Reducing the Channel Scanning Latency for Intermittently Connected IEEE 802.11 Networks in Vehicular Environments

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Abstract—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 opportunistic 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.

Keywords-IEEE 802.11, intermittent connectivity, scanning, opportunistic communication, vehicular Internet access

I. 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; i.e., there is no continuous network access. This poses numerous challenges: limited short periods of connectivity, unpredictable connection times, and varying transmission characteristics [1], [6]. Nevertheless, experiments have shown that WLAN can be workable over significant distances for mobile users at high speeds [2]–[4]. Fig.1 introduces a sample of an intermittent connectivity scenario.

In this paper, we focus on the challenges that accompany short and unpredictable connectivity periods, i.e. an intermittent connectivity environment. 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. 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 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 II. Next, in Section III, we examine the IEEE 802.11 standard...
scanning procedure. In Section IV, we introduce and explain our proposed protocol and algorithms. Simulation results based on vehicle traffic models along with an analysis is presented in Section V. Finally, we conclude our work in Section VI, laying out our plan for future work.

II. RELATED WORK

A. Internet Access for Vehicular Networks

The Drive-thru Internet project [2] introduces the idea of using WLAN technology to provide opportunistic network access for users traveling by car. This project exploits WLAN APs at the roadside to conduct experimental evaluations on 802.11b 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 higher number of packet loss.

Experiments conducted in [3] 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. [4] build on a more detailed experimental analysis based on [2] and [3]. They analyze each phase and draw out ten problems that cause throughput reduction. In particular, connection setup delays, such as lengthy AP selection results in a loss of 25% of the overall throughput. They further remark, consistent with [2] and [3], that a robust connection setup is crucial in order to fully utilize throughput. They divide a connection into three phases depending on the production phase of a short-lived connection period.

In [5], the authors introduce a new paradigm for wireless access called opportunistic collaborative networking. We use this concept when stations have an opportunity to cooperate by sending AP reports to other stations to maximize the network’s utility.

B. 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 work to reduce this delay.

The handoff process occurs when a MS migrates from one AP to another, changing its point of attachment, as shown in Fig. 1, where MS is moves from AP to AP. The handoff latency consists of three phases: scanning, authentication, and re-association. Scanning delay is the dominant contributor to the overall latency which accounts for more than 90% of the total handoff latency [7].

The emerging draft 802.11k specification [8] 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). A 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, 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.

III. 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.

A. Passive Scanning

In passive scanning, APs contend with other stations to gain access to the wireless medium and periodically broadcast beacon frames. A 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.

B. Active Scanning

The active scanning mode involves the exchange of probe frames. Rather than listening for beacon frames, a 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.

C. 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. Hence, it is important that MSs fully utilize the given network. The total time that a MS can stay connected to an AP, i.e., the time connected \( t_c \), can be calculated using \( t_c = \frac{d_{AP}}{v_{MS}} \), where \( v_{MS} \) is the velocity of the vehicle, and \( d_{AP} \) is the communication range of the AP. Given the scanning delay \( S_d \) and using (1), we are able to derive the portion of the scanning delay \( S_p \).

\[
S_p = S_d \cdot \frac{100}{t_c}
\]

An optimal example of the connectivity time where a MS (120 km/h) passes through the diameter of an AP (a range of 200m) is 6 seconds. If the average delay in active scanning is 750 msec as in [3] and 1200 msec in passive scanning, the total portion of the scanning delay is 12.5% and 20%,
IV. AP Report (APR) Protocol Description

A. Overall Procedure

Referring to Fig. 1, as MS4 moves into AP3’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 MS3, can utilize the AP report. Meanwhile, MS3 will approach AP3, and before it enters AP3’s communication range, it will broadcast the AP report a single hop (e.g. to MS2) away. As MS2 enters AP3’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 sub-sections below.

B. Main Operation of a Mobile Station

1) A Mobile Station Relaying AP Reports

After a MS completes a full scan and acquires a beacon frame or probe response in the passive or active mode, respectfully, 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 Fig. 1, this is illustrated as MS2 relaying information to MS3. 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: Broadcasting AP report on each Channel

[Cycle 1]
for each channel to broadcast do
  if medium is busy 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
  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

Algorithm 1 consists of two cycles. A 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, i.e., the amount of time required to transmit an AP report 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.

\[ T_d = \frac{L}{R} \]  
(2)

\[ B_d = [(C - 1) \cdot SW_d + SC_d \cdot T_d] + [(C - SC_d) \cdot SW_d + SC_d \cdot T_d] \]  
(3)

where:
- \( T_d \): frame transmission time
- \( L \): length of the frame (bits)
- \( R \): transmission rate (bits per sec)
- \( C \): total number of channels
- \( SW_d \): channel switching time
- \( SC_d \): number of channels that successfully transmitted APR during the first cycle
- \( SC_d \): number of channels that successfully transmitted APR during the second cycle

The context information of the AP report is shown in Fig. 2. 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 [8]. Additional fields added to the AP report are the AP’s location and the signal strength.

Figure 2. AP Report Frame Structure

Thus, we use 15 octets for the frame size. Also, assuming we use IEEE 802.11b, we use 11 channels with a data rate of 11 Mbps. With current development, the channel switching delay can be reduced to 80 μsec, 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 [3], we believe 16.12 msec of delay has improved the overall network performance as shown by the simulation results in Section V.

2) A Mobile Station Receiving AP Reports

A 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 the following algorithm.

Algorithm 2: Deciding whether to use an AP report

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

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 Fig. 1. As MS\(_6\) and MS\(_7\) enter AP\(_4\) and AP\(_3\) 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.

Depending on the information extracted from the AP report, MSs can predict when a connection can be established and when to relay the AP report. Using the two parameters, AP signal strength and AP location, a MS can estimate the coverage range of the AP. Once the coverage range is calculated, the MS will relay the cached AP report before it enters the coverage range so that it will not have to spend time transmitting the broadcast packet. This will allow the MS to fully utilize the short connection time.

V. SIMULATIONS

A. Vehicle Traffic Model

1) Car Following Model

In civil engineering, the Car Following Model [9] 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:

\[ S = \alpha + \beta \cdot V + \gamma \cdot V^2 \]  

where \( S \) is the average spacing from rear bumper to rear bumper. The coefficients \( \alpha, \beta, \gamma \) 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.

2) Traffic Volume Model

To accurately calculate realistic traffic models we use a set of traffic volumes (veh/hr) produced in [10] which used empirical traffic data. We are interested in the 4 types of traffic volumes produced in [10].

(a) Rush hour traffic with high traffic volume of approximately 3300 veh/hr.
(b) Non-rush 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) which is approximately 1000 veh/hr.

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

3) Poisson Distributed Arrival Model

In the classical vehicular traffic theory, vehicles’ arrival process is assumed to be Poisson distributed with mean arrival rate \( \lambda \) in veh/sec [10], [11]. Thus, the inter-arrival time of vehicles is shown to be exponentially distributed with probability density function (pdf),

\[ f_t(t) = \lambda \cdot e^{-\lambda t} \]  

With the distribution of time gaps between vehicles, we can find the pdf of distance \( d \),

\[ f_d(d) = \frac{\lambda}{v_m} \cdot e^{-\frac{d}{v_m}} \text{ for } d \geq 0 \]  

where \( d = v_m \cdot t \) in meters and \( v_m \) is the mean speed of vehicles in m/sec.

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

\[ F(d) = 1 - e^{-\frac{d}{v_m}} = p, \quad 0 < p < 1 \]  

we obtain the distance in terms of \( \lambda \) 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.

\[ d = \frac{v_m}{\lambda} \cdot \ln(1-p) \]  

B. Simulation Model

1) Simulation Setup

In our simulation we measured the average scanning delay for 100 vehicles using an AP report. 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, which is suitable for perfect packet reception since the reliable communication range for DSRC equipments are 250 m.

We set the total number of channels to 11 as in 802.11b. For comparison, we use the mean scanning time of 750 msec in [4] for active scanning. For passive scanning we use 1200 ms since the default beacon interval is 100 msec and each channel listening time must be longer than the beacon interval.

2) Applying Vehicle Models

Using the car following model equation (4), we set \( \alpha \) to a
value between 3–6 meters, which expresses various vehicle lengths. The reaction time, \( \beta \), is randomly selected from 0.7–1.5 sec, and we set \( \gamma = 0.075 \text{ sec}^2/ \text{m} \). For speeds of up to 55 m/sec (approx. 200 km/h), we simulate 100 samples with 100 vehicles. We calculate the average spacing (S) for each speed of up to 55 m/sec for 100 vehicles. Two parameters, S and \( v_m \), are used in varying \( \lambda \) in the Poisson distributed arrival model. Fig. 3 illustrates the results of this simulation.

On applying the traffic volume model to the Poisson distributed arrival model we vary \( \lambda \) based on the 4 types of traffic volume, as shown in Fig. 4.

In the traffic volume model, 4 types of traffic volume have been measured for active scanning alone, because the improvements are almost the same 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 non-rush and rush hours we can easily see that the average scanning delay is nearly negligible.

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

VI. CONCLUSION

Much research has been conducted and concluded that the areas of ‘open’ Wi-Fi wireless 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 and provide hints to users on when connections can be established. When vehicles have high 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.

REFERENCES