Cost-Effective Vertical Handoff Strategies in Heterogeneous Vehicular Networks

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1 Introduction

Vehicular network aims to connect vehicle-to-vehicle (V2V) or vehicle-to-the roadside unit (RSU) using wireless communication technologies. IEEE has released 802.11p standard for vehicular ad hoc network (VANET) that connects V2V or V2I using dedicated spectrum. Currently vehicles are able to access Internet via cellular networks GPRS/UMTS/LTE. Other wireless technologies like Wi-Fi, Zigbee, Bluetooth, RFID are also being used as an alternative for short distances. Wi-Fi technology is an attractive solution for increase in data demand in mobile network because of high data rate achieved with low cost. However, limited coverage of Wi-Fi access points and user mobility poses difficulty to optimize offloading performance. Cellular and Wi-Fi radio access technologies are involved in data offloading. An interworking between cellular and Wi-Fi network may help to offload cellular data. Better offloading performance can be achieved if more number of Wi-Fi APs available in certain geographical area due to their short range. However, large-scale dense Wi-Fi APs deployment may incur high capital cost. Hence tradeoff between cost and offloading performance should be examined. A good strategy is to consider population density, user mobility, mobile data usage patterns, and communication environment while deploying Wi-Fi APs.

Internet applications are infotainment such as entertainment, web browsing, mobile commerce, etc., through Internet. Many Internet applications require continuous Internet connectivity. This connectivity becomes more challenging when vehicle moves across overlapping heterogeneous wireless networks. In such a case frequent switching from serving network to target network may occur, which often degrades the performance of the network. High vehicle mobility results in very short connection time with Wi-Fi APs (e.g., several tens of seconds) which limits volume of data transferred because one has to consider time spent in Wi-Fi association, authentication, and IP configuration before data transfer which is not negligible. Communication in vehicle environment suffers from high packet loss rate due to channel fading, shadowing, and Doppler shift because Wi-Fi protocol stack is not designed for high mobility environments [1].

We focus on cellular networks interworking with Wi-Fi in HVN. WLAN offers higher data rates with lower cost for a short range while cellular network offers low data rates with high cost but with large range. In the presence of both above, vehicle on-board unit (OBU) can choose either of two for data transfer. However, when OBU

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leaves the Wi-Fi due to short range, cellular network will be connected to OBU, if V2V communication is not feasible. The availability of base stations (BS) and APs, and their data transfer prices are represented by cc ($) and cw ($), respectively, broadcasted periodically by all BSs in cellular and all APs in Wi-Fi network [2]. Next, we consider APs on the roadside on a model according to more practical situation like urban, semi-urban, and highways. Further, we include V2V communication where vehicles use multi-hop data transfer approach to relay the data to the APs. In this paper Sects. 2 and 3 discusses about efficient VHO decision with fixed inter-distance APs, and statistical inter-distance APs in urban, semi-urban, and rural areas. Section 4 includes V2V in addition to cellular and Wi-Fi network for VHO decision, Sect. 5 discusses performance evolution, and Sect. 6 concludes the paper.

2 VHO Decision with Inter-distance APs

For minimizing the cost of data transfer Wi-Fi is always preferred over cellular network. The data transfer cost c1 ($) per bit for cellular and c2 ($) per bit for Wi-Fi is assumed in VHO decision algorithm.

2.1 Cost Minimization Approach

Let us assume that all vehicle's OBU consists of both cellular and Wi-Fi interfaces. Let *bt* be the number of bits transmitted, *rc* and *rw* be the data rates (bits/sec.) of cellular and Wi-Fi, respectively, at the time of decision-making, and let *W* meters be the range of Wi-Fi AP. All APs are equidistant and remaining area between two consecutive APs is *A* meter as shown in Fig. 1. Let *v* (m/s) is velocity of the vehicle again at the time of decision-making, then the cost *c1* for cellular and *c2* for Wi-Fi can be obtained as

$$c1 = bt \times cc \tag{1}$$

$$c2 = Nw \times \frac{W}{v} \times rw \times cw + \left(Tw - Nw \times \frac{W}{v} \right) rc \times cc \tag{2}$$

In Eq. (2) *Nw* is number of APs and *Tw* is time taken by Wi-Fi to transfer data. Again in Eq. (2), first term represents cost of data bits to be transmitted by Wi-Fi

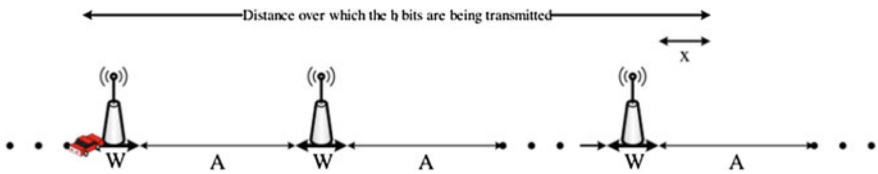

Fig. 1. Vehicular network with inter-AP distance [3]

network and second term represents cost of signaling bits and data transmitted by cellular network [3].

If b_{VHO} represents signaling bits and Nw the maximum integer for VHO, then

$$Nw \times \frac{W}{v} \times rw + (Nw - 1) \times \frac{A}{v} \times rc - 2Nw \times b_{VHO} \le bt \quad (3)$$

$$Tw = \frac{[x + Nw \times W + (Nw - 1)A]}{v} \quad (4)$$

and x as shown in Fig. 1 is obtained by

$$bt - \left[Nw \times \frac{W}{v} \times rw + (Nw - 1) \times \frac{A}{v} \times rc - 2Nw \times b_{VHO}\right] = \frac{x}{v} \times rc \quad (5)$$

In Eq. (3) cellular network signaling is comparable with overhead of VHO signaling, and $2Nw \cdot b_{VHO}$ bits for signaling are needed irrespective of initial location of vehicle user. As velocity increases, number of VHO also increases which may cause more VHO signaling bits compared to data bits which result in high cost for data transmission.

2.2 Transmit Time Minimization Approach

User has no control over Wi-Fi and cellular network data rates, but appropriate access network at any instant can be chosen to minimize the total data transmit time. Let *Tc* be the total data transmission time by cellular network and *Tw* when Wi-Fi together cellular network is used, then

$$Tc = \frac{bt}{rc} \quad (6)$$

and *Tw* is given by Eq. (4). The vehicle will select the network to minimize the transmission time. It may be noted that the decision-making process is event based, and thus parameters will be computed whenever any significant changes in the network like new data rates, or new access network, or change in the velocity or direction of vehicle, or advertisement of new costs [4].

3 VHO Decision Based on Statistical Inter-distance APs

The distance between consecutive APs follows a pattern designed according to the area urban, semi-urban, or rural/highway chosen. The distance between APs and velocity of vehicle have been chosen arbitrarily as shown in Table 1. Urban areas will have maximum vehicle density, hence vehicle speed will be quite low compared to semi-urban and rural areas. Also due to higher traffic and higher Internet requirements, APs inter-distance is quite low to ensure better connectivity to all the vehicles. In rural areas, density of vehicles is quite low and velocity is quite high. APs inter-distance is large enough. This lowers the installation cost of APs as well. The cost using Eq. (2) and transmission time using Eqs. (6) and (4) for the above three areas are calculated and handover is performed accordingly.

Table 1. Distribution of APs

Velocity		Inter-AP distance	Area
Min. (km/h)	Max. (km/h)		
20	45	0.3 km	Urban
47	65	0.6 m	Semi-urban
67	90	1 km	Rural

4 VHO Decision Including V2V Mode

VHO decision algorithm is generalized by including multi-hop V2V communication between vehicles. In multi-hop V2V communication intermediate vehicles relay data to next vehicle using ad hoc network which can act as an alternative to costlier network to some extent. The V2V delays include multi-hop relaying delays and delays when no next hop vehicle is available. These delays are quite large compared to communication delays in core network. Above delays should be investigated thoroughly particularly for delay-sensitive applications (voice/video).

4.1 Ad hoc Network Delay

Vehicles should be equipped with GPS receiver to know their accurate geographical positions. Vehicles broadcast beacon messages periodically to inform their own position to the neighbor vehicles and based on the above information vehicles update neighbors list in LUT (look-up table) [5]. Consider inter-distance between APs fixed then distance between two adjacent APs d = A + W from Fig. 1. Let ad hoc communication delay *dAH* be the time taken by a vehicle to forward the data to adjacent vehicles. This delay depends on average vehicle speed *vh* (m/s), average hop delay d_{hop} (s), average vehicle population density ρ (cars/km) at different points of highway [6]. If arrival of vehicles on highway behaves like *Poisson,* then inter-distances between vehicles on highway is exponential distribution with an average $1/\rho$ where ρ is *av*erage density of vehicles. Then,

$$dAH = (1 - e^{-\rho r})\left(\frac{A/2}{r}\right)d_{hop} + e^{-\rho r}\left(\left(\frac{A/2}{v_h}\right)\right) \tag{7}$$

where $e^{-\rho r}$ is the probability of vehicle to carry packet itself when next hop vehicle is not available within its range, and $(1 - e^{-\rho r})$ is the probability of packet forwarded in wireless communications mode. If the packet is carried by the vehicle along a distance of *A*/2 then $\{(A/2)/vh\}$ is the packet delay while if packet goes through V2V hop, then $\{(A/2)/r\}$ is the number of hops needed to cover a distance of *A*/2, which constitutes the forwarding delay when multiplied by d_{hop}.

4.2 Wi-Fi and Ad hoc Network

The combined cost c3 of Wi-Fi and ad hoc network can be represented by

$$c3 = T_u r_w c_w \tag{8}$$

where *Tu* is the usage time (total time for which connection to APs remains established) represented by

$$Tu = (Nw - 1)\left(\frac{W + A}{v} - d_{AH}\right) + \frac{W}{v} + \left(\frac{x}{v} - d_{AH}\right) \tag{9}$$

and *Nw* maximum integer value can be found out by

$$\left[(Nw - 1)\left(\frac{W + A}{v} - d_{AH}\right) + \frac{W}{v}\right] rw \leq bt \tag{10}$$

and *x* is obtained from

$$bt - \left[(Nw - 1)\left(\frac{W + A}{v} - d_{AH}\right) + \frac{W}{v}\right] rw = \left(\frac{x}{v} - d_{AH}\right) rw \tag{11}$$

Note that the transmission time ($\mathbf{T_{w+AH}}$) is different from of Tu when Wi-Fi and ad hoc network is used and it is given by

$$T_{w+AH} = \frac{[(Nw \times W) + (Nw - 1)A + x]}{v} + d_{AH} \tag{12}$$

4.3 Combination of Cellular, Wi-Fi, and Ad hoc Network

The combination of Wi-Fi, cellular, and ad hoc network is beneficial when dAH does not satisfy delay requirements and the vehicle is willing to have the most economical set of access networks. In above network number of VHOs is lesser or equal to the Wi-Fi and cellular network. Thus, if c2 < c1, the cost (c4) incurred by using combination of Wi-Fi, cellular, and ad hoc network will also be c4 < c2 < c1. Similarly, if Tw < Tc, the transmission time in the case of combination of Wi-Fi, cellular, and ad hoc network will be T_{c+w+AH} < Tw < Tc.

5 Performance Evolution

Simulations using MATLAB 2014R were conducted for methodologies discussed above in Sects. 2–4. The latest Wi-Fi and cellular standard taken for simulation are Gigabit IEEE802.11ac Wi-Fi and 4G LTE cellular respectively. The parameters used for simulation are shown in Table 2.

Table 2. Simulation Parameters

Cost	Parameter
150 m	W (AP range)
300 m	A (Inter-AP distance)
18–90 km/h	v (Decision-making vehicle's velocity)
2–10 veh/km	ρ (Average vehicle density)
1.3 Gb/s	r_w (Data rate of WLANs)
1 Gb/s	r_c (Data rate of cellular)
8.8 Mb	b_{VHO} (Handover signaling bits)
Rs. $4.025 * 10^{-8}$ = 1 unit	c_w (Cost of transferring one bit in WLAN)
Rs. $8.05 * 10^{-8}$ = 2 units	c_c (Cost of transferring one bit in cellular)
300 Gb	b_t (Total data to be transferred)
100 m	r (Transmission range)

The other factors like *Nw* (Number of APs on the roadside), total distance traveled by the car, the preference, the area in which the node is, etc., are required from the user and the cost and time functions are calculated based on them. We have investigated performance of VHO decision algorithm for fixed and statistical inter-AP distances and then analyzed both transmission cost and transmission time versus velocity of decision-making vehicle.

5.1 VHO Decision with Fixed Inter-AP Distance

User Parameters: Total Distance the car travels: 2 km, number of APs on the road: 8.

The cost of cellular is fixed at Rs. 600 while Wi-Fi cost varies from Rs. 350 to Rs. 540 as velocity goes up from 20 to 90 kmph. User will prefer to be in Wi-Fi network because Wi-Fi frequency band is unlicensed and is less costly than the licensed cellular, which is also what we have considered in the fixed parameters in Table 2 the cost of Wi-Fi is half of the cost of cellular. If the user is currently using Cellular, it will switch to Wi-Fi by performing the Vertical Handover. The Wi-Fi data rate is faster than cellular. If the preference of the user is to minimize the transmission time of data bits or maximize the Quality of Service, it will at all times stay in Wi-Fi and not switch to cellular. Despite the wide connectivity of cellular, the node tries to stay in Wi-Fi network in fixed inter-AP distance case due to cellular higher cost and lower data rate.

5.2 VHO Decision with Statistical Inter-AP Distance

- **Urban area**. Total distance covered is 2 kms.

Considering transmission cost, the crossover takes between Wi-Fi and cellular at 28.6 kmph, the cost of Wi-Fi system was higher at lower velocity and lesser at higher velocity. Also transmission time followed similar pattern but the crossover is near 33 kmph. There is higher traffic in urban areas i.e. higher vehicle density and hence a significant amount of vehicles would be connected to a single AP which slows down the data rate and thus require higher transmission time when connected to an AP. The cost is also proportional to time because more the time it is connected to an AP, more is the cost. While at higher speeds, the vehicle can effectively switch APs at a much faster rate and expect an average overall load to be distributed among rest of the APs, hence the transmission time is less and likewise the cost.

- **Semi-urban area**. Total distance covered is 3 kms.

Due to higher velocities and greater inter-AP distances, the vehicle tends to move faster and hence the switchover of the two networks comes at a comparatively early stage compared to urban area. The vehicle tries to stay maximum in Wi-Fi network after a certain speed. The cost is low and data rate of the Wi-Fi network is usually higher than Cellular which is one of the other reasons why it tries not to switch back to cellular. However, for larger total distance of say 5 km the cost and time are at all velocities are less in cellular compared to Wi-Fi which could be due to high installation costs of APs in semi-urban areas and due to the greater inter-AP distances, the vehicle is mostly connected to cellular. So, if a node is in Wi-Fi, it will always tend to vertical handover to cellular network.

- **Rural area**. Total distance covered is 8 kms.

The interpretation of this scenario is comparable to the one in semi-urban but with greater distances. The inter-AP distance is pretty high leaving the node connected to cellular for most of the time. Also, the installation cost of APs plays a key role in rural areas, hence the vehicle tries to stay in Cellular network and will hand over from Wi-Fi at all velocities.

5.3 VHO Decision Including V2V Mode

We have included V2V mode in addition to Cellular and Wi-Fi network. The ad hoc delay calculated in Sect. 4 depends on the vehicle density, hopping delay, etc., and then the cost and transmission time is accounted for. Since, the global knowledge of the roads is not considered here, hence the user provides the vehicular density in a certain area. The hopping delay is considered to be 30 ms.

User inputs: Total Distance: 2 km, number of APs on the road: 8, vehicular Density: 5

It is expected to have the ad hoc network the minimum amount of transmission cost when compared to the other two networks because of an additive feature of car hoping to transfer the data. The vehicles in a network communicate through DSRC and hence the cost inculcated is minimal. Hence, ad hoc network plays the best role to minimize the cost. It is observed that as long as the speed is too high, the combination of Wi-Fi, cellular, and ad hoc network yields remarkable performance improvements over the above cases. This could be because at higher speeds the inter-AP distance is covered faster compared to the case of lower speeds. Let us consider the worst case scenario with a minimal amount of vehicular traffic on the roads, and the data to be deployed by the vehicle has to be carried by itself until the next AP arrives. Thus, at lower velocities, the transmission time will automatically shoot up because the vehicle takes more time to cover the same distance while at higher speeds the adjacent AP arrival rate increases and transmission time gradually falls.

6 Conclusions

Optimal choice of access technology is needed in a vehicular network particularly in a heterogeneous wireless environment. The cost-effective VHO decision depends on capacity available in each access network, cost of transmitting data traffic in the network, and the speed of the vehicle. In this paper we have discussed a heterogeneous vehicle network using Wi-Fi and cellular network. The results show that VHO can be avoided and stay in Wi-Fi network at higher speeds while VHO is an appropriate choice in lower speeds to minimize the communication cost and time in fixed inter-AP distance. However, in the statistical inter-AP distance to stay in cellular networks is better choice at higher speeds in semi-urban and rural areas due to the extensive installation costs of APs. By including V2V communication in Wi-Fi and cellular network, the combination of Wi-Fi, cellular, and ad hoc networking outperforms in terms of transmission time and cost at higher speeds compared to the above two networking strategies.

Considering future aspects, the analysis can be extended by lifting off the assumptions made in this paper to further extent. Also, the case where the algorithm is location specific, it can be extended by adding digital maps of the area which are readily available on the Internet. This will provide more accurate vehicular density and road data of cities and states, and by incorporating them one can get more accurate results.

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