Directional Antennas for Vehicular Communication – Experimental Results

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***Abstract*— This paper presents first results of experiments in vehicular-to-roadside communication using directional antennas. With directional antennas on one side, the duration of connection to a fixed access point or a road side communication unit can be extended and on the other side the interference caused to others can be reduced. In this work results of experiments with electronical steerable directional antennas mounted on a car communicating with stationary access points are presented. The measurements show the benefit of using directional antennas in different environments typical for vehicular communications. The duration of potential 802.11b connections have been compared using directional and omnidirectional antenna patterns when driving through suburban environment. This comparison is based on passive scanning for access points in order to validate the approach in realistic scenarios. The results clearly prove a substantial potential improvement when using directional antennas.**

***Index Terms*—directional antennas, vehicular communications, road side communication, IEEE 802.11, experiments, measurements**

I. Introduction

With pervasive computing and increasing use of Internet technology on one side and ever cheaper and better information and communication technology available on the other side, communication from a car to access points or road side communication units is becoming increasingly important and accepted. Different applications and value-added services are discussed for vehicular communications.

Communication from a car to access points while driving has been proven to be feasible with existing IEEE 802.11b technology [1]. Using omni-directional antennas and speeds between 80 km/h to 180 km/h on German freeways a usable connection between 4 and 9 seconds could be established from a car to an access point, e.g. located at a rest area.

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In the US, Digital Short Range Communication (DSRC) is being standardized for communication between car and road side units for both safety and traffic information as well as for entertainment and tourist information [2], [3]. Therefore a 75 MHz frequency spectrum has been assigned in the 5.9 GHz range, being just above the 5.8 GHz ISM band. The physical and MAC layer are standardized at IEEE as 802.11p standard [5], [6].

In this work the idea to use directional antennas for vehicular communication is investigated. Directional antennas can increase the communication range and with this the duration a vehicle can communicate with a road side communication unit or an access point. In addition the interference caused to other users is reduced and a higher spatial reuse can be achieved resulting in a higher capacity.

Integrating several antenna arrays into the car body or the windows can be feasible for new car models. Using directional antennas which coming for rather low prices with new cars can therefore potentially improve the performance of car-to-roadside and car-to-car communications based on IEEE 802.11 technology significantly.

The authors have performed experiments using electronically steerable directional antennas scanning for access points in suburban environments. With these experiments the duration of the connection to an access point with and without antenna directivity has been studied. The results show the benefits of using directional antenna to improve connectivity.

The remainder of the paper is structured as follows: In the next section an overview on related work is given. Section III describes the measurement system and the test set-up. Section IV summarizes the results of the experiments and the authors' observations and Section V gives an outlook on future work planned.

II. Related Work

The feasibility to use IEEE 802.11 based communication from moving vehicles has been shown in [1]. Here the authors show how long a connection between a car passing an access point at a rest area can be maintained and used while driving at different speeds between 80 and 180 km/h. The authors show that approximately a third of the connection can be reasonably used and so communication is possible between 4 and 9s. Up to 9 Mbytes of data could be transmitted using the TCP/IP protocol and speeds around 80 km/h.

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In [2] experiments have been performed to connect to unprotected access points in the Boston area and use it for data communication. These experiments performed over 290 drive hours showed that the average duration of a single connection could be maintained for around 24s. However the average interarrival time between two access points is only 75s, meaning, that a connection is often not possible.

In the above mentioned publications typical omni-directional antennas are used on the vehicles to communicate with the access points. Use of directional antennas could potentially increase the connectivity to the access points from a moving vehicle.

Most of the work in the context of directional antennas has been in the design of MAC layer protocols supporting directional antenna in ad hoc networks and evaluate the performance using simulations, e.g. [11] or analytically [12]. To the best of the authors' knowledge, up to now, no real experiments have been reported using directional antennas in vehicular environment.

III. Measurement Set-Up

The measurement results reported in this paper are from experiments performed using electronically steerable directional antennas from Fidelity Comtech [7] for IEEE 802.11b/g. The Phocus Array antenna system consists of 8 element phased arrays and 8 individual receive-transmit boards, providing 17 different antenna patterns: one omnidirectional beam and 16 beams directional beams, each approximately 45° wide and overlapping with half of the adjacent beams. The maximum antenna gain equals 7 dBi if only one beam is used. The switching between different antenna beams can be done within 75µs.

The antenna system consist of an onboard embedded computer (Soekris net4511 [8]) which has an 802.11b/g Atheros chipset based miniPCI card. The embedded computer runs *pebble linux* with the linux 2.4.26 kernel.

The antenna system comprising the Phocus antenna array and the Soekris embedded computer was mounted on a car as shown in Figure 1. In addition, a laptop connected to a serial Garmin GPS receiver [9] and running a GPS server provided the location data to the embedded computer.

Fig. 1: Directional Antenna System mounted on Test Vehicle

The kismet war driving software [10] was modified by the authors to tag the traces with the direction of the packets received and the GPS data. For every packet received, the measurement script dumps the GPS location, ESSID, BSSID, received signal strength, noise level, PHY mode characteristics and the encryption method. In order to perform the measurements in realistic vehicular network scenarios without having to set up the complete infrastructure of road-side communication units, the existing access points in the campus area of Stony Brook University were used to measure all data.

Passive scanning of the access points has been done by listening to the beacon packets sent. This way the normal operation of the existing infrastructure was not disturbed. The default beacon interval in 802.11 based access points is 100ms. This implies that the same antenna configuration (17 options) and same channel (11 different channels in 802.11b/g) is only repeated every 18.7s, which is too slow even when driving with low speed. Within 18.7s, with a speed of 20km/h (approx 12Mph) the car moves 104m and with a speed of 50 km/h (approx. 31 Mph) 260m, which is close to the range of standard WLAN equipment.

The initial measurement of scanning through all the 11 channels showed that 43% of access points operated in channel 6, 38% operated in channel 11 and 9% operated in channel 1. Figure 2 shows the number of access points operating in the different channels. It can be seen from the graph that it suffices to scan only in channels 1, 6, 11 to obtain significant amount of data and reduce the scan time. Figure 2 also shows the number of open access points with which possibly a connection can be set up and data be sent.

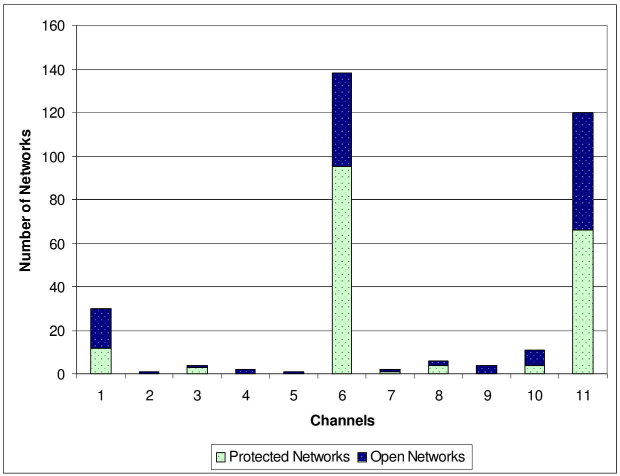

Fig. 2: 802.11g/b channels used in suburban environment

Using one channel only leads to a sample rate of 1.7s, meaning that the identical direction and channel will be measured every 1.7s; in this time the vehicle moves with 20km/h approx. 9.4m, with 50 km/h around 24m. Short term fading should be negligible due to the spreading applied in the IEEE 802.11 standard. Shadowing effects are in the range of the shadowing objects, e.g. size of houses and cars. Therefore the sampling rate of 1.7s is sufficient when driving with low speed.

The results presented in the next section refer to measurements taking on monitoring one channel only. The same route has been driven twice for monitoring channel 6 and 11 sequentially.

Measurements taken driving through suburban environment in and around Stony Brook campus show the potential benefits of directional antennas.

For DSRC concepts discussed directive antennas are expected to have an even stronger impact, because access points (road side units) will be closer to the freeways, have external antennas and will not be obstructed by buildings.

The measurements taken, however, firstly give an insight into the improvement by using directional antennas and secondly show the potential applicability in future scenarios for vehicular communications without dedicated infrastructure.

IV. Experimental Results

The first set of experiments shows how good the directivity of the antenna is, proving the potential benefits and their applicability. Several static measurements have been performed in which the car with the antenna mounted was stopped and the signal strength of packets received from an access point on all the beams of the antenna was measured. No active probing was done, the receiver was listening to beacons of existing access points only. This experiment was repeated in different environment with very little obstructions causing reflection and environments where there was a high degree of reflection. The results are shown in Figures 3 and 4.

Figure 3 shows the SNR of the packets received from one access point in the different beams of the antenna in a low populated area like a highway traffic junction. The access point is far away from the car and was only seen using the directional antenna. One can notice that in this environment, the directionality of the antenna can be seen very well. Only beams 13, 15 and 16 could see the beacons and all the other beams do not see them.

Figure 4 shows the SNR of packets received in the different beams in a typical suburban environment, near the dormitories in the Stony Brook University campus with 2-3 story buildings very close to each other. Here reflections from the different buildings provide lower directivity. Still there are positions like shown in Figure 4, where the packets from the access point can only be received with the higher gain of the directional antenna, but from different directions. This means that reflected paths only provide sufficient power to receive the signal when using the directional antenna.

The next sets of experiments were done driving through the campus area where lots of access points are operated by the students. In total 349 different access points were detected, 180 of them operating in channel 11 and 169 of them operation in channel 6. The vehicle was driven with low speeds between 5 Mph around the dormitories (see figure 5) and below 30 Mph on the highway in order to capture the data (beacons) from all directions.

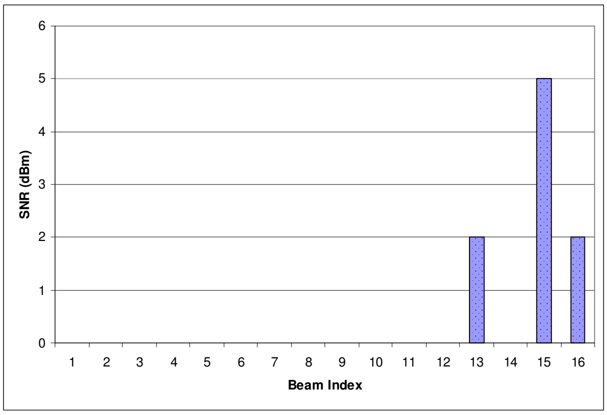

Fig. 3: Environment with low density of buildings

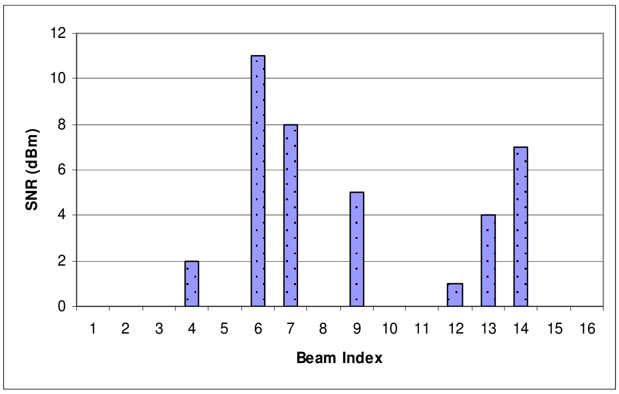

Fig. 4: Environment with high density of buildings

The main result from the experiments show that the connectivity period to an access point using omni-directional antenna in averages was around 25s and with the directional antenna was around 95s. A significant improvement (factor of 4) can be seen when using the directional antenna proving their performance potential in vehicular communication where the duration of connectivity is very important to support any application from the moving vehicle.

Fig. 5: Student Dormitories at Stony Brook

In the following the measurement results detailing the performance potential of using a directional antenna are elaborated.

Fig. 6 and Fig. 7 show the SNR values captured by the Wifi card and the connection duration (x axis) for two particular access point to understand the benefit in detail. The dotted line shows for each sampling period (1.7s) the maximum value of all directions over time, which represents the SNR achievable with an optimal direction pointing. The solid line shows the SNR received on the omnidirectional beam over time. It shows several interruptions, which last over several seconds, even at locations where the directional beam is showing a high SNR ratio. As it occurs in several sampling sequentially this cannot be explained by a randomly lost beacon, but rather by the inaccuracy of the SNR measurements of the Wifi card and interferences from another direction, which are not received by the directional beam.

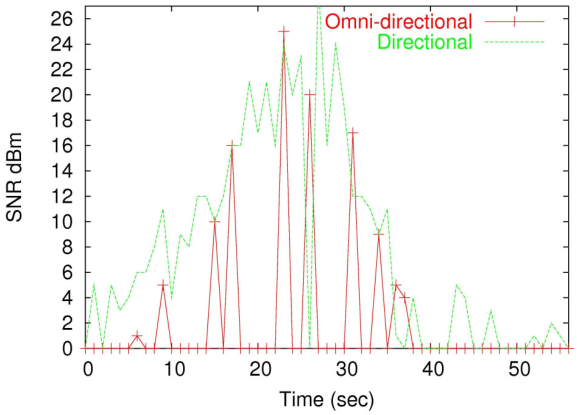

Fig. 6: SNR received with directional and omnidirectional antenna over time

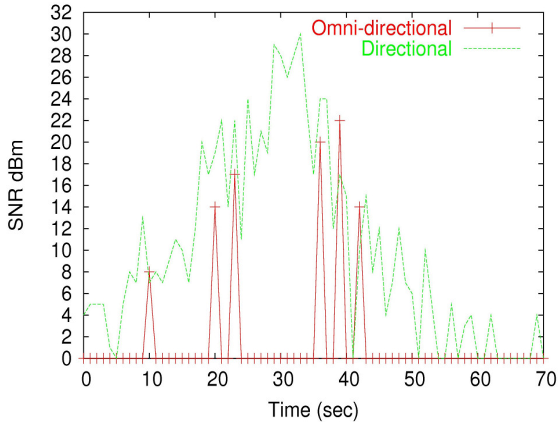

Fig. 7: SNR received with directional and omnidirectional antenna over time

For specific analysis a connection to an access point is defined as uninterrupted even if up to two beacon signals are not received, this means up to 3.4s interruptions are tolerated.

Figure 8 shows the duration of connectivity for each of the 169 access points operating in channel 6 and Figure 9 shows the duration for the 180 access points operating in channel 11. It can be seen that the duration of connectivity is substantially higher in most cases when using the directional antenna. However, there are also locations where directional antennas have little advantage over omnidirectional antennas.

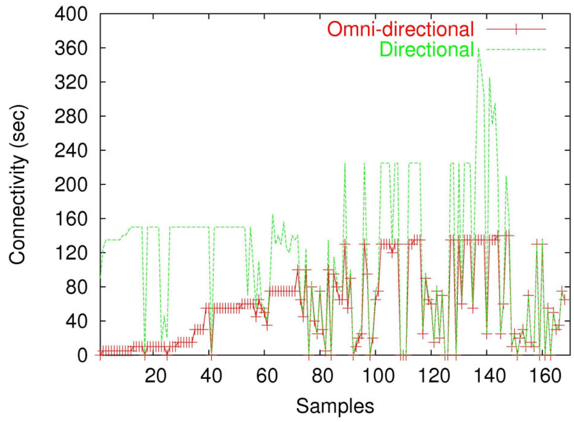

Fig. 8: Connectivity for each Access Point in Channel 6 measurements

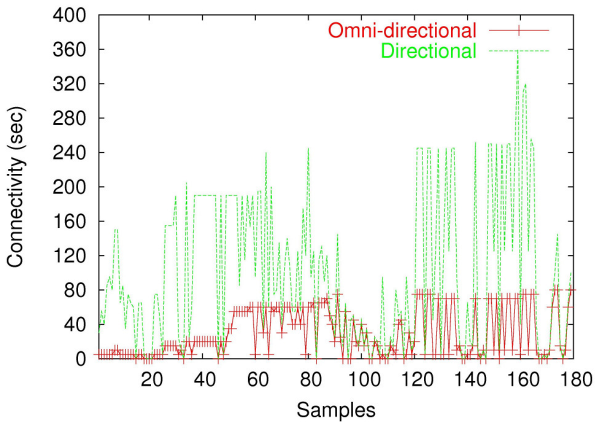

Fig. 9: Connectivity for each Access Point in Channel 11 measurements

In Figure 10 the cumulative distribution function (CDF) of the duration of the potential connection as defined above is given for omnidirectional and directional antennas. As there are no physical differences for channel 6 and 11, both measurements are summarized in this graph. The maximum connectivity period using omni-directional antenna was 140s and with the directional antenna was 360s. One can see from the CDF the mean connection duration with an omni-directional antenna was around 25s and with the directional antenna was around 95s which is an improvement of factor 4.

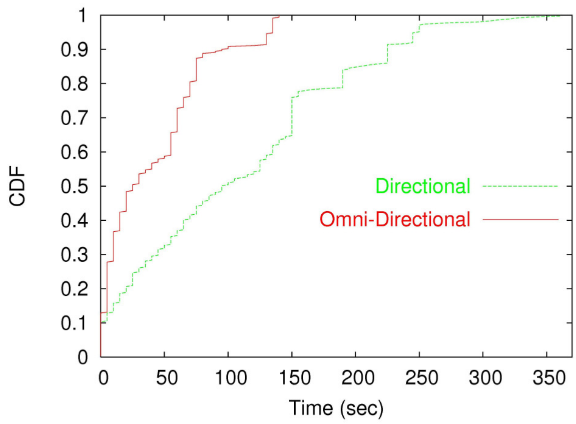

Fig. 10: Cumulative Distribution Function of Connection Duration

V. Conclusion and Outlook

In this paper the authors show first experimental results of measurements taken in suburban environment with directional antennas for vehicular applications. It has been shown that directional antennas can potentially increase the mean duration of a connection by a factor of 4 when connecting from a car to existing access points in suburban environment. The improvement is caused by the higher antenna gain when used in directional mode as well as by the exclusion of interference from other directions.

As the measurements have been taken with different receive antennas and without changing the transmit power or antenna, they impressively show how directivity on receive side only can improve connectivity.

The potential benefit shown however assumes optimal pointing. Algorithms on pointing with a-prior knowledge of the location of access points and without this knowledge are under investigation by the authors and will be presented in upcoming publications.

References

[1] Joerg Ott and Dirk Kutscher, Drive-thru Internet: IEEE 802.11b for "automobile" users, INFOCOM 2004. Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies, 2004, 1, -373

[2] Raja Sengupta and Qing Xu, DSRC for Safety Systems, Intellimotion Vol. 10, No.4, pp2-5, 2004

[3] DSRC, http://www.leearmstrong.com/DSRC/DSRCHomeset.htm

[4] Bychkovsky, V.; Hull, B.; Miu, A.; Balakrishna, H. & Madden, S. A Measurement Survey of Vehicular Internet Access Using In Situ Wi-Fi Networks 12th ACM MobiCom '06, September 24-29, Los Angeles, California, USA, 2006

[5] IEEE DSRC, http://grouper.ieee.org/groups/scc32/dsrc/index.html

[6] Telecommunications and Information Exchange between Roadside and Vehicle Systems— 5.9 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical ayer (PHY) Specifications," ASTM International, www.astm.org.

[7] Fidelity Comtech, www.http://www.fidelity-comtech.com

[8] Soekris Engineering, http://www.soekris.com/

[9] Garmin GPS system, http://www.garmin.com/

[10] Kismet Wireless, http://www.kismetwireless.net/

[11] Z. Huangand C. Shen, A comparison study of omnidirectional and directional MAC protocols for ad hoc networks Global Telecommunications Conference, 2002. GLOBECOM '02. IEEE, 2002, 1, 57-61 vol.1

[12] S. Yi, Y. Pei and S. Kalyanaraman, On the capacity improvement of ad hoc wireless networks using directional antennas MobiHoc '03: Proceedings of the 4th ACM international symposium on Mobile ad hoc networking & computing, ACM Press, 2003, 108-116