Directional Traffic Light Base Station

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***Abstract*—In this paper, we build up a scenario using traffic lights at a crossroad as BSs and simulate the downlink transmission to the vehicles passing by. In the simulation, we use two kinds of radio propagation model, one with directional antennas, and the other with omnidirectional ones. And then we compare the similarities and differences between the system performances of both models. We find that outage happens more often in a directional model when the MSs are close to the BS, whereas it consumes power much more efficiently in the long-distance transmission than an omnidirectional model. According to the results, we propose a hybrid-radio-propagation-method that covers the advantages of both models in our conclusion.**

I. Introduction

The CEO of Tesla, Elon Mus, has proposed the companys source opening project to clients in 2014, marking a beginning of the era of smart cars. For this reason, we would like to build up a wireless network simulation related to vehicles. A traffic light is an ideal infrastructure to be added in the system of vehicle network since it can serve as a base station and downlink data to the smart cars passing by without extra device. Also, traffic lights can provide useful traffic information such as GPS location, recommended acceleration considering traffic situation, and on-time accident notification. Thus, a simulation on the I2V communication is desperately needed. Instinctively, we use a directional broadcast model for a traffic light since the corresponding MSs always come from several same directions. Also, since other BSs diagonal to the one transmitting data to MSs wont cause interference, it is more preferable to use a directional BS than omnidirectional one in real life because it should be easier to deal with hand off. Also, the power consumption of the directional model should be much less than the omnidirectional one since it only concentrate the transmit power on specific directions, serving the MSs in target area. However, as a tradeoff, we cannot send any information to the MSs located outside the serving beams, which might lead to data loss.

The remainder of this paper is outlined as follows. In section II we introduce two related paper that we studied before our work. Section III introduces the system model used in our simulation in detail, including both directional and omnidirectional scenario, the deployment of the crossroad and traffic lights, and the mobility model of the cars. We present our simulation results with analysis in section IV and section V concludes the paper with our proposal of a possible solution to the mentioned dilemma according to our results.

II. Related Work

There are two paper that we studied before our work. Iglesias et al. [1] presented an on-board driving assistance system that brings traffic light information inside the vehicle. With this on-board traffic light assistant, drivers will acquire the forthcoming traffic light state and the remaining time until next change of state over a WiFi-like link, and thus is able to adapt his driving behavior to the situation. Moez Jerbi et al. [2] presented an extensive measurement campaign evaluating the performance of IEEE 802.11 in different vehicular communication scenarios: vehicle-to-vehicle(V2V) and infrastructure-to-vehicle(I2V) and concentrate the evaluation on multi-hop communication. The experiment found the feasibility to use ad hoc networks to extend the transmission range of the infrastructure and the connection time for cars in motion.

Inspired by this application of I2V wireless communication, we decided to simulate the performance of traffic light-to-vehicle data transmission in our work.

III. System Model

In this section we present the components in our simulation, including the configuration of the crossroad and traffic lights, the mobility model of cars, how directional and omnidirectional schemes work, and the performance metrics we are interested in.

In our scenario, there is a crossroad centered at coordinate $(0, 0)$ with road length 800 meters and road width 80 meters. There are 2 lanes on each road thus 4 directions(north to south, south to north, east to west, and west to east), and each lane has a 40 meters lane width. The center base station located at $(0, 0)$ from which all the cars received downlink data. The other 8 base stations located either at the end of a road(for example, $(-840, 0)$) or at the corner of the total map(for example, $(-840, 840)$), from some or all of which the cars may suffer downlink interference.

After the simulation starts, at every second the appearance of 4 cars at the end of corresponding lane follows Poisson distribution. Each car appears at the end of a lane $(-840, -20)/(-20, 840)/(840, 20)/(20, -840)$ and follows a single direction east/south/west/north with a constant speed generated uniformly randomly from $[11, 17]$ m/s as the car appears. While the existing cars keep moving to the other end, new cars continue to appear at each second until the total number of car reaches 50. When a car reaches the end of its lane, it disappear and after all the cars disappear the simulation is over.

For the directional scheme in our simulation, we assume that a base station is broadcasting same data to all the cars in four direction: $\{0, 90, 180, 270\}$ degree, with effective beam width 25 degree. Any car that is out of the region of any effective beam of a base station will not receive any data(no data or interference). We utilize the two-ray propagation model in our simulation, from which we have:

$$g(d) = \frac{(h_t * h_r)^2}{d^4}$$

$$P_r = \frac{g(d)P_tG_tG_r}{a(\theta)}$$

$$a(\theta) = 12 * (\frac{\theta}{\theta_B})^2$$

For every car in our simulation, it receives data from the center base station as it appears in the map and considers transmission of other base stations as downlink interference. Once a car appears(and in the region of effective beam of the center base station) it starts to receive data; once the car disappears (or get out of any effective beam of the center base station) it stops to receive data.

As for the omnidirectional scheme, all base stations are able to broadcast data to all the cars in the map instead of only those in specific beams. This also suggests suffering from interference from all the other 8 base stations after a car appears before it disappears. Depriving the $a(\theta)$ term from the propagation model of directional scheme gets us the expression of receiving power P_r for a car in the directional term.

For the data transmission of the center base station we consider the Poisson data arrival scheme with $\{\lambda_L, \lambda_M, \lambda_H\} = \{0.25, 0.5, 1\}M$ bits, representing low/medium/hight data traffic at center base station.

During the simulation, we record SINR, Shannon Capacity, total data received, and packet loss of each car for comparison between directional and omnidirectional scheme. We will summarize the simulation results and our observations in the next section.

IV. Simulation Results and Observations

In the following 2 figures, we observe that the received data of the MSs accumulated while traveling through the traffic light is different between the two models. First, from Fig.2 it is apparent that in the directional BS case, the growth of the total received data ceases in the mid-band. The phenomenon occurs because when a MS runs too close to the BS, it is likely that the MS may be out of the limit angle of serving beams, which would severely damage the channel condition. Secondly, we observe a light increment on the received data at the beginning and the end of the curve as well. The reason is that downlink transmission from the central BS at a crossroad would be interfered by its diagonally neighboring BSs at the ends of each lane. However, the interfering BSs are also directional, and the interference a MS suffered by would vanish when it is at the ends of each lane. Thus, a light increment on the received data is observed. From Fig.1, however, we can see that the phenomenon mentioned above doesn't happen since all the position in the map is covered by the transmission range of the center BS in the omnidirectional scheme.

Another observation should be brought out viewing the following 2 figures. According to Fig.4, the sum of the total data received by each MSs in the directional model is 9 times

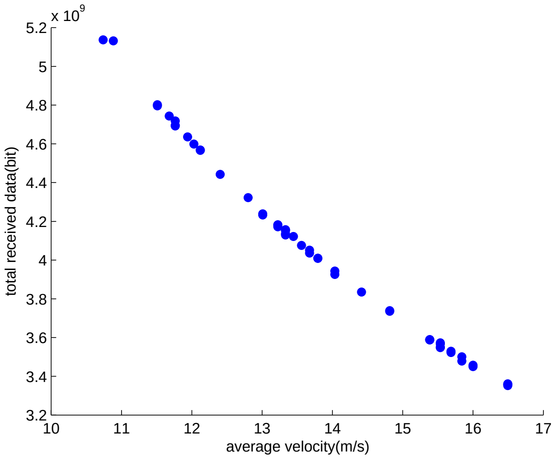

Fig. 1: total received data under different average speed in omnidirectional scheme

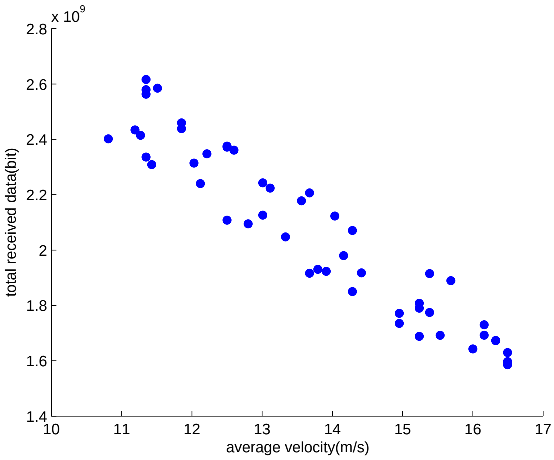

Fig. 2: total received data under different average speed in directional scheme

more than that of the omnidirectional model shown in Fig.3. That is to say, the power consumption of a directional model is relatively efficient. This can be easily understood since omnidirectional BSs are responsible for MSs from everywhere whereas directional BSs only serve the ones in specific broadcast area.

V. Conclusion and Future Work

In the previous chapter, we can observe that directional BSs cost less power than omnidirectional ones whereas the broadcast of omnidirectional base station can cover all the MSs in its nearby domain. Thus, we proposed a hybrid model which includes double physical layers. In the first physical layer, a directional BS should be used to handle the GPS information and velocity control since the directional model is more efficient in the long-distance transmission and that the mentioned information are needed as soon as possible before arriving at the crossroads. In the second physical layer, we use an omnidirectional BS to handle emergent event in a limited distance in order to save energy. The arrangement allows us

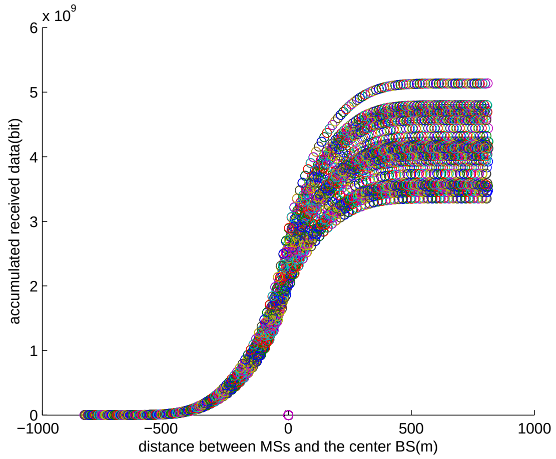

Fig. 3: accumulated received data at different distance from the center base station in omnidirectional scheme

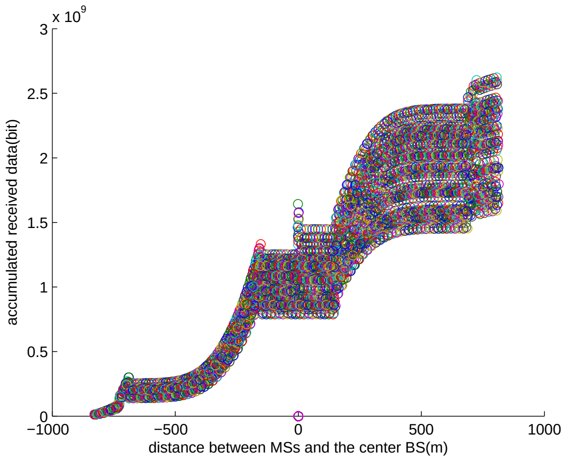

Fig. 4: accumulated received data at different distance from the center base station in directional scheme

to reduce the cost of transmit power and maintain the function of accident awareness simultaneously, thus, providing a better solution to I2V wireless communication.

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