Selective Beam Discovery Techniques for VANETs

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ABSTRACT

During the recent years, 802.11 wireless networks (Wi-Fi) have spread widely within houses, offices and industries. Nowadays, large scale Wi-Fi networks are chaotically deployed in metropolitan areas. Thus, vehicles could benefit from the connectivity offered by 802.11 Access Points (AP) “open” for mobile clients. Furthermore, directional antennas improve the communication performancess of infrastructure assisted VANETs.

In this work, we focus on AP scan phase and we introduce *Selective Beam Discovery* (SBD), a method that relies on directional antennas and beam steering techniques. We bring in the concepts of front-rear asymmetry and beam pattern lateralization and we exploit them to achieve better metrics during the AP probing phase. The results of our simulation study show that SBD improves localization up to 90% and achieves quicker association and longer connectivity of 802.11 links between a moving vehicle and roadside “open access” APs.

Categories and Subject Descriptors

C.2.1 **[Computer-Communication Networks]**: Wireless communication – Vehicular communication;

General Terms

Performance, Design, Measurement, Experimentation.

Keywords

Directional antenna, Vehicular Internet Access, Mobile networks, mobility, vehicular mobility, connectivity, wireless LAN, 802.11, Wi-Fi.

1. INTRODUCTION

Vehicular Ad hoc Networks (VANETs) can be implemented anytime, anywhere, dynamically, with or without pre-established communication infrastructures. They allow nearby vehicles to exchange information and provide communication between roadside infrastructure and moving units; Also, they enable to collect and process data (i.e. accidents and road blocks) useful to re-route traffic and prevent jams and they improve safety (i.e. real-time collision avoidance). Nonetheless, there are other potential applications that are suitable for dynamic traffic planning in emergency situations or in establishing a network between vehicles at a disaster site. In addition to this, vehicular networks will offer many services (i.e. automatic toll payment and parking services). VANETs also provide passengers with additional comfort, as they support multimedia sharing and Internet connectivity (i.e. hotel and restaurant reservation, video and music download, etc). Thus, business companies are interested in the broadcast-based commercial applications (i.e. geographical advertising). Roadside infrastructure (InfoStations and APs) acts as a gateway to the Internet and extends the facilities of a vehicular network (e.g. high bandwidth connectivity, low latency communication, distribution of time-critical data). Many projects [2] rely on open urban Wi-Fi networks to give free Internet use to the general public (including Personal Area Networks, MANETs and VANETs). However, before accessing the Internet, a vehicle unit must run several steps: scan for nearby APs, associate with an AP and acquire an IP address (with DHCP or other methods). Unfortunately, the coverage offered by roadside infrastructure is limited (compared to cellular base stations); so, the duration of the scanning and the handshaking phase often does not leave sufficient time for the exchange of traffic [5] and fast moving vehicles are not able to access to the Internet. Although directional antennas improve the connectivity performancess [4], one of the main issues is the still the long amount of time required to localize open APs. Moreover, if the vehicle unit fails to establish link-level connectivity (e.g. the AP requires an authentication), it must scan again. Considering the average duration of a connection, scan and association account for more than 90% of the overall time [11]. Our system minimizes the discovery phase and enlarges the time window available for real traffic. Another significant factor is the IP address acquisition [11], which is beyond the purpose of this work.

In the next section, we review the main techniques to achieve Internet access in VANETs. In Section 3, we detail the *Selective Beam Discovery* (SBD) mechanism and we discuss its feasibility: it can be implemented on vehicle units equipped with a directional antenna to reduce the time required to discover APs. In Section 4, we discuss the results of our simulation study focused on the improvements in terms of connectivity performances. In Section 5, we detail our findings and we introduce our future work.

2. RELATED WORK

Several studies involved omni-directional antennas, which radiate equally in all directions, but different types of antennas have been investigated in [6]. Although in a static situation it is possible to concentrate the radiation in the direction of the AP to increase coverage and connectivity, in vehicular networks omni antennas were considered as more suitable because the units move with respect to the APs. However, [8] demonstrated that it is not convenient to receive in all directions due to scarce spatial utilization and poor link reliability. Conversely, smart (or adaptive) directional antenna arrays cycle their narrow beams while distributing the same amount of RF energy over a limited area, increasing the actual signal strength and enlarging the coverage, resulting in better connectivity, lower latency and also longer battery life. Moreover, they reduce interference and multipath fading, they increase spatial reuse and achieve higher network throughput [10]. As the vehicle moves with respect to the AP, in [4] and [6'] the directional pattern continuously changes to select an AP-beam combination such that the link quality is maximized at each point along the drive. Such steering extends connectivity time and enhances throughput because it achieves a better transmit or receive gain level. Using active probing (the car sends a message to the AP and waits for its reply): it takes ~3sec to scan all beams and channels. During this interval, a vehicle can move a considerable distance (~84m driving at 100 Km/hr, more than half of the typical range of an AP). As probing and communication are exclusive, in order to connect to the APs, vehicle units must already have determined the optimal beam associated with its position. For this reason, a connected vehicle will not be able to discover a change in the topology until it disconnects and scans again. When information about the best AP-beam combinations is cached at every node along the path using a Global Positioning System (GPS) device the system relies on the stability of the topology of the APs. However, the availability of APs highly varies with time. Unfortunately, such information is cached locally (individualistically) and only frequent drivers of an area can benefit. On the other hand, occasional visitors are interested in accessing the Internet (i.e. to book a flight, to make a hotel reservation). Hull et al. [7] introduced *IP caching* to improve the IP acquisition phase: combinations of AP-IP address values are stored in association with GPS data for further reuse. However, this leads to scalability problems because the number of addresses is limited. *IP Passing* [12] reduces the overhead for obtaining a new IP with DHCP: once a car leaves the coverage area of an AP, it passes its address backwards to another vehicle unit. However, this requires that (at least) two cars (close enough) synchronize their beams.

3. SELECTIVE BEAM DISCOVERY

Actual solutions based on directional antennas perform the scan assuming that all of the beams have both equal probability, at any time, of being in the coverage area of an AP, and the same connectivity metrics. However, this may not be always true: considering a real urban area, there is a low probability for APs to be directly in the middle of roads. Typically, they are located in buildings, they could be far from the street, and vehicle units may not intercept their coverage range when pointing the main lobe of the antenna towards the driving direction of the car. Also, it may happen that APs found with the backwards beams are suddenly lost, especially when a car is moving at high speed. So, it may be not be useful to scan them at all. Furthermore, due to the driving behavior, the nearest buildings are on the right side of the road (UK is an exception); so, there is a higher probability to find an AP when pointing the antenna to a fixed direction rather than cycling the beam pattern. For example, when parking on a two-way street, we search for a place on the right side of the road.

SBD exploits this phenomenon to reduce the time required to perform the scan of the available nearby APs by prioritizing the directivity (the ability of an antenna to focus or to acquire RF energy in a particular beam when transceiving). SBD assigns different priorities to beams according to several parameters that depend on the vehicle (i.e. movement, direction, speed, and driving situation) and on the environment (i.e. position, road topology). Thus, instead of constantly scanning all beams, SBD acquires data about the above parameters (with on-board sensors and/or a GPS device) and extracts information (with classification algorithms) to draw inference that can be used to determine, at each time, the most eligible beam pattern for probing an AP with the highest success probability. SBD can also predict the future position of the vehicle and it is able to estimate the best beam to scan with while coping with high mobility. In addition to this, as several adjacent frequencies of 802.11(b) overlap, some channels are used with a higher probability $P(c_j) \ll P(c_i)$, and precisely, $0.2 \leq P(c_i) \leq 0.3$ where for i ={1,6,11} and $0.0125 \leq P(c_i) \leq 0.025$ else, because they have separate bands [2] [5] [1]. So, the probing time can be reduced with a Selective Channel Discovery (SCD) mechanism, which gives considers channel priority.

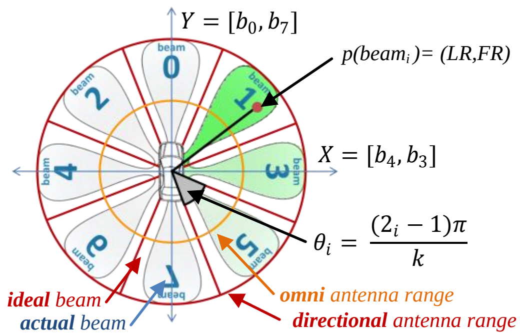

Figure 1. Model of the fixed orientation of the antenna

In our car-centric antenna model (see Fig.1), we assume k=8 and we fix the orientation: b_0 (pointing to the front) is the reference, b_7 points to the rear, b_3 and b_4 to the right and to the left side (orthogonally to the b_0-b_7 axis). There is a trade-off between the directivity and the capacity of an antenna: the narrower the beam width, the higher the gain; however, a high number of beams increases the time for a complete scan. In this study, we consider directional antennas equipped with individual radio boards and we assume the gains to transmit and to receive are the same. [5] and [6] implement a brute force algorithm having only one degree of freedom, the spin direction: the steering pattern probes all the beams in sequence by changing the positivity of θ ($\theta < 0$ meansfor clockwise rotation and $\theta > 0$ for counterclockwise). Most APs broadcast at a Beacon Interval of ~100ms (~50ms is used in condition of poor reception). According to [2] [5] [6], in order to scan all channels of an AP, a vehicle (with omni or directional antenna) may spend up to 11*200ms = 2200ms. As a result, this requires 17,6sec to probe all the beams. During this time, a car drives ~490m at 100Km/hr, which is significant, compared with the typical range of an AP (~150m [13]). Moreover, long inter-beam intervals cause AP misses. Another negative factor is the *restricted AP redundancy*: insisting on a beam which finds a protected AP is a waste of resources. The SBD architecture is modular and consists of the following components.

The *Aggregator* acquires and preprocesses data sampled by on-board sensors to obtain an estimate of the drive situation. Although SBD does not require any geographical knowledge, it may be useful integrate data from a GPS device. The aggregator collects two vectors: V^m (where m is the number of sensors) and E^n , which represent the parameters acquired respectively with sensors (i.e. direction, speed) and with other sources (i.e. GPS position, route, road topology). The *Classifier* identifies the best beam pattern to intercept the AP signal: it calculates $S^{n\times m} = V^{m} * (E^{n})^{-1}$; it uses the matrices *Weighted FrontBack (WFB)* and the *Weighted LeftRight (WLR)* having the same dimensionality as $S^{n\times m}$, containing the weights for V^{m} an E^{m}d; with *WFB* and *WLR* it computes the resulting probability as the scalars *FrontBack (FB)* and *LeftRight (LR)*:

$$FB = \sum_{i=0,j=0}^{i<m,j<n} WFB * S_{i,j} \qquad LR = \sum_{i=0,j=0}^{i<m,j<n} WLR * S_{i,j}$$

which are a linear combination of $S^{n\times m}$ and their respective weight matrix; *FB* and *LR* represent respectively front-rear and left-right panning control signal. Basically, *FB* and *LR* (see Fig. 1) are the coordinates of a point *p(beam)=(LR,FB)* (on a probability plane on the axes X=[b_4,b_3] and Y=[b_0,b_7]) in an area

$$i = \pi P^2 \frac{\frac{2\pi}{k}}{2\pi} \text{ (where } k \text{ is the number of beams)}$$

enclosing the eligible beam. The distance e_i=*[O,p(beam)]* measured as $\sqrt{LR^2 - FB^2}$ represents the eligibility confidence of *i*. A normalized maximum value $P = min_{i=1}^{i=k}(|e_i|)$ bounds e_i, so that for any value $e_i > P$ we assume $e_i = P$. The *Scanner* probes according to the selected beam pattern. Instead of using a brute force approach, it performs a scan on a specific beam pattern (an ordered vector) $BM = \{e_1, \dots e_{s\leq k}\}$ of beams such that, given a probability threshold t, $e_i > t\ \forall i \leq k$. It supports both active and passive probing. With the former, instead of waiting for beacons, vehicles send out periodic probe requests at short (~30ms) intervals and listen to responses from APs. The *Filter* uses post-processing techniques to adjust the parameters of the classifier according to the success rate of steering patterns. Basically, it uses updates the weights beam-channel in WFB and WLR to minimize the failure rate for the given combination of beam, channel and parameters (*E* and *S*). The *Storage* saves the final results in memory. In this work, we did not implement a caching mechanism for the combination beam-GPS coordinates because the information overhead would be greater than the advantages.

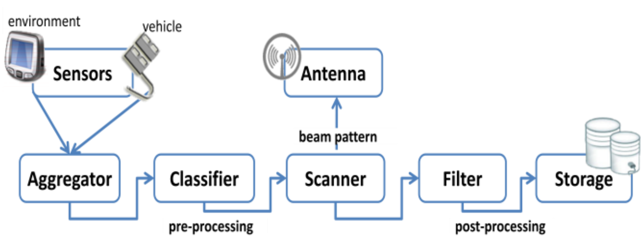

Figure 2. Architecture for SBD

4. SIMULATION STUDY

Our simulation evaluates the performances of SBD in non-sparsely connected networks and in traffic and driving conditions with an acceptable level of realism. Our aim was to determine the main factors that impact on directivity during the scan. The following parameters were considered as the most relevant for the analysis of the probing phase: *AP number* (the distribution of APs in an urban zone), *AP location* (the position of the APs in the area and their relative position with respect to the vehicles), *AP range* (the coverage of each APs with an omni antenna), *AP interception rate* (the number of successful scans), *AP loss rate* (the number of AP misses scans after a successful scan as a reliability metric), *Vehicle speed* (the average speed of the vehicle), *Vehicle range* (the coverage of the antenna), *Vehicle position* (the GPS location of the car at each time). For our simulation scenario we used data about the real distribution of "open access" Wi-Fi APs from OpenWiFiSpots database, which is accessible on the web via a Google Maps interface. To accurately simulate both vehicular movement and the real AP topology we developed an ASP.NET control which acts as a wrapper for the Google Maps API. For this simulation, we generated data using information from previous studies [2] about Wi-Fi connectivity with VANETs. We deployed also routers of private users in proportion to the real-data about the AP coverage. Additionally, we assumed that APs are distributed not uniformly, in chaotic clusters. Coverage areas of the APs were generated considering a transmission radius of ~120mt ±50mt. We introduced modeled interference which was chosen randomly according to a threshold so that Signal to Noise Ratio is ~35dB ±15dB. We built a vehicular traffic flow model based on [9] and we generated car routes with a driving schedule representative of typical urban driving patterns. Parameters about the environment (e.g. time, direction of the road) and the vehicles (i.e. speed, position) there were continuously logged (1 sample/epoch). Each vehicular unit is equipped with the directional antenna model (see Fig.1) with a range of ~200mt ±50mt; slight variations were introduced in the parameters to differentiate between 5 types of antennas. In our discrete event simulator, time advances at fixed epoch e = 1ms, corresponding to 10 actual msec; i.e. the minimum active probing time duration (30ms) is simulated within 3 epochs (3ms). We considered beam switching latency as negligible (in the order of μsecs). We ran our simulator for ~96 hours on two 2.19 GHz computers (with 1 Gb of RAM each) . We generated data of ~576 drive hours. Our simulation involved 50 cars driving in 30 different cities of the U.S. along 20 predefined paths for each area. The vehicles covered a total distance of 31144km (at ~54km/h ±29km/h) driving several times over the same roads.

Table 1 shows the results of a scan with 8 beams at the same time. Even though it is not feasible, our purpose was to understand the relationship between speed and the performancess of individual beams. Results show that the probability for b_0 and b_7 (pointing to the street, especially on large roads) to encounter an AP is low as buildings are on the sides, while, depending on the speed, other beams are more effective.

Table 1. APs discovered (average) at different speeds-beams

beams	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7
35 km/h	17.5	41.7	39.1	49.9	39.1	36.8	28.3	8.3
60 km/h	7.8	40.4	24.6	33.5	24.6	24.3	19	4.7
85 km/h	4.3	35.5	15.7	21.3	15.7	15.2	11.1	2.1

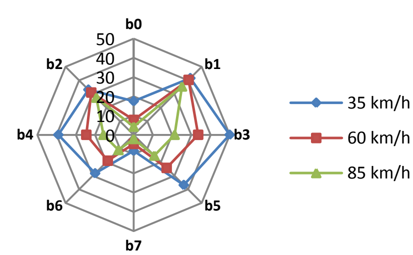

Figure 3. AP asymmetry at different speeds-beams

Also, we found a lateralization effect (on all channels). Simulation data (see Fig.5 and Table 1) show that the beams on the right side were able to discover a greater number (+13.11%) of APs with respect to the left side. This confirms that the drive side forces vehicles closer to the (buildings on the) right of the street. So, the beam pattern can also be lateralized to exploit this phenomenon.

Also, we found an asymmetry between the two main axes (front-rear and left-right). Then, we set the weight for the WFB and the WLR matrices and we ran another simulation to evaluate the improvement. In Table 2, MIN is the minimum and MAX is the maximum scan time; rmin (minimum), avg (average) and rmax (maximum) refer to actual values. Results (see Fig.7, Fig.9 and Table 2) show the improvement with SBD: even though the minimum bound are equal for both with active probing and with SBD, the latter reduces the minimum scan duration to ~1.51%, with an average optimization of ~97.37%. Finally, we simulated real-traffic conditions, including the probability for each beam to miss an AP after a successful scan. We weighted the discovery rate with the loss rate (see Table 3 and Fig.8). Results show that both right lateralization (+20,61%) and biaxial asymmetry persists, as well as the relationship between the speed of the vehicle and the most eligible beam (i.e., at ~35km/h the most reliable is b_3; at ~65km/h the best choice is to scan b_1, which is the most eligible beam also at higher speeds of ~85km/h).

Table 3. Weighted APs (average) at different speeds-beams

beams	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7
35 km/h	16.7	39.7	29.5	45.7	32.8	24.3	15.4	4.2
60 km/h	7.4	34.5	20.4	27.1	16.6	12.7	9	1.6
85 km/h	3.2	28.4	20.1	10.3	4.2	4.3	1.4	0.1

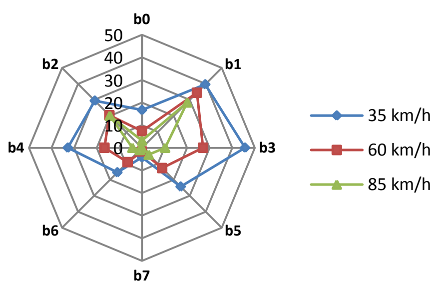

Figure 8. Weighted AP asymmetry at different speeds-beams

Table 2. Time required to discover an AP (ms)

method	MIN	rmin	avg	rmax	MAX
PassiveProbing (PP)	200	15400	16743	17600	17600
ActiveProbing (AP)	30	1980	2284	2310	2640
PP SBD + SCD	100	200	298	900	2400
AP SBD + SCD	30	30	60	270	720

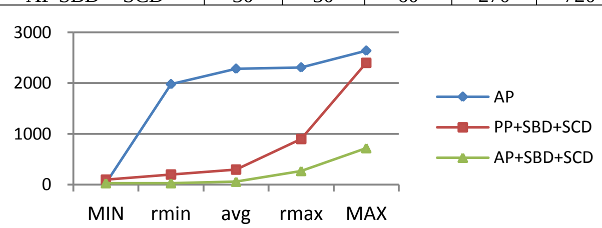

Figure 9. Active probing optimization using SBD

5. CONCLUSIONS AND FUTURE WORK

In this paper, we described Selective Beam Discovery (SBD) to localize 802.11b APs with directional antennas. We quantitatively evaluated the improvement when discovering APs with SBD in relatively well covered (~65%) urban areas; however, the implications of our findings may also extend to sparsely connected networks. From the results we concluded that optimizations of beam steering patterns improve Internet connectivity with urban Wi-Fi. SBD shortens the scan required by [5] [6] and it can be integrated with other techniques (i.e. IP caching and IP passing) that are effective in other phases. Simulation results show a significant improvement: scan time can be reduced and connectivity duration can be extended as well. Furthermore, SBD can be effectively implemented in several applications in the context of VANETs, with or without any GPS information. We demonstrated that with SBD tourists, salesmen and vehicles transiting occasionally in a urban area can benefit from an immediate Internet connection. To this end, many companies may also be interested in the commercial opportunities of offering free Wi-Fi access. Future work will consist in situ experiments to validate the simulation results. Moreover, we will develop variants for continuous switching antennas. Furthermore, given the topology variability, vehicles moving over the same routes on a daily basis (i.e. public transportation, garbage collecting vehicles), might continuously scan for APs, store the information locally, merge it at the depot, upload it on the Internet or pass lists of beam-channel combinations to the other units driving on the opposite way using mechanisms for data exchange (i.e. push-pull [3]). Although we applied SBD to AP localization, the same approach can be also used for tracking multiple different types of nodes (vehicle or roadside units). Consequently, we can imagine several probability tables for each target. For instance, when a car wants to connect to another car, it simply chooses another probability table that, considering simulation data, would contain higher values for b_0 and b_7. However, with respect to this, the deafness problem discussed by [8] should be considered.

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