hand, it is not practical to manually reconnect the applications either due to the same reason. Hence, a good solution to these issues should protect the data connections from network disruption, allow change of IP address and also efficiently utilize any contact opportunity. By "efficiently", vehicles should utilize not only direct contacts with the roadside AP but also indirect contacts through other vehicles as relays.

Existing work has been focused on these issues individually, such as mobility management (Al-Surmi and Othman, 2011; Perkins et al., 2011; Gundavelli et al., 2008; Lim et al., 2009), AP deployment strategies (Zhu et al., 2012; Trullols et al., 2010; Zheng et al., 2010, 2009), content prefetching (Zhang and Yeo, 2012; Shevade et al., 2010; Balasubramanian et al., 2008) and cooperative downloading (Trullols-Cruces et al., 2012; Malandrino et al., 2011; Chen and Chan, 2009). However, none of them offers a complete solution to all the aforementioned issues. Hence, another step towards a better mobile Internet access solution would be a framework that:

1. Shields application from intermittent connectivity.
2. Manages change of IP addresses across intermittent connectivity.
3. Provides a common signaling mechanism for mobility management and content delivery.
4. Allows integration with existing research work such as cooperative downloading, content prefetching or AP deployment strategies.

In this paper, we propose one such framework called Mobile Network Access Protocol (MONA). To protect application connections from intermittent connectivity, MONA introduces a Terminal Local Proxy (TLP) at client side. Application connections will be redirected to the TLP which will relay the traffic between the applications and the remote servers. This essentially splits the application connection into two segments, the connection between application and the local TLP and the connection between the TLP and remote servers. When network disruption occurs, only the latter connection will be affected and the network disruption will be transparent to the application.

The issues caused by change of address usually comes from the close coupling of node identifier and locator, i.e. by using IP address to identify a node as well as specify the network location of the node. To address this issue, MONA identifies each node using a Session Initiation Protocol (SIP) (Rosenberg et al., 2002) URI. IP addresses are used as node locator that are updated dynamically. Whenever a node acquires a new IP address, address fields in connections established over the old and expired IP address will be dynamically updated such that the change is transparent. In addition, MONA also provides a signaling mechanism based on SIP message exchange which enables node movement detection, notification and opportunistic content delivery.

To enable data transfer across intermittent connectivity and efficiently exploit brief contact opportunities, MONA makes use of an emerging technology, Disruption Tolerant Network (DTN) (Cerf et al., 2007), for data transport among vehicles and roadside APs. DTN does not assume end-to-end connectivity and it does not rely on IP addresses for node identification, either. It identifies nodes using Endpoint Identifier (EID) and routes data traffic based on EID instead of IP addresses. DTN forwards data in *Bundles* progressively in a hop-by-hop manner towards the destination. In this way, data can be delivered along a path in which end-to-end connectivity might not exist at all.

Furthermore, MONA is designed to support prefetching and cooperative download to improve the data delivery. MONA allows the downloading of content when the vehicle is disconnected and pushing the content to the APs which are likely to be traversed in the future. In addition, when a 3G/LTE uplink is available, MONA can forward delay sensitive traffic through the uplink during the coverage gaps of the roadside APs such that these sessions are not interrupted.

The major contribution of our work lies in that it offers a framework with application support to enable communications for existing applications over intermittent network connectivity. Our work can integrate with other research works such as cooperative downloading schemes, prefetching or AP deployment algorithms to provide a more complete solution for mobile Internet access. In the next section, the related work is discussed. The detailed design of MONA is presented in Section 3. The evaluation of the scheme is shown in Section 4. Section 5 discusses the deployment and performance issues of MONA and Section 6 concludes this paper.

2. Related work

Plenty of previous works have studied the issues due to highly mobile nodes which we have highlighted in Section 1, namely, intermittent connectivity, brief contact opportunity and change of network address. However, these work focused on the issues individually and do not provide a complete solution for all issues.

Handling the issues of IP address change belongs to the realm of mobility management. In the past few years, numerous mobility management schemes (Al-Surmi and Othman, 2011; Perkins et al., 2011; Gundavelli et al., 2008; Lim et al., 2009) have been proposed. The basic idea of mobility management is to redirect the traffic sent to the old IP address to the new IP address after the mobile node roams to a new AP using mechanisms such as tunneling (Perkins et al., 2011) or header modification (Lim et al., 2009). However, these schemes are designed for overlapping wireless networks with the design goal of seamless handover between networks. They do not consider the scenario in which the handover delay between the APs is long enough to break the data connections. Therefore these schemes are not suitable for our application. One class of mobility management scheme (Fernandes and Karmouch, 2012) seems to be promising solutions which support vertical handover between heterogeneous technologies, e.g. between the cellular network and the roadside APs. These schemes appear to be the solution to the aforementioned issues. However, because these schemes rely on cellular network to bridge the connectivity gap between APs, they will not be able to utilize additional contact opportunities created through cooperative relays. In addition, since cellular networks will be used most of the time, the majority of the traffic load will be in the cellular link and hence only marginal benefit from the roadside APs can be derived. Hence they are not the most efficient solutions.

Recent research work has mainly focused on tackling the issues of brief contact between the fast moving vehicles and the roadside APs. Researchers has tackled the problem from several perspectives including maximizing contact opportunities through different AP deployment strategies (Zhu et al., 2012; Trullols et al., 2010; Zheng et al., 2010, 2009), improving the utilization of the contact opportunities through content prefetching (Zhang and Yeo, 2012;