Load-Aware Association with AP for Internet-Connected Vehicles

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***Abstract*—For connected vehicles, vehicle ad-hoc network is capable to support various communication-based applications. Specially, WLAN-based vehicular Internet access can be a complementary and cost-effective solution considering the cost of cellular service. For WLAN-based Internet connected vehicles, we propose an efficient load-aware association mechanism which allocates vehicles to roadside APs properly, and eliminates the unnecessary steps during scanning phase. We defined the load condition as a set of parameters, relative priority of parameters, and determined decision weights in order to select one AP for each vehicle. We evaluated the performance of the proposed mechanism, comparing with the strongest-RSSI-first selection for AP. Depending on the traffic volume, the proposed mechanism showed better performance in the average throughput ratio by about 20%.**

Keywords—load balancing; vehicle to Internet; decision weight; WLAN

I. Introduction

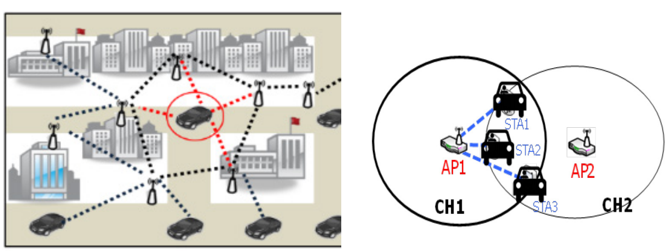
For connected vehicles, vehicle ad-hoc networks (VANETs) are capable to support various communication-based applications including infotainment, road safety, and traffic monitoring and management services [1], [2], [3]. To support these applications, there are many different types of wireless communication for VANETs as well as the dedicated infrastructure (road side units for WAVE/DSRC service) for intelligent transport systems [4], [5], [6]. Specially, vehicular infotainment services such as high-quality video streaming service, interactive gaming, or file sharing are already provided using immediate access to Internet through V2I (Vehicle to Internet) communication by on-board system or smartphones [7], [8]. Furthermore, the technology for firmware over-the-air (FOTA) update is introduced in the automotive industry, which needs to constantly and remotely update firmware or software to support various in-vehicle infotainment (IVI) systems or a lot of ECUs in a vehicle. FOTA update may be performed over wireless communication for Internet connections, including Wi-Fi service to avoid high data cost or cellular network to provide a continuous connection. One of the concerns of connected vehicles toward *autonomous vehicles* or *self-driving cars*, is how to make well-connected nodes for improving data throughput for communication-based applications. For example, VANETs are taking information delivery into account for the various infrastructures which are already deployed in the urban road, such as access points (APs) of wireless local area network (WLAN) directly connected to Internet at bus stations in the manner of ubiquitous communication. In other words, connected vehicles can use a variety of technologies to achieve almost seamless and reliable communication with a reasonable delay between vehicles and infrastructure or between vehicles (V2V). In V2I communication, there are currently two promising communication technology candidates for Internet-connected vehicles: cellular-based access and WLAN-based access [9]. It is also possible to provide vehicles with reliable and efficient communication by seamless handover between cellular network and multi-hop WLAN networks as one possible way for vehicular network [10]. WLAN-based vehicular Internet access can be a complementary and cost-effective solution to an expensive cellular service. It, however, imposes many challenges in terms of a short connection time to AP and a long connection establishment time before data transmission, since the topology of VANET is highly dynamic due to the velocity of vehicle, driving path diversity depending on highway or city road, the timing of traffic signal at the intersection, and a driver's unexpected driving behaviors. There have been several attempts to characterize WLAN-based vehicular Internet access and evaluate their performance under the a high mobility environment [11], [12], [13], [14]. They clearly present that intermittent connections and severe channel contentions might be the cause of low throughput when either a driver or a passenger wants to access to Internet through legacy roadside APs of WLAN. Therefore, it is necessary to figure out an adequate solution to the mentioned problems by allocating vehicles to roadside APs efficiently, and eliminating the unnecessary steps during scanning phase.

In this paper, we propose an efficient load-aware association mechanism for WLAN-based Internet connected vehicles, which consists of load-aware AP selection and fast scanning. The proposed AP selection mechanism goes towards reaching a goal to distribute the traffic load of vehicles among APs, and increase both the overall throughput of vehicular Internet access and the utilization of channel for communication. In addition, the proposed mechanism indirectly intends to decrease total scanning delay by rapid detection of only one AP among nearby APs on every channel, and prevent an overflow of management frames from given channels because a vehicle recognizes only one AP selected by our load balancing mechanism during scanning phase. Therefore, once connected, vehicle can be provided with good service in the coverage of associated APs.

The remainder of this paper is organized as follows. In Section II, we describe the environment of multi-hop WLAN infrastructure for vehicular Internet access. Section III includes the detail description of the proposed load-aware association mechanism along with its processes. We discuss the performance of the proposed mechanism, comparing with IEEE 802.11 association protocol in Section IV. Finally, we provide conclusions in Section V.

II. Envrionment for Vehicular Internet Access

This section describes an environment of multi-hop WLANs for Internet-connected vehicles as shown in Fig. 1(a), and discusses practical considerations to make use of the existing WLAN with wireless mesh networking architecture for vehicular Internet access. We consider the *drive-thru Internet* where vehicles should pass through the coverage of AP installed at roadside, and attempt to obtain the connection opportunity for Internet access for very short time (several tens of seconds under high vehicle mobility) [9]. Roadside APs as well as installed any APs can wirelessly cooperate with each other in order to indirectly connect to wired network. The deep market penetration of IEEE 802.11-based WLAN in vast metropolitan areas facilitates data exchange between the vehicle and roadside APs in VANETs. In this infrastructure, an AP can operate as a relay AP for other APs because it as a networking node provides a multi-hop data forwarding for Internet-enabled vehicular services. Vehicles within the direct wireless transmission range of the AP are also capable of communicating with another nodes not within direct wireless transmission range of it.



(a) Multiple APs around a vehicle (b) Case of $RSSI_{AP1}>RSSI_{AP2}$

Fig. 1. WLAN-based vehicular Internet access.

When a vehicle wants to connect to APs, the connection must be properly established before data transmission through three phases (scanning phase, authentication phase, and association phase). In accordance with IEEE 802.11 standards, a vehicle generally uses a simple method to make decision on APs to associate with. A vehicle is associated with the AP which has the strongest RSSI (Received Signal Strength Indicator) among nearby APs from the vehicle geographical position, which is referred to as RSSI-first-based AP section. For example, all vehicles which want to connect to a AP choose only AP1 on CH1, taking only the signal level of APs into account as shown in Fig. 1(b). The overloaded AP1 will suffer from the performance degradation as the number of vehicles associated with AP1 increases, and will not guarantee the fair sharing of resource for any associated vehicles. Consequently, it leads to concentrate a large volume of traffic on the connected AP. The vehicles are unevenly distributed among APs. The point is that the vehicles completely ignore the load condition of APs when vehicles attempt to associate with AP.

The load condition of AP is intuitively related to how much the AP satisfies the requirements of vehicles associated with it. Furthermore, the communication opportunity between vehicles and an AP is obviously limited because of the high-mobility of vehicles. In this respect the fast scanning and the efficient resource distribution are crucial for Internet based applications of connected vehicles.

III. Load-Aware Association

We propose an efficient association considering load balancing. Our load-aware association mechanism is divided into two parts: 1) each AP performs load-aware AP selection to determine one AP with the potential for high throughput of vehicles, and 2) each vehicle performs fast scanning based on active scanning for vehicle mobility. Firstly, the load-aware AP selection among nearby APs aims to autonomously filter out almost all of the APs having lower performance before a vehicle finds the AP through fast scanning. Secondly, the proposed fast scanning aims to eliminate unnecessary procedures from the traditional scanning phase in active scan mode. We count on the fast scanning to improve the connection establishment time indirectly. This is possible because, in the first part, each AP has already known one selected AP which is responsible for the requests of vehicles during a certain period of time. We assume that each individual AP within the overlapping coverage of APs can always know their load condition each other from listening beacon with the additional information defined in Subsection A below.

Each AP usually transmits beacon with its own load condition. Before fast scanning of vehicles, APs continuously collect the various information about the load condition of nearby APs from received beacon, and periodically select one AP providing better services for vehicles. In this paper, an AP potential for having the best performance among APs, which is referred to as *Star AP*. A vehicle broadcasts probe request message so that it conducts the proposed fast scanning as the active scanning mode to search an adequate AP. Our fast scanning differs from original active scanning phase in that one Star AP around vehicles only responds by transmitting probe response. Note that the reliability and performance of the proposed mechanism may depend on the selection period of Star AP, but for sake of simplicity in our problem, we assume that all of the nearby APs always maintain the local information related to the load condition of APs in real-time, and have time enough to immediately attempt to select Star AP from the local information before transmitting management messages such as probe responses. Each AP can make a list of the candidates for Star AP around a vehicle from probe request frame including vehicle’s position. For this, we may put this information into vendor-specific field of frame body. Although this environment involves several problems, such as interference among APs and synchronization of beacon interval, they are beyond of scope of this paper.

A. Parameters for Load Condition of AP

Since an efficient load balancing mechanism needs to consider the status of each AP, it is worth defining the load condition of AP as a set of parameters, which is related to how many vehicles are associated with a certain AP, how well AP supports the transmission of vehicles, and how much volume of traffic a vehicle has to transmit/receive in the coverage of a AP. Parameters we newly define are as follows: 1) vehicle density, 2) channel status for an AP, 3) channel utilization of vehicles, and 4) vehicle activity index.

A.1. Let N_{veh} be vehicle density representing the mean number of vehicles associated with an AP during a certain time period. The mean number of vehicles associated with an AP indicates that a large population of traffic sources implies high traffic load and high potential for transmission collision during a certain time period. The vehicle density, N_{veh}, is given by the following equation:

$$N_{veh} = \frac{\sum_{i=1}^{p} n_i}{p*m}, \quad (1)$$

where p is the amount of time to measure representing the number of superframe, m is the maximum number of vehicles allowed per AP, and n_i is the number of vehicles associated with AP per superframe.

A.2. The channel status for an AP indicates how well traffic is moving to another AP which it wants to send data to. The queue of the AP can be overwhelmed by the excess traffic due to frequent collisions while connected APs generally contend for a certain time slot. Specially, a relay AP can be easier congested than other APs directly connect to a vehicle. Therefore, we define the channel status of the AP as the ratio of frames dropped in transmission queue of the AP, D_{AP}, i.e. the number of frames dropped in transmission queue is divided by the total number of frame in transmission queue. From this parameter, the AP can roughly assess the status of channel contention in a given time period. It is needed in order to get the transmission or contention status of APs.

A.3. It is desirable to have low overhead related to control data per frame such as header field in a MAC frame or preamble and header fields in PHY frame whenever vehicles send/receive data. This is because vehicles can deliver a relatively small amount of data for short connection time caused by high mobility. In this regard, we consider the mean utilization of vehicles associated with AP in equation (2), which is defined as the amount of real data to transmit divided by maximum PHY rate supported in the coverage of AP:

$$\mathrm{U}_{veh} = \frac{\sum_{j=1}^{p}\sum_{i=1}^{n} \mu_i(j)}{n*R_{phy}*p}, \quad (2)$$

where n is the number of vehicles successfully transmitted per superframe, R_{phy} is the maximum PHY (physical layer) rate which the a vehicle supports when data moves across wireless link, and p is the amount of time to measure representing the number of superframe. Let μ_i be the average size of transmitted data frames for a superframe by a vehicle i, where t is the number of transmission per vehicle i, and x is the number of the time units per superframe. μ_i is specified as the following equation:

$$\mu_i = \frac{\frac{1}{t}\sum_{j=1}^{t} size(payload\ of\ MAC\ frame\ j)}{x*1TU} \quad (3)$$

A.4. The activity index of vehicles indicates how many vehicles have successfully transmitted during a certain period of time in the coverage of the associated AP. Although a lots of vehicles are associated with a certain AP concurrently, most of them may seldom take part in transmitting data. If the activity index of vehicles is high, it indicates that the AP provides pretty good coverage (high service ratio and lower collision rate) where vehicles actually need it for transmission. AP also has the capability to support a larger number of vehicles with higher data rate. Therefore, let C_{veh} represent the ratio of active vehicles to the associated vehicles during a given time period (p superframes).

B. Decision on Star AP

We propose the load-aware AP selection that involves decision-making by each AP. The load-aware AP selection uses predetermined decision weights (defined as W_{4*1} below) for above-mentioned parameters related with vehicles and APs. In other words, a set of nearby APs is denoted by $S = \{AP_1, AP_2, \ldots, AP_m\}$, where m is the number of nearby APs. One element with maximum weighted value in set S could be Star AP. Each AP needs the predetermined decision weights to select one Star AP among neighbors APs, which are calculated after defining each relative priority of parameters by pairwise comparison method of the concept of Analytic Hierarchical Process (AHP) [15], [16]. It employs multi-criteria decision making method. Consequently one valid AP ($AP_i \in$ S) with the largest weighted value $\omega \in \Omega$ is selected as Star AP. The set of weighted value Ω is given by:

$$\Omega = \{\omega | \omega = (-1) * w_1 * n_{veh}^{AP_i} + w_2 * c_{veh}^{AP_i} + w_3 * u_{veh}^{AP_i} + (-1) * w_4 * d_{veh}^{AP_i} \wedge w_1 + w_2 + w_3 + w_4 = 1\}, \quad (4)$$

where $n_{veh}^{AP_i} \in N_{veh}(t), c_{veh}^{AP_i} \in C_{veh}(t), u_{veh}^{AP_i} \in U_{veh}(t), d_{veh}^{AP_i} \in D_{AP}(t)$, and $w_j \in W_{4*1}$. N_{veh}(t) represents a set of vehicle density to each AP_i ($0 < i \leq m$) at time t, which is denoted $N_{veh}(t) = \{n_{veh}^{AP_1}, n_{veh}^{AP_2} \ldots, n_{veh}^{AP_m}\}$. A set C_{veh}(t) denotes vehicle activity rate to data transmission in each AP_i ($0 < i \leq m$) at time t by $C_{veh}(t) = \{c_{veh}^{AP_1}, c_{veh}^{AP_2}, \ldots, c_{veh}^{AP_m}\}$. A set of transmission utilization of vehicles, $U_{veh}(t)$ and a set of channel status for AP, $D_{AP}(t)$ in each AP_i ($0 < i \leq m$) at time t can be given by $U_{veh}(t) = \{u_{veh}^{AP_i}, u_{veh}^{AP_2}, \ldots, u_{veh}^{AP_m}\}$ and $D_{AP}(t) = \{d_{AP}^{AP_1}, d_{AP}^{AP_2}, \ldots, d_{AP}^{AP_m}\}$, respectively.

W_{4*1} represents the predetermined decision weights for each parameter. To make W_{4*1} we define relative priority relation between each pair of parameters. It is made by the pairwise comparison because it is not easy to make absolute certitude among four parameters. According to the pairwise comparison method, when we think that N_{veh} is relatively more important than C_{veh} considering the performance of network, N_{veh} to C_{veh} is rated with a relative point of r, and the value of C_{veh} to

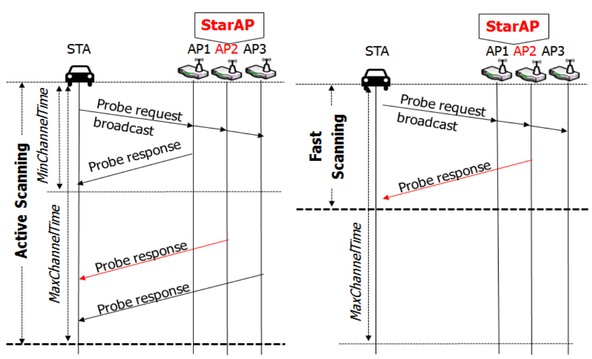
N_{veh} is $1/r$, These values made by pairwise comparison entered row by row into a cross-matrix which is a square matrix as shown in Fig. 2(a). Therefore, the cross-matrix could vary according to the definition of relative priority with the different values.

$$\blacksquare R_{4*4} = \begin{array}{c} \\ N_{veh} \\ C_{veh} \\ U_{veh} \\ D_{AP} \end{array} \begin{array}{c} \begin{array}{cccc} N_{veh} & C_{veh} & U_{veh} & D_{AP} \end{array} \\ \begin{bmatrix} 1 & 1/3 & 1/3 & 1/5 \\ 3 & 1 & 1/3 & 1/5 \\ 3 & 3 & 1 & 1 \\ 5 & 5 & 1 & 1 \end{bmatrix} \end{array} \qquad \blacksquare W_{4*1} = \begin{array}{c} N_{veh} \\ C_{veh} \\ U_{veh} \\ D_{AP} \end{array} \begin{bmatrix} 0.0779 \\ 0.1368 \\ 0.3414 \\ 0.4439 \end{bmatrix}$$

(a) An example of cross-matrix by relative priority relation (b) Predetermined decision weights

Fig. 2. Calculation procedure of decision weights.

For example, if we determine that C_{veh} is more important to transmission opportunity than N_{veh}, we award C_{veh} 3 points out of 3, and the point of N_{veh} is given by the reciprocal of 3 points. We calculate normalized eigenvector (W_{4*1}) corresponding to maximum eigenvalue from our 4-by-4 matrix denoted by R_{4*4}, as shown in Fig. 2(b). Each value of calculated eigenvector is considered as the predetermined decision weight to each parameter respectively. Consequently, it allows APs to make the same decision on selection of Star AP at certain time as they use the predetermined decision weights, although the calculated decision weights are only dependent on the our definition of the relative priority relation between each pair of parameters.



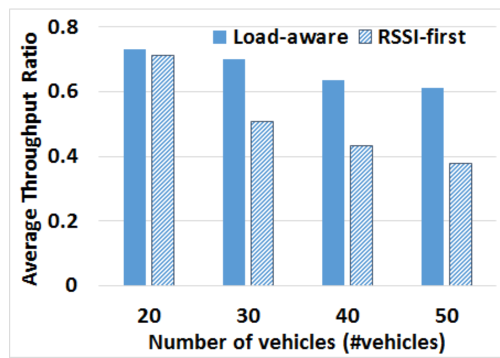
(a) Traditional scanning phase based on active mode (b) Proposed scanning phase

Fig. 3. Procedure of fast scanning.

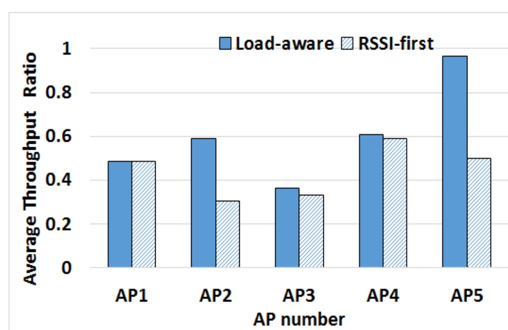
After the load-aware AP selection is performed, only one Star AP during a certain time period serves the vehicles. In other words, the selected Star AP only responds to the request of the vehicle by sending probe response frame during fast scanning as shown in Fig. 3. Therefore, the vehicle will immediately attempt to associate with Star AP.

IV. Evaluation

In this section, we evaluate the performance of the proposed mechanism in an Matlab, and simulates WLAN model (with log-normal shadowing model and at 2.4GHz) and small-scale topology to clearly validate the effectiveness of the proposed load balancing scheme [17]. In initial environment there are 5 APs and the total number of vehicles associated with all APs is ten. After a certain time, many vehicles suddenly arrive around APs simultaneously, and traffic volumes generally increase until the total number of vehicles reaches 50. We does not consider channel switching in our simulation. The vehicles are moving in the coverage of each AP and follow non-uniform distribution on the map. After the vehicle completely associates with a AP, either the associated vehicles to the AP or the AP connected to APs (APs can be connected to some or all of the APs using a mesh topology) transmits packets up to average 20 packets per second (pps) from minimum10pps as CBR traffic with 100 byte packet size only toward the AP. To show the achievable performance of the proposed mechanism, we plot the average throughput ratio (total received packets/total sent packets in the coverage of AP) in Fig. 4(a) indicating proportional fairness which considers the trade-off between the fairness for data transmission among vehicles and high throughput of vehicles. If the proposed mechanism achieves the proportional fairness by load balancing mechanism of both APs and vehicles, it has experienced an average throughput ratio of 1. By comparing Fig.4(a) and (b), we can observe that the average throughput ratio achieved by the proposed mechanism is higher (about 20%) than that of RSSI-first selection for AP as the number of vehicle increases. It turns out that the proposed mechanism properly distributes the traffic load of vehicles across the APs, and skillfully finds out Star AP which has resources sufficient to support much more communication although a large of vehicles are concurrently concentrated in certain APs such as AP3 and AP4, comparing to APs selected by RSSI-first in Fig. 4(b) when traffic volume is 50 and the number of AP is 5.



(a) Average throughput ratio



AP ID		AP1	AP2	AP3	AP4	AP5	SUM
Number of its associated vehicles and APs	RSSI-first	11.7	16	7	11	9.3	55
	Load-aware	14.7	3	13	19.6	4.7	55

(b) Number of vehicles and APs associated with each AP

Fig. 4. Results of our experiment for proportional fairness.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we propose the efficient load-aware association mechanism for WLAN-based Internet connected vehicles, in order to properly distribute the traffic load of vehicles among APs and increase both the overall throughput of vehicular Internet access and the utilization of channel for communication. The results of simulation have shown that the proposed load-aware association has better performance in the average throughput ratio than IEEE 802.11 using strongest-RSSI-first selection for AP, even though the number of vehicle increases. It indicates that the proposed mechanism properly distributes the traffic load of vehicles across the APs. In addition, the proposed mechanism indirectly intends to decrease total scanning delay by rapid detection of only one AP among nearby APs on every channel because we eliminate unnecessary procedure from the traditional scanning phase. A vehicle recognizes only one AP selected by our load balancing mechanism during scanning phase.

Since we have not considered the mobility of traffic in our experiment, we will evaluate the performance of the proposed mechanism under the vehicular environment with short connection time in the future. We will also extend our mechanism to synchronize the load information of APs, and analyze the performance of load balancing as the interval of AP selection t and by time-varying decision weights $W_{4*1}(t)$ to each parameter. We need to analyze the efficiency of establishment time by fast scanning.

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