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On Performance Simulation in Vehicular Hybrid Networks of WiFi and LTE

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Abstract

Integration of high-bandwidth Wi-Fi technology (e.g. 802.11p) and large-scale 4G network (e.g. Long-Term Evolution, shortly for LTE) could offset mutual limitations and provide vehicles ubiquitous Internet available. In this paper, we propose a novel vertical handover algorithm, and a feasible integrated architecture of heterogeneous 802.11p and LTE technologies through comparing Received Signal Strength (RSS) from both interfaces. We perform extensive simulations to investigate and analyze the performance of the proposed architecture using NS3. Results show that the proposed architecture behaves with the high throughput and low round trip time.

Keywords: *Vehicular networking; Wifi; 802.11p;LTE*

1. Introduction

Vehicular Ad-hoc Network (VANET) is a typical example of Mobile Ad-hoc Network (MANET) [1], where vehicles could enjoy numerous safety and efficiency applications and share information among vehicles through diverse communication technologies *e.g.* Bluetooth, Wi-Fi, and 3G/4G. Since there have been much academic and industrial work on every separated vehicular communication technology in recent years, guaranteeing uninterrupted network connection and incessant Internet service in quick vehicles' mobility is a long-term goal because of complex traffic situation and frequently changed topology. Therefore, it is necessary to seamlessly integrate multiple access technologies to achieve the goal.

The integration of different communication technologies especially of middle and long range is important due to large-scale distributed vehicles and diverse performance requirements of vehicular applications. Some communication technologies (*e.g.* UMTS and LTE) could provide large-scale coverage, while other networks (*e.g.* Wi-Fi) could provide high bandwidth and low cost of deployment. This paper focuses on vehicle-to-infrastructure (V2I) communication, and chooses Wi-Fi (*i.e.* 802.11p) and 4G (*i.e.* LTE) as candidates of access technologies, considering that LTE theoretically provides 50Mbps uplink and 100Mbps downlink data rates that are much suitable for delay-sensitive services. In order to improve the overall performance, we also propose a power-aware handover algorithm by comparing the received signal strength from LTE and Wi-Fi interfaces.

2. Related Work

Benslimane *et al.* [2] proposes a WiFi-UMTS architecture in which vehicles are dynamically clustered based on different metrics, and a minimum number of vehicles equipped with 802.11p and UTRAN interfaces are selected as gateways to link ad-hoc

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networks. Manoharan *et al*. [3] proposes a multi-metric gateway selection mechanism that selects an optimal gateway from the dual-interface-enabled gateway candidates. Sivaraj *et al*. [4] presents a heterogeneous architecture of combining 802.11p and LTE. Mangel *et al*. [5] analyzes the suitability of UMTS and LTE for cross-traffic assistance in the worst case with respective to load and latency requirements and the results show that UMTS suffers from capacity limitations while LTE could work well. Remy *et al*. [6] presents LTE4V2X for a centralized vehicular network structure using LTE to solve the large number of mobile nodes and their extremely dynamic network topology. They also gave performance evaluation on LTE4V2X in a highway scenario in order to evaluate the impact of high mobility [7]. The results show that LTE4V2X is able to efficiently deal with fast mobility. Cherif *et al.* [8] introduces CSP and CGP that are proactive and active cluster-based self-organizing protocols respectively to solve problems like the large number of mobile nodes and extremely dynamic network topology. Both two solutions depict the vehicular network in permanent manner by portioning roads into adjacent segments as geographic fix clusters. Durrani *et al.* [9] concentrates on connectivity and proposes a new equivalent speed parameter and designs an analytical model to explain the effect of vehicle mobility on the connectivity of highway segments. A handover process is composed of three steps [10], *i.e*. handover information gathering, handover decision, and handover execution.

The above handover algorithms all use technologies like mobile IP or similar methods. They are dependent on the home agent to assist the handover during the establishment of IP connection. We modify the relevant layers of OSI model to make it unnecessary in the step of handover execution, thus reducing the traffic of routing and tunneling.

3. Integrated Network Architecture

Our integrated architecture is mainly focused on vertical and initiated by the mobile vehicle without any assistance from access routers. The handover algorithm compares the received signal power of LTE and Wi-Fi interfaces within one period. Figure 1 shows the stack architecture of the mobile vehicle, which is jointly designed by ETSI and ISO.

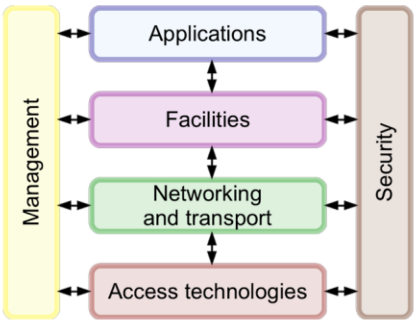

Figure 1. ETSI/ISO C-ITS Reference Station Stack Architecture

The application layer provides various vehicular applications *e.g.* time-critical and non-time-critical. The facilities layer provides common functions independently from access technologies. The Transport & Networking layer offers transmission and networking protocols *e.g*. IPv6 for delivering data from a source to one or more destination(s). The access layer manages different access technologies. The security entity is supposed to provide security mechanisms concerning all relevant layers, but we do not implement it in the simulations. The management entity is a control module wherein we implement the handover algorithm. It has the following members: TCP_socket_for_change records all the existing TCP sockets; IsUsingLTE and IsUsingWiFi are used to judge to which interface the vehicle should send packets; NeedToChange indicates that a handover process should be performed when it turns to true; changeTimer controls the periodical comparison of received signal strength from LTE and Wi-Fi interfaces; compareTimer is to analyze the received signal strength within one period; Min_interval is the minimum time interval between two adjacent handovers; percentLTE is equal to count_for_LTE/count_for_comparison, count_for_LTE is the times of LTE interface stronger than Wi-Fi interface during one period; percentWiFi is equal to 1-percentLTE. Threshold_toLTE is the threshold of percentLTE when handover to LTE, and Threshold_toWiFi is the threshold of percentWiFi when handover to Wi-Fi, Last_time records the time when the last handover happens. By the above variables the management entity could decide to activate appropriate communication interface for continuous connection and delivering data as quickly as possible.

Now we explain how changeTimer, compareTimer and Min_interval work together and affect each other. If we set the value of changeTimer to *m* seconds, then the value of Min_interval is an integral multiple of *m*. We should set changeTimer and compareTimer appropriately. If the period of changeTimer is too long, it is unable to reflect the changes of network performance timely, and if too short, it cannot reflect the performance of different networks steadily, thus causing the "Ping Pang" effect. If the value of compareTimer is too small, we could not know how the real network performance is, and this leads to a bad handover decision.

Figure 2 shows the working process of handover algorithm. The connection and disconnection of Wi-Fi interface trigger the handover event. During initialization, the default values of some parameters are: IsUsingLTE=true, IsUsingWiFi=false, and Last_time=-1(*i.e.* handover never happens). So the default interface used for transmitting data is LTE. And then a function in Wi-Fi interface starts to monitor whether or not the interface is connected. If a Wi-Fi connection losses, it performs handover to LTE, otherwise it notifies the management entity that a Wi-Fi connection is completed, then the management entity starts the handover process. If there is only Wi-Fi connection, a handover to Wi-Fi is needed. If Wi-Fi and LTE coexist, then the management module sets changeTimer (when changeTimer expires, it resets compareTimer) and the RSSs of the two interfaces are recorded every 100ms that corresponds to the typical beacon interval value of an access point until compareTimer expires, then it processes the recorded data and decides whether or not to handover.

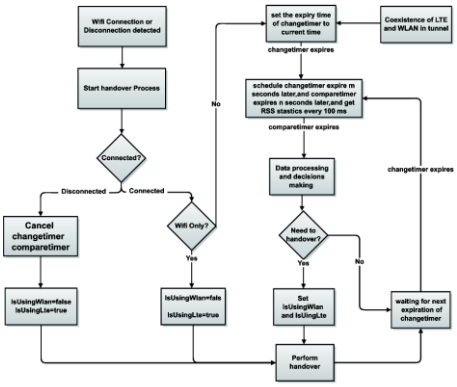

Figure 2. The Working Process of Handover Algorithm

The details of executing a handover are as follows.

Step 1: Send notices to all sockets in queue Tcp_socket_for_change, indicating a handover is ready to be executed;

Step 2: Applications receive prepare-to-handover messages and close the current sockets;

Step 3: Applications create new sockets;

Step 4: Applications continue working until new connection is established.

After the sockets in queue Tcp_socket_for_change receive the message from Step 1, they perform the following actions.

Step 1. Tcp socket gets notification that a handover is ready to occur;

Step 2. Socket sends a message to its application to inform that a handover is ready to occur and the socket continues transmitting data until Step 2 in " execute handover" closes itself.

Step 3. Socket removes itself from queue Tcp_socket_for_change and closes itself after cleaning the queued application data;

The following steps explain how a socket and its connection are created in Step 3 of "execute handover":

Step1. Socket adds itself to queue Tcp_socket_for_change after creation;

Step2. Socket chooses an interface address as the local address for this connection according to the value of IsUsingWiFi and IsUsingLTE;

Step 3. Three-way handshake is executed.

Vehicles should make an adaptive decision on whether or not to handover. If the handover algorithm acquires assistance from access networks, the consumed time of making decision is reduced. In our algorithm, the shorter compareTimer is, the better the performance of handover algorithm is.

4. Simulations

We perform extensive simulations through realizing the new cooperative ITS architecture in NS3. Figure 3 shows the scenario of simulations.

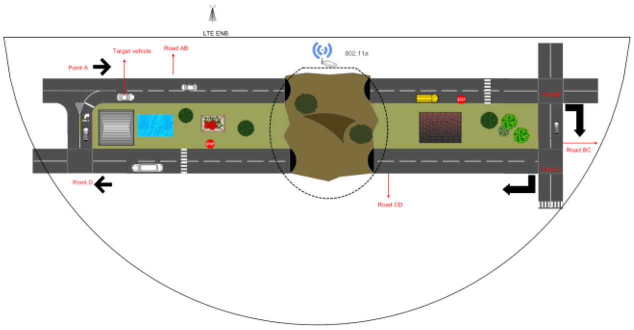

Figure 3. Simulation Scenario

The solid semi-cycle represents the area covered by LTE while Wi-Fi covers the dashed oval area. Tunnels across the mountain exist inside the oval. The LTE ENB (Evolved Node B) is located at coordinate (250,400), the coordinate of AP is (500,420), and the coordinates of Point A, Point B, Point C, and Point D are (50, 430), (800, 430), (800, 460), (50, 460), respectively.

In all the simulations, the vehicle starts at point A, travels along the black arrows and finally arrives at point D, which covers 1530 meters, *i.e.* Road AB, Road BC, Road CD are 750 meters, 750 meters and 30 meters. We set the transmission power of LTE ENB as 36 dbm, the transmission power of AP as 20 dbm, and both the transmission power of Wi-Fi and LTE interfaces are 10dbm. We use Friis propagation loss model in calculating the received signal strength of LTE and Wi-Fi interfaces. In every simulation, there is one vehicle that runs Bulk-Send-Application (*i.e.* a client simply sends data to a server until the application is stopped) and the size of packet is 512 bytes each time.

We conduct different simulations against different parameters to investigate how these parameters affect the proposed handover algorithm and how they affect the performance of vehicular communication. We use NoX-1 to represent results of throughput and use NoX-2 to represent results of RTT. In all the scenarios, the values of Threshold_toWiFi and Threshold_toLTE are 1.

4.1 Handover in Congested Traffic

We set the velocity as 2.5m/s (*i.e.* 9km/h) for simulating congested traffic. The parameters of simulation I to IV are shown in Table 1. UL is short for UpLink and DL is short for DownLink and they are measured in RBs (Resource Block).

Table 1. Parameters of Simulation I to IV

no	UL,DL	changetimer/s	comparetimer/s	Count_for_comparion	Min_interval/s
I	UL=DL=25	4	3	25	8
II	UL=50 DL=100	4	3	25	8
III	UL=DL=25	4	3	25	4
IV	UL=DL=25	3	2	15	6

In simulation I, UL and DL are both set to 25 RBs while 50 RBs and 100 RBs in simulation II. But the result of throughput of LTE is increased by 0.817Mbit/s (*i.e.* 9.3%), thus lowering the bandwidth usage.

Figure 4 shows the throughput of simulations I to IV, indicated by NoI-1, NoII-1, NoIII-1 and NoIV-1. Figure 5 shows the RTT of simulations I to IV, noted by NoI-2, NoII-2, NoIII-2 and NoIV-2. Seeing I-1 in Figure 4 and I-2 in Figure 5, the path is divided into 5 sections with respective to handover. The vehicle chooses the LTE interface to transmit packets when entering Section 1, and the handover algorithm detects that a handover to Wi-Fi is needed after travelling 418 meters along road AB (*i.e.* 167.142 seconds), and after this handover the vehicle enters Section 2, and the application has low RTT and high throughput compared to in Section 1 due to the relatively high data rates. The Wi-Fi signal is weakened as the vehicle continues moving along the road and the second handover occurs after 35.9 seconds in Section 3. The vehicle first drives away from LTE ENB, and then moves towards to LTE ENB when it enters road CD, so the RSS of LTE interface first declines and then keeps increasing and the throughput of LTE interface has the same trend while the RTT follows the opposite trend. The decision of handover to Wi-Fi again is made after 419 seconds (*i.e.* 267.855 meters away from Point C) in Section 4. The last handover happens 36 seconds later and the vehicle enters Section 5 and switches to LTE interface. Even the throughput of NoII-1 in Section 3 has the same trend as in Section 3 of NoI-1, but it is improved due to more RBs assigned to UL and DL.

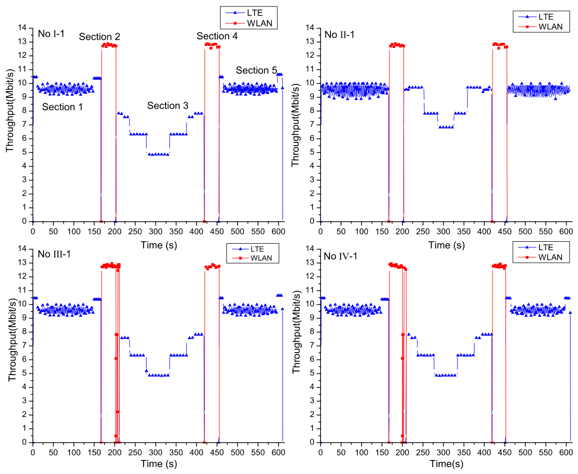

Figure 4. Throughput of Simulations I to IV

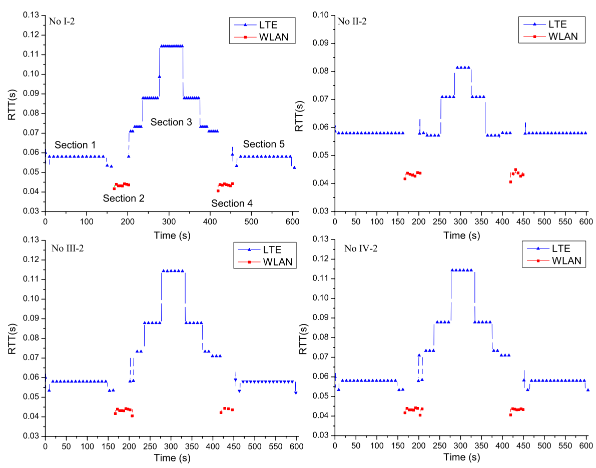

Figure 5. RTT of Simulations I to IV

4.2 Handover in Free Traffic

The vehicles run at 10m/s (*i.e*. 36km/h) for simulating free traffic. Table 2 shows the parameters of simulations V to XI.

Table 2. Parameters of Experiment V to XI

no	UL,DL	changetimer/s	comparetimer/s	Count_for_comparion	Min_interval/s
V	UL=DL=25	4	3	25	8
VI	UL=50 DL=100	4	3	25	8
VII	UL=DL=25	3	2	15	6
VIII	UL=DL=25	3	2	15	3
IX	UL=DL=25	3	2	15	9
X	UL=DL=25	4	3	25	12
XI	UL=DL=25	4	3	25	4

The average transmission rate of the Wi-Fi interface is 12.804 Mbit/s in simulations V to XI while it is 13.232 Mbit/s in simulations I to IV, decreased by 0.428 Mbit/s (3.3%), it is caused by increasing the velocity from 2.5ms/s to 10m/s. One can know from Table II that if changeTimer is *m* seconds, then the value of Min_interval of simulations VIII and XI is *m* seconds, the value of Min_interval of simulations V, VI and VII is 2**m* seconds, and the value of Min_interval of simulations IX and X is 3**m* seconds. These settings do not have any impact on the handover algorithm. In simulation V, UL and DL are both set as 25 RBs. For a comparison, UL and DL are set as 50 RBs and 100 RBs in simulation VI. The throughput of LTE is increased by 0.801Mbit/s (*i.e.* 9.23%), which is similar to the results of simulations I and II. It shows that the average transmission rate of the LTE interface is not affected as the velocity increases.

Figure 6 shows the throughput of simulations V to VIII, noted by NoV-1, NoVI-1, NoVII-1 and NoVIII-1. Figure 7 shows the throughput of simulations IX-XI, noted by IX-XI NoIX-1, NoX-1 and NoXI-1. Figure 8 shows the RTT of simulations V to VIII, noted by NoV-2, NoVI-2, NoVII-2 and NoVIII-2. Figure 9 shows the RTT of simulations IX to XI, noted by NoIX-2, NoX-2 and NoXI-2. See V-1 in Figure 6 and V-2 in Figure 9, it is basically the same to I-1 in Figure 4 and I-2 in Figure 5. The vehicle first transmits packets through LTE interface when in Section 1, and at time 47.1423 seconds handover to WLAN, and then the vehicle enters Section 2, and the RTT is reduced and throughput is improved compared to that in Section 1 due to the relatively high data rates of Wi-Fi. The signal of Wi-Fi interface is weakened as the vehicle continues driving along the road, and the second handover happens after 7.9592 seconds, at this moment the vehicle is already 551 meters from point A in Section 3. In this section, the vehicle first drives away from LTE ENB, and then moves towards to LTE ENB when entering road CD. The RSS of LTE interface first declines and then keeps increasing, so the throughput of LTE interface also declines first and then keeps increasing, and the RTT follows the opposite trend. The handover to Wi-Fi again is made after 107.141 seconds (*i.e.* 291.41 meters behind from point C) in Section 4, and the last handover happens after 7.96 seconds and the vehicle enters Section 5 and switches to LTE interface.

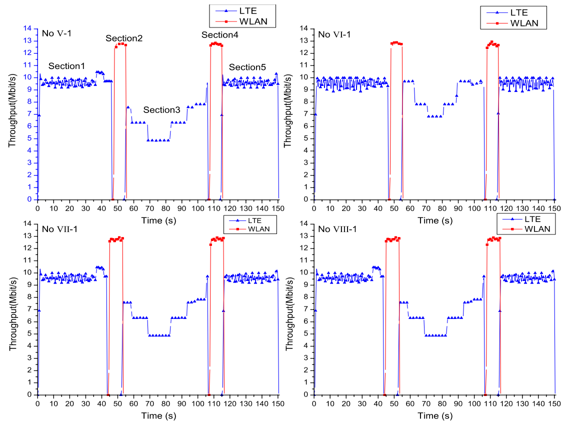

Figure 6. Throughput of Simulations V to VIII

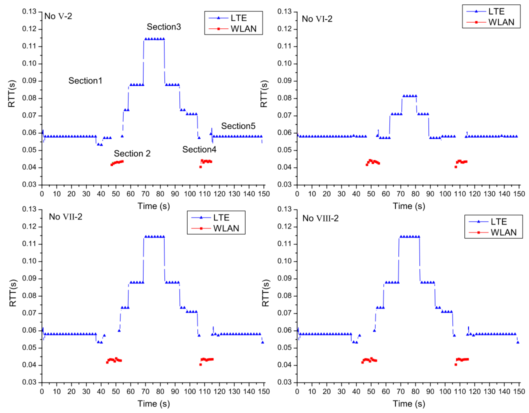

Figure 8. RTT of Simulations V to VIII

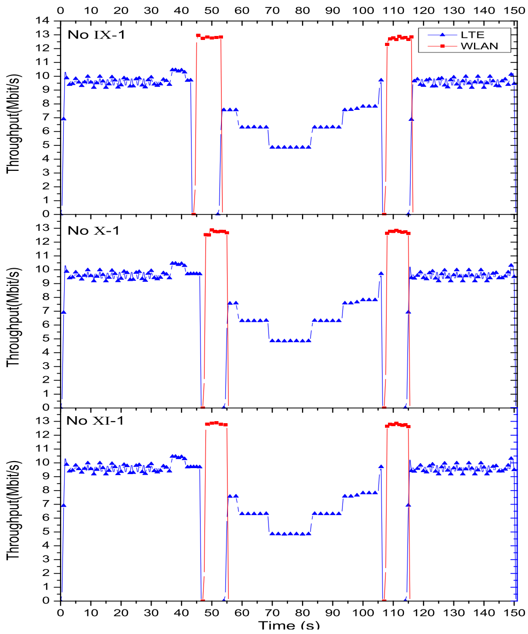

Figure 7. Throughput of Simulations IX to XI

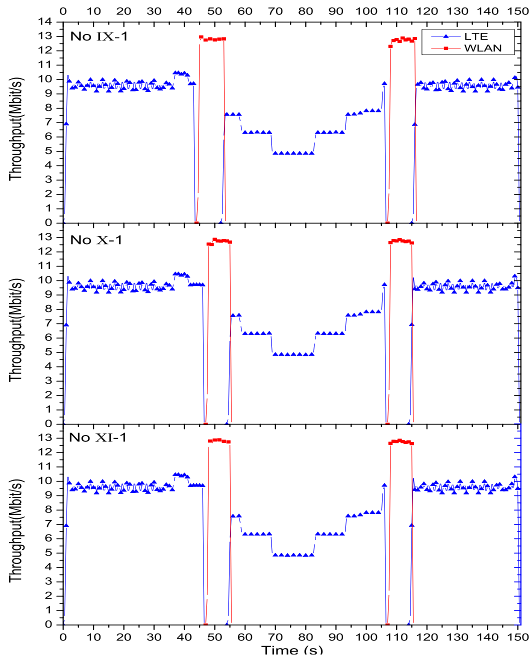

Figure 9. RTT of Simulations IX to XI

5. Conclusion

We propose a novel handover algorithm by comparing the received signal strength of Wi-Fi and LTE interfaces, and implement hierarchical communication architecture in NS3. We conduct a series of simulations to investigate how the relevant parameters affect the performance of handover algorithm. All the simulations demonstrate that Wi-Fi network could be integrated with LTE effectively with the help of the proposed power-aware handover algorithm. Results show that the performance of integrated Wi-Fi and LTE is increased by 24% at least and up to 76.37% in terms of throughput.

Acknowledgment

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