Research Article

Reducing the MAC Latency for IEEE 802.11 Vehicular Internet Access

Daehan Kwak,[1] Moonsoo Kang,[2] and Jeonghoon Mo[3]

[1] *UWB Wireless Communications Research Center, Inha University, Incheon 402-751, Republic of Korea*
[2] *Department of Computer Science and Engineering, Chosun University, Gwangju 501-759, Republic of Korea*
[3] *Department of Information and Industrial Engineering, Younsei University, Seoul 120-749, Republic of Korea*

Correspondence should be addressed to Moonsoo Kang, mskang@chosun.ac.kr

In an intermittently connected environment, access points are sparsely distributed throughout an area. As mobile users travel along the roadway, they can opportunistically connect, albeit temporarily, to roadside 802.11 (Wi-Fi) APs for Internet access. Networking characteristics of vehicular Internet access in an intermittently connected environment face numerous challenges, such as short periods of connectivity and unpredictable connection times. To meet these challenges, we propose an Access Point Report (APR) protocol where mobile stations opportunistically collaborate by broadcasting an APR to other mobile stations to fully utilize the short-lived connection periods. APR can optimize the use of short connection periods by minimizing the scanning delay and also act as a hint that enables mobile users to predict when connection can be established.

1. Introduction

As the word "ubiquitous" is becoming an essential part of our lives, *seamless connectivity* gains a growing importance. The everlasting demand for ubiquitous network connectivity has driven many developments in wireless technologies over the past years: WLAN (IEEE 802.11), WiMAX (IEEE 802.16), and 3G networks. IEEE 802.11 wireless access, in particular, has experienced a tremendous rise in popularity by providing inexpensive, yet powerful wireless Internet access. However, 802.11 hotspots have a limited coverage range of up to a few hundred meters and are based on *intermittent connectivity*. Intermittent connectivity implies that connected and disconnected communication areas are altered while the user is moving along a path; that is, there is no continuous network access. This poses numerous challenges: limited short periods of connectivity, unpredictable connection times, and varying transmission characteristics [1, 2]. Nevertheless, experiments have shown that WLAN can be workable over significant distances for mobile users at high speeds [3–5]. Figure 1 introduces a sample of an intermittent connectivity scenario.

In this paper, we focus on the challenges that accompany short and unpredictable connectivity periods, that is, an intermittent connectivity environment [1]. These challenges can be met by *maximizing the use of short connectivity periods* and *providing hints for other mobile users to help them predict when connection can be established*. For instance, as a vehicle makes an entrance into the edge of the communication range of an AP, wireless losses occur due to the low signal quality. This leads to lengthy connection establishment in the MAC (scanning) and Network (network address acquisition) layer, continuing to influence the full utilization of the high-quality link access, that is, near the AP where the signal is strong [4, 5]. To make the best use of short-lived connectivity periods, we reduce or eliminate the 802.11 scanning latency. This goal is similar to the objective in the 802.11 handoff operation. The major difference between the two is that our proposal is based on reducing the delay in a stand-alone, single-cell network while the well-known handoff operation aims to reduce the latency in an infrastructure network consisting of multiple overlapping cells.

Our basic idea to reduce the scanning latency is as follows. Once a mobile station (MS) enters a service range
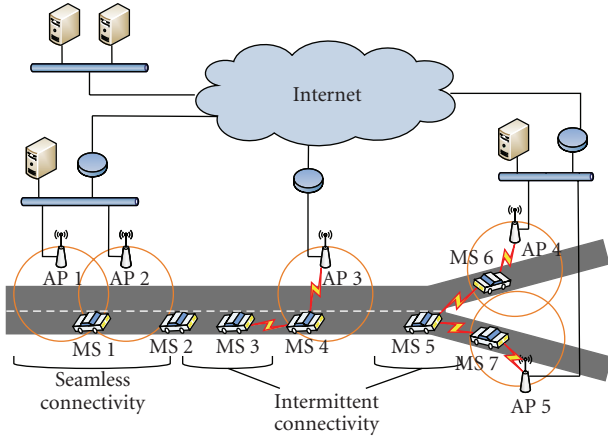
FIGURE 1: Intermittently and Seamlessly Connected Environment.

and associates itself with an access point (AP), it will opportunistically collaborate with other MSs by relaying the AP's information to the incoming MSs that are about to enter the AP's communication area. This will allow new incoming MSs to be directly associated with the AP as soon as they enter the communication range, avoiding scanning procedures and, thus, improving the overall performance of the system. The relayed information can also be used as a hint on where a connection can be established, which will be a solution to our second goal. With that in mind, we propose an Access Point Report (APR) protocol that settles both our goals.

To accomplish our goals, we initially investigated some related work for preliminary purposes as discussed in Section 2. Next, in Section 3, we examine the IEEE 802.11 standard scanning procedure. In Section 4, we introduce and explain our proposed protocol and algorithms. Simulation results based on vehicle traffic models along with an analysis are presented in Section 5. Finally, we conclude our work in Section 6, laying out our plan for future work.

2. Related Work

2.1. Feasibility Study of WLAN Usage in Vehicular Environments. The Drive-thru Internet project [3] introduces the idea of using WLAN access to provide opportunistic Internet access for users traveling in vehicles. This project exploits WLAN APs at the roadside to conduct experimental evaluations on 802.11 b at speeds from 80 to 180 km/h and confirm the feasibility of data communication for fast moving vehicles. They divide a connection into three phases depending on connection quality: the entry, production, and exit phase. The production phase exhibits high throughput while throughput is low during the entry and exit phases due to low signal quality.

Experiments conducted in [4] present the use of "open" Wi-Fi networks for vehicular Internet access. Based on their measurement data for over 290 drive hours under prevalent driving conditions in urban areas, they show that even if only about 3.2% of all APs participate, it is adequate to support opportunistic Internet connections for a variety of

applications. They also identify the mean and maximum active scan latency to be 750 ms and 7030 ms, respectively.

More recently, Hadaller et al. [5] built on a more detailed experimental analysis based on [3, 4]. They analyze each phase of a connection and draw out ten problems that cause throughput reduction. In particular, connection setup delays, such as lengthy AP selection result in a loss of 25% of the overall throughput. They further remark, consistent with [3, 4], that a robust connection setup is crucial in order to fully utilize the production phase of a short-lived connection period.

Along with 802.11 b, a myriad of research has been conducted for other standards in the 802.11 family, confirming the suitability of 802.11 WLANs for vehicle scenarios [6, 7].

2.2. Handoff. In the IEEE 802.11 standard, stations (STA) are required to consecutively scan all channels. Scanning (or probing) multiple channels is time consuming; however, a number of proposals in the handoff area works to reduce this delay.

The handoff process occurs when an MS migrates from one AP to another, changing its point of attachment, as shown in Figure 1, where MS_1 moves from AP_1 to AP_2. The handoff latency consists of three phases: scanning, authentication, and reassociation. Scanning delay is the dominant contributor to the overall latency which accounts for more than 90% of the total handoff latency [8].

The emerging draft 802.11 k specification [9] introduces Neighbor Report, which contains information on candidate handoff APs. A neighbor report is sent by an AP and its element contains entries of neighboring APs that are members of an extended service set (ESS). An MS willing to use the neighbor report will send a Neighbor Report Request frame to its associated AP. An AP can send a Neighbor Report Response frame either upon request or autonomously. To reduce the scanning latency, using the neighbor report allows MSs to selectively scan channels or skip the scanning procedure.

The neighbor report is similar to our proposed APR protocol. The difference is that (a) neighbor reports require adjacent APs to fill in its neighbor list entries and (b) APs send the report. Condition (a) is not suitable for an intermittently connected environment where APs are sparsely distributed and condition (b) is not suitable because APs cannot transmit a neighbor report outside its communication range.

3. The IEEE 802.11 Scanning Procedure

The process of identifying an existing network is called scanning. In the scanning procedure, STAs must either transmit a probe request or listen on a set of channels to discover the existence of a network. The IEEE 802.11 standard defines two types of scanning procedures: passive and active scan.

3.1. Scanning Procedure. In passive scanning, APs contend with other stations to gain access to the wireless medium
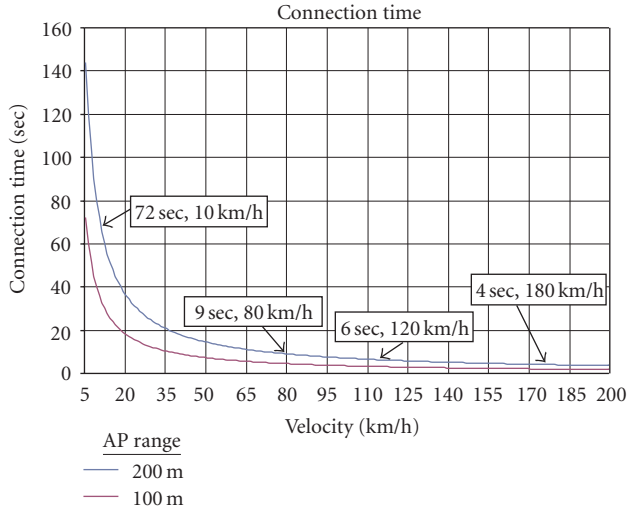
Figure 2: Connection time.

and periodically broadcast beacon frames. An MS willing to access to an AP in its area will probe each channel on the channel list and wait for beacon frames. After a complete channel set is scanned, the MS will extract the information from the beacon frames and use them along with the corresponding signal strength to select an appropriate AP to begin communication.

The active scanning mode involves the exchange of probe frames. Rather than listening for beacon frames, an MS wishing to join a network will broadcast a probe request frame on each channel. Scan time can be reduced by using active scanning; however, it imposes an additional overhead on the network because of the transmission of probe and corresponding response frames.

3.2. Scanning Delay. Due to the scanning delay and the high mobility of vehicles (esp. on highways); the total amount of time connected to an AP is generally small compared to static users. As shown as a plot of a mathematical function in Figure 2, higher speeds mean lesser time to connect to a single AP. For pedestrian walking speed (10 km/h) the total connection time is about 72 seconds. However, as speed rises the total connection time drastically drops. For speeds of 80 km/h, 120 km/h, and 180 km/h the total connection time is 9, 6, and 4 seconds, respectively. Hence, it is important that MSs fully utilize the given network.

The total time that an MS can stay connected to an AP, that is, the time connected (t_c), can be calculated using $t_c = d_{AP}/v_{MS}$, where v_{MS} is the velocity of the vehicle, and d_{AP} is the communication range of the A. Given the scanning delay (s_d) and using (1), we are able to derive the portion of the scanning delay (S_p) as follows:

$$S_p = s_d \cdot \frac{1}{t_c} \cdot 100\%. \tag{1}$$

An optimal example of the connectivity time where an MS (120 km/h) passes through the diameter of an AP (a range of 200 m) is 6 seconds. If the average delay in active

scanning is 750 msec as in [4] and 1200 msec in passive scanning, the total portion of the scanning delay is 12.5% and 20%, respectively.

The total portion of the scanning delay may look negligible; however, the total scanning portion increases as the MS crosses the border of the communication range and it is important to minimize the connection setup time so the delay does not continue into the high-quality production phase. Again, this is our motivation to reduce or eliminate the scanning delay.

4. AP Report (APR) Protocol

4.1. Overall Procedure. Referring to Figure 1, as MS_4 moves into AP_3's radio range, it will first sweep each channel in the channel set with passive or active scanning mode. If any beacon frame or probe response is detected, the MS buffers and extracts the AP's information. Before the MS is associated with the AP, it will opportunistically broadcast an AP report on each channel so that other MSs, like MS_3, can utilize the AP report. Meanwhile, MS_3 will approach AP_3, and before it enters AP_3's communication range, it will broadcast the AP report a single hop (e.g., to MS_2) away. As MS_3 enters AP_3's communication range, the MS will directly associate itself with the AP, eliminating the scanning phase. Details of the aforementioned procedures are explained in the subsections below.

4.2. Main Operation of a Mobile Station

4.2.1. A Mobile Station Relaying AP Reports. After an MS completes a full scan and acquires a beacon frame or probe response in the passive or active mode, respectively, it will extract the buffered AP's information and place it in its transmission queue. The MS will then relay the received information one hop away with a broadcast destination address. Looking back at Figure 1, this is illustrated as MS_4 relaying information to MS_3. However, other MSs may be tuned to other channels and, thus, cannot hear the information being relayed. In order to allow other MSs on a different channel to receive the relayed frame, the relay node is required to broadcast the frame on each channel. The procedure of broadcasting an AP report on each channel is shown in Algorithm 1.

Algorithm 1 consists of two cycles. An MS will attempt to broadcast an AP report on each channel during the first cycle. When a medium is in use, other than backoffing a certain time, the corresponding channel is to be skipped so that the broadcasting delay can be minimized. After a channel set is swiped, the MS will attempt to retry sending the AP report on each skipped channel. The duration of the first cycle will act as a backoff time, and thus it would be more probable to successfully transmit on the skipped channel. Skipped channels are neglected if the medium is in use again during the second cycle.

A question arises here; the main objective is to eliminate the scanning delay, but we end up with broadcast delay, that is, the amount of time required to transmit an AP report

```
[Cycle 1]
for each channel to broadcast do
    check if medium is busy on channel c
    if medium is idle on channel c then
        broadcast AP report with a broadcast destination
    else if medium is busy on channel c then
        do not back off
    end if
end for

[Cycle 2]
for each skipped channel do
    check if medium is busy on channel sc
    if medium is idle on channel sc then
        broadcast AP report with a broadcast destination
    else if medium is busy on channel sc then
        do not back off
    end if
end for
```

ALGORITHM 1: Broadcasting AP report on each channel.

TABLE 1: Notations and Parameters.

T_d	Frame transmission time
L	Length of the frame (bits)
R	Transmission rate (bits per sec)
B_d	Broadcast time
C	Total number of channels
SW_d	Channel switching time
SC_1	Number of channels that successfully transmitted APR during the first cycle
SC_2	Number of channels that successfully transmitted APR during the second cycle

TABLE 2: APR broadcast time.

Data rate	Worst case	Best case
1 Mbps	5.962 msec	3.498 msec
11 Mbps	4.818 msec	2.354 msec

on each channel. Accordingly, it is necessary to compare the scanning delay and the broadcast delay. We use (2) and (3) to calculate the broadcast delay upon sending an AP report for each channel;

$$T_d = \frac{L}{R}, \tag{2}$$

$$
\begin{aligned}
B_d &= [(C-1) \cdot SW_d + SC_1 \cdot T_d] \\
&\quad + [(C - SC_1) \cdot SW_d + SC_2 \cdot T_d] \\
&= (2C - SC_1 - 1) \cdot SW_d + (SC_1 + SC_2) \cdot T_d.
\end{aligned}
\tag{3}
$$

The context information of the AP report is shown in Figure 3. Each AP report consists of BSSID (AP's MAC address), BSSID information, channel number (indicates the current operating channel of the AP), channel band, and PHY options as in [9]. Additional fields added to the AP report are the AP's location and the signal strength.

Thus, we use 15 octets for the frame size. Also, assuming we use IEEE 802.11 b, we use 11 channels with a data rate of 11 Mbps. With current development, the channel switching delay can be reduced to tens or hundreds of microseconds [10, 11], but we set it to 1 msec. We assume that an AP report was successfully transmitted on 5 channels during the first cycle and 6 channels during the second cycle. Using (2) and (3), the broadcast delay was calculated to be 16.12 msec. Compared to the minimum scanning delay of 120 ms measured in [4], we believe 16.12 msec of delay has improved the overall network performance as shown by the simulation results in Section 5.

Another possible issue may be the following. How are MSs that are in scanning mode, that is, switching channel, going to hear the relayed AP reports.

If mobile stations are located outside a communication range (e.g., MS$_3$), they are likely to be on a scan mode.

Therefore, even though MS$_4$ broadcasts an AP report on each channel, MS$_3$ may have trouble to hear this message because they are on a scan mode, that is, constantly switching channels. A question arises here; since MSs are switching channels at an interval time, APR broadcast frames may not be heard. Accordingly, it is necessary to compare the time that a mobile waits on a channel for each scan mode and the time that it takes to broadcast an APR on every available channel.

First, the time that an MS stays on a channel is determined by the *MinChannelTime* and *MaxChannelTime*. In the active scanning mode, after a probe message is sent, the MS will wait for *MinChannelTime* and if no response is received, the next channel will be scanned. If the medium is busy during the *MinChannelTime*, the MS will wait until *MaxChannelTime* is achieved in order to allow the AP or multiple APs to gain access to the medium and send a probe response. The IEEE 802.11 standard does not specify a value for both the *MinChannelTime* and *MaxChannelTime*. Both times vary depending on vendors. However, an empirical measurement shows that *MinChannelTime* is about 20 ms, and 40 ms for *MaxChannelTime* [8]. In the passive scanning mode, the time that an MS stays on a channel is 100 ms by default, based on the standard [12].

Second, we use (2) and (3) to calculate the broadcast delay upon sending an AP report for each channel. We use 15 octets for the frame size. Also, assuming we use IEEE 802.11 b, we use 11 channels with the fastest data rate of 11 Mbps and slowest data rate 1 Mbps. We assume that an AP report was successfully transmitted on 0 channels during the first cycle and 11 channels during the second cycle (worst case). Also, we assume that an AP report was successfully transmitted on 11 channels during the first cycle and did not needed to enter the second cycle (best case). Table 2 shows the results for the best and worst case for 11 Mbps and 1 Mbps.

As shown in Table 2, at the lowest rate and worst case scenario the time to broadcast an APR on each channel is
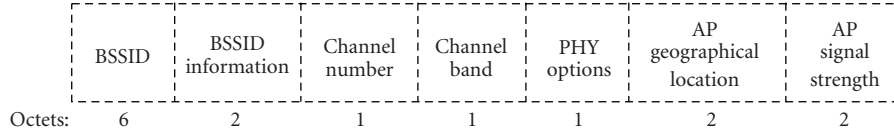
BSSID	BSSID information	Channel number	Channel band	PHY options	AP geographical location	AP signal strength
Octets: 6	2	1	1	1	2	2

FIGURE 3: AP report frame structure.

```
if a STA receives an AP report x then
    if no other AP report exists and queue is buffered then
        cache AP report x
    end if

    if other AP reports exist then
    compare with other received AP reports
        if same AP report exists (x = x) then
            discard
        else if there is no same AP report (x ≠ x) then
            cache AP report x
        end if
    end if
end if
```

ALGORITHM 2: Deciding whether to use an AP report.

```
for n = 1 to APRₙ
    Dₙᵗ = √((xₙ − xₜ)² + (yₙ − yₜ)²)
    Dₙᵗ⁺¹ = √((xₙ − xₜ₊₁)² + (yₙ − yₜ₊₁)²)
end for

for n = 1 to APRₙ
    if Dₙᵗ⁺¹ − Dₙᵗ = Dₙ₊₁ᵗ⁺¹ − Dₙ₊₁ᵗ
    then
        t++
    else if Dₙᵗ⁺¹ − Dₙᵗ > Dₙ₊₁ᵗ⁺¹ − Dₙ₊₁ᵗ
    then
        use APRₙ₊₁
    else if Dₙᵗ⁺¹ − Dₙᵗ < Dₙ₊₁ᵗ⁺¹ − Dₙ₊₁ᵗ
    then
        use APRₙ
    end if
end for
```

ALGORITHM 3: Deciding which AP report to use.

approximately 6 msec. Since 6 msec is smaller than 20 msec for active scanning and 100 msec for passive scanning on one channel, we can see that an APR can be broadcasted on every channel before the receiving node switches channels in either scan mode. Therefore, we show that broadcasting on all channels does not affect other nodes from receiving it due to being in a scan mode.

4.2.2. A Mobile Station Receiving AP Reports. An MS within the radio range of a relaying MS will receive the AP report since it is broadcasted on each available channel. The receiving MS will then extract the contents but will not return an ACK. This is when the receiving MS will determine if it will use the AP report or not. The decision is made according to Algorithm 2.

When a mobile station receives multiple AP reports, it must decide which AP report to use. An example of this scenario can be explained with Figure 1. As MS_6 and MS_7 enter AP_4 and AP_5, respectively, MS_5 will receive two AP reports from both MS_6 and MS_7. MS_5 will use Algorithm 2 and determine to cache both AP reports. Finally, MS_5 will decide to use either MS_6's or MS_7's AP report depending on its current location.

4.2.3. Decision Usage on Multiple AP Reports. As an MS station travels along the road it can receive multiple APRs as depicted in Figures 4 and 5. Deciding what APR to use is shown in Algorithm 3. Algorithm 3 is based on the assumptions and parameters given in Table 3.

In Algorithm 3, the MS will first calculate its distance with the AP_n's location at time t for every APR it has received. If we assume the MS's GPS location is updated every second,
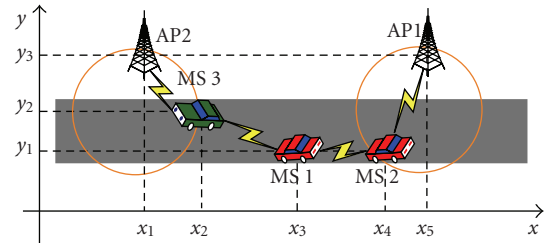

FIGURE 4: Multiple AP report usage scenario 1.

the MS's location at time $t+1$ will again calculate the distance with the AP_n's location, illustrating the first **for** iteration in Algorithm 3. Both distances are then compared to check whether the MS is moving toward (in both x and y axis) or away AP_n, illustrating the second **for** iteration in Algorithm 3. If the MS is moving toward AP_n then the APR is utilized and if it is moving away, the APR is discarded. Otherwise, if there is no movement of the MS or if the MS is exactly in the middle of two comparing APs, time $t + 1$ and time $t + 2$ are compared. This process is executed for every received APR.

4.3. State Transition Diagram. Putting it all together, we show the overall procedures in a state transition diagram shown in Figure 6. As an MS scans each channel i and if a packet is received on the corresponding channel, the packet is checked whether it is an (a) ordinary beacon frame or (b) an APR. If it is (a) an ordinary beacon frame, then
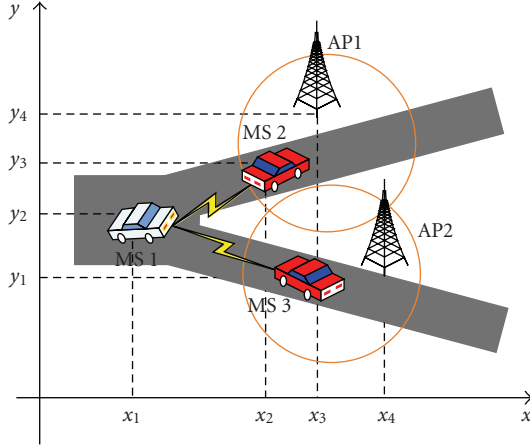
FIGURE 5: Multiple AP report usage scenario 2.

TABLE 3: Parameters and Assumptions.

Dimension	2
x axis, y axis	Positive
Location update	1 sec interval
APR is received at time	t
Number of APR	APR_n
AP_n's geographical location	(x_n, y_n)
MS's geographical location at time t	(x_t, y_t)
Distance from AP_n to MS at time t	D_n^t

this means that it will collaborate and notify other MSs of the AP's information, thus constructing an APR frame. The MS will then broadcast it on each channel according to Algorithm 1 which is equivalent to the right bottom box in the state transition diagram. After broadcasting the APR, the MS will then follow the legacy 802.11 procedure, that is, authentication and association to the AP. When the corresponding AP's signal strength decreases, the MS will then search for an adjacent AP within its vicinity. If an AP is detected, it will use existing handoff algorithms to initiate handoff to the next AP, which is illustrated on the left bottom corner of the transition diagram. If it is (b) an APR, the MS will check to decide whether it will use the APR or not by using Algorithm 2 and if multiple APRs are received then which to use or discard is based on Algorithm 3. If the APR is useful, then it will broadcast it to other MSs and then skip the scanning phase and directly associate to the corresponding AP. Again, if the corresponding AP's signal strength decreases, it will initiate handoff if an AP is available within its vicinity or if no AP is available, signal lost will occur.

5. Simulations

5.1. Vehicle Traffic Model. In Mobile Ad hoc Networks (MANETs), mobile nodes tend to move randomly and, thus, the network topology changes rapidly and unpredictably. However, with vehicles, rather than moving randomly,

vehicles tend to move in an orderly manner because they are limited to move within a paved road. As a result, much research to analyze and predict the mobility patterns of vehicles is in progress [13–15].

5.1.1. Car-Following Model. In civil engineering, the *Car-Following Model* [13] is used to describe traffic behavior on a single lane. It is a class of microscopic models that uses (4) to describe the behavior of one vehicle following another on a single lane of roadway. This model assumes that a car's mobility follows a set of rules in order to maintain a safe distance from a leading vehicle. The mathematical model can be represented by the following equation:

$$S = \alpha + \beta \cdot V + \gamma \cdot V^2, \qquad (4)$$

where S is the average spacing from rear bumper to rear bumper. The coefficients $\alpha, \beta,$ and γ are the effective vehicle length, reaction time, and reciprocal of twice the maximum average deceleration of a following vehicle, respectively. The term, $\gamma \cdot V^2$, is used so that a following vehicle has sufficient spacing to completely stop without collision if the leading vehicle comes to a full stop.

5.1.2. Traffic Volume Model. To accurately calculate realistic traffic models we use a set of traffic volumes (veh/hr) produced in [14] which used empirical traffic data. We are interested in the 4 types of traffic volumes produced in [14].

(a) Rush hour traffic with high traffic volume of approximately 3300 veh/hr.

(b) Nonrush hour traffic with moderate traffic volume of approximately 2500 veh/hr.

(c) Night traffic with low traffic volume of approximately 500 veh/hr.

(d) Steady traffic with traffic volume between (b) and (c), approximately 1000 veh/hr.

According to [14], the traffic volume in (a) is usually seen during 8 am~9 am, for (b) is 10 am~12 pm, and 1 am~3 am for (c). We use this set of traffic volumes to produce a realistic traffic flow behavior for simulation inputs.

5.1.3. Poisson-Distributed Arrival Model. In the classical vehicular traffic theory, vehicles' arrival process is assumed to be Poisson distributed with mean arrival rate λ in veh/sec [14, 15]. Thus, the interarrival time of vehicles are shown to be exponentially distributed with probability density function (pdf),

$$f_\tau(t) = \lambda \cdot e^{-\lambda t}, \qquad (5)$$

with the distribution of time gaps between vehicles, we can find the pdf of distance d,

$$f_d(d) = \frac{\lambda}{v_m} \cdot e^{-(\lambda/v_m)d}, \qquad (6)$$

where $d = v_m \cdot \tau$ in meters and v_m is the mean speed of vehicles in m/sec.
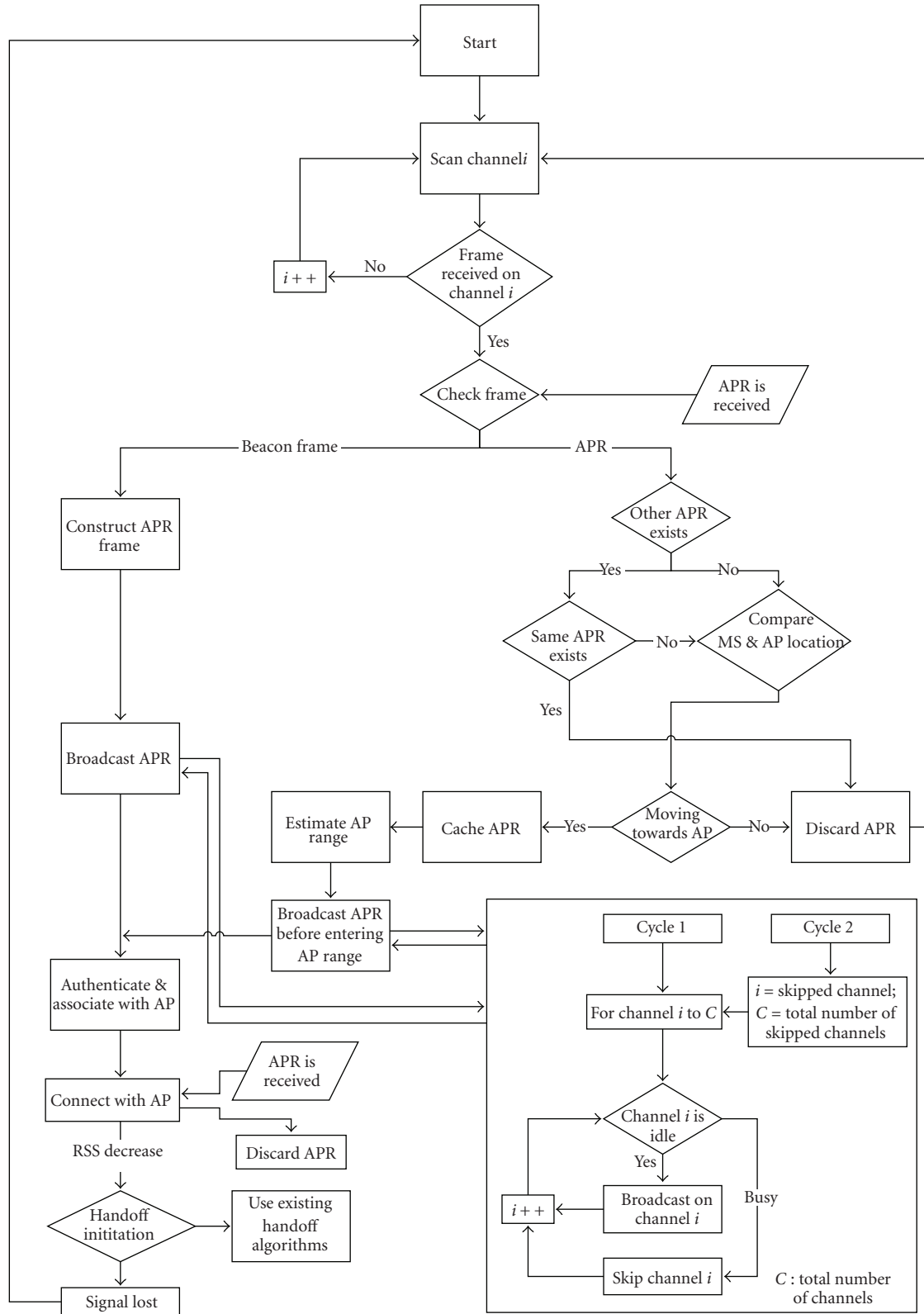
APR: access point report
RSS: received signal strength
MS: mobile station
AP: access point

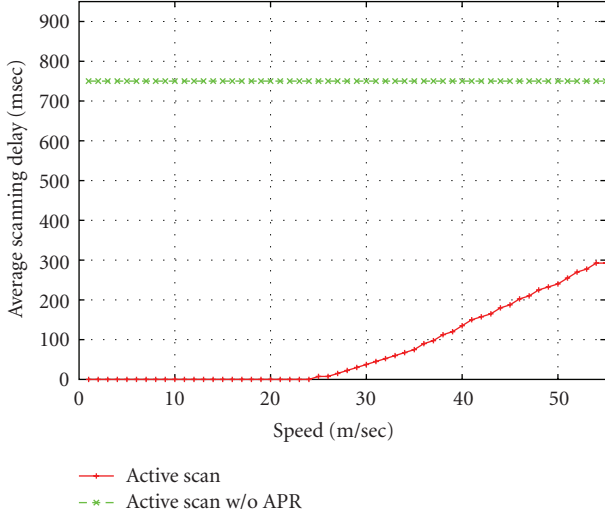FIGURE 6: AP report state transition diagram.
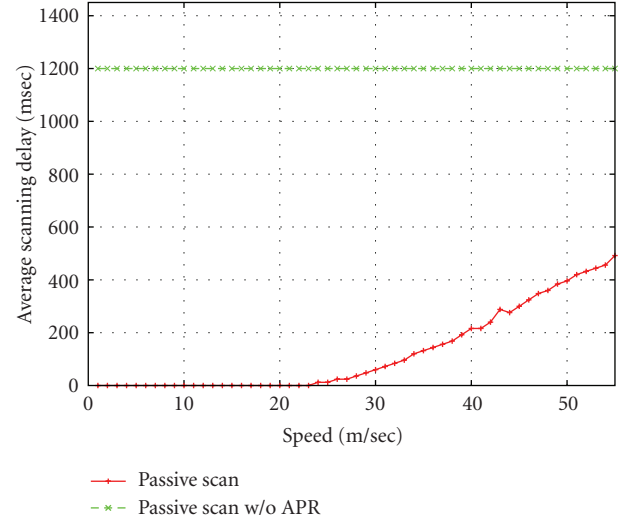
FIGURE 7: Active scan for car-following model.

FIGURE 8: Passive scan for car-following model.

With (6), and the cumulative distribution function (cdf) of d,

$$F(d) = 1 - e^{-(\lambda/v_m)d} \equiv p, \quad 0 < p < 1, \tag{7}$$

we obtain the distance in terms of λ and v_m (8) which will be used in the following simulation with the inputs based on the car-following model and traffic volume model,

$$d = -\frac{v_m}{\lambda} \cdot \ln(1 - p). \tag{8}$$

5.2. Simulation Model

5.2.1. Simulation Setup. In our simulation we measured the average scanning delay for 100 vehicles. Vehicles are placed on a straight single lane, moving in one direction based on a constant speed, where the inter-arrival time follows the distribution given in (5). The communication range of a vehicle is set to 200 m and placed in the center of the road.

We set the total number of channels to 11 as in 802.11 b. For comparison, we use the mean scanning time of 750 msec in [5] for active scanning, that is, the active scan w/o APR in Figure 7. For passive scanning we use 1200 ms, that is, the passive scan w/o APR in Figure 8, since the default beacon interval is 100 msec and each channel listening time must be longer than the beacon interval. Table 4 is a summary of our simulation settings.

5.2.2. Applying Vehicle Models. Using the car-following model equation (4), we set α to a value between 3~6 meters, which expresses various vehicle lengths and the reaction time, β, is randomly selected from 0.7~1.5 sec for each vehicle [16], respectively. For speeds of up to 55 m/sec (approx. 200 km/h), we simulate 1000 samples with 1000 vehicles. We calculate the average spacing (S) for each speed of up to 55 m/sec for 1000 vehicles. Two parameters, S and v_m, are used in varying λ in the Poisson-distributed arrival model. Figures 7 and 8 illustrate the results of this simulation.
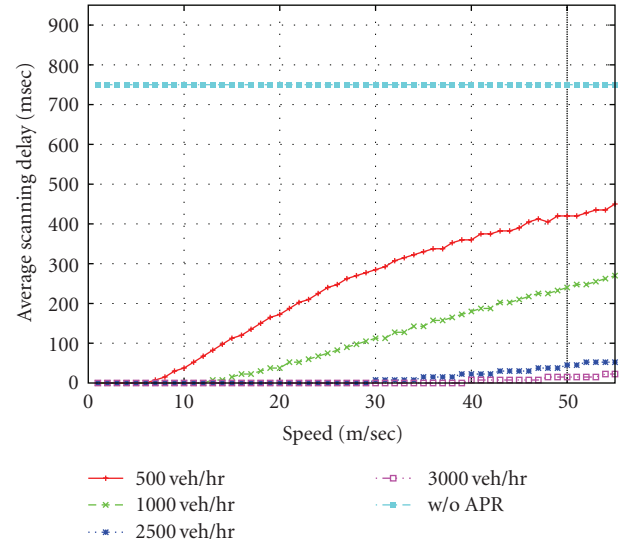

FIGURE 9: Traffic Volume Model.

TABLE 4: Simulation settings.

Simulation environment	C++
AP's communication range	200 m
Number of vehicles	1000
Number of samples	1000
Mean scanning time (Active)	750 msec
Mean scanning time (Passive)	1200 msec
Velocity (v)	1 m/sec~55 m/sec
Vehicle length (α)	3~6 m
Reaction time (β)	0.7~1.5 sec
Maximum average deceleration (γ)	0.0075 sec^2/m

On applying the traffic volume model to the Poisson-distributed arrival model we vary λ based on the 4 types of traffic volume, as shown in Figure 9.

5.2.3. Results and Analysis. Since our main focus is to analyze the overall average scanning delay, we assumed an ideal PHY/MAC layer, where all packets are received within the communication range, to simplify our implementation. Therefore, it is expected that the average scanning delay will be higher than what is presented in this paper, since it will be likely that more vehicles will not receive an AP report.

First, the car following model has seen improvements in using AP reports. Compared with vehicles with no AP reports, vehicles at even speeds up to 55 m/sec (about 200 km/hr), which means that the spacing between vehicles is high and thus implies less vehicles/hour, have an average scanning delay of 295 msec (active) and 495 msec (passive) per vehicle. This is an improvement reducing the average scanning delay per vehicle by approximately 60% regardless of the scanning mode compared to the mean scanning time of 750 msec in [5] for active scanning and 1200 ms for passive scanning.

In the traffic volume model, 4 types of traffic volume have been measured for active scanning alone, because the improvements are similar in both scanning modes. In the night traffic scenario we can see that the average scanning delay can be improved by 48% and for the steady traffic scenario, by 71%. For both nonrush and rush hours, since there are more vehicles per hour, we can easily see that the average scanning delay is nearly negligible. In short, this implies that the more vehicles per hour the more vehicles collaborate and share the AP's information to reduce the overall scanning delay.

Our approach may be even more favorable for 802.11 a than for 802.11 b, since the scanning delay will be even higher for 802.11 a with 32 channels.

6. Conclusions

Much research has been conducted and concluded that intermittently connected WLAN networks are capable of providing a variety of applications, especially those that can tolerate intermittent connectivity. However, due to the high mobility of vehicles, users connect to a network for only a short period of time. Also, because MSs have no information on when connectivity is available, MSs will continuously search for beacon frames or transmit probe requests. In this paper, we proposed an AP report protocol that can reduce the scanning delay for fast connection establishments and provide hints to users on when connections can be established. When vehicles have higher density, our approach reduces the scanning delay even more, thus contributing to the overall network efficiency. To fully utilize the short connection periods, potential areas of future work include reducing the IP acquisition time.

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