Quarter-Omni: Improving Coverage and Throughput through Partial Directional Communication in IEEE 802.11p WAVE (extended abstract)

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I. Introduction

Vehicle-to-roadside (V2R) communication between vehicles and the roadside unit (RSU) as specified in the IEEE 802.11p Wireless Access in Vehicular Environment (WAVE) [1,2] can facilitate so called the "drive-thru" applications [3]. Namely, the vehicle users can upload or download data to or from the RSU as they pass by. However, the biggest issue with drive-thru communication is that the Wi-Fi coverage of the RSU is small, and the time window available for communication is short due to the vehicle speed. A study in 2006 shows that with the current IEEE WAVE specifications, the vehicular access to a RSU is quite short, approximately 13 seconds on average [4]. One solution to the coverage problem is to use the vehicles in the RSU transmission range as relays so that those outside the coverage can still communicate with the RSU [5]. However, this approach has problems such as low efficiency due to multiple transmissions of the same data, unreliability due to possible lack of relay nodes, and lack of incentives for cooperation. Another approach is to use directional communication. The directional transmission using digital beam forming (DBF) has begun to appear in commercial access points, even claiming up to 3-fold increase of covered distance [6]. As a matter of fact, there is rich literature that considers directional communication in general mobile ad-hoc networking contexts [7,8,9]. In particular, Xu *et al.* [9] focuses on vehicular environment and considers various combinations of directional and omni-directional RTS/CTS and data frame transmission. It shows through analysis that the directional data transmission in combination with Request-to-Send (RTS) / Clear-to-Send (CTS) is less desirable than omni-directional RTS/CTS. In this paper, we explore a new combination of RTS/CTS and data frame transmission in their directionalities. We show that the directional RTS/CTS can still lead to significant improvement in both RSU coverage and system throughput if it is used by vehicles whereas omni-directional RTS/CTS is used by the RSU.

II. Quarter-Omni Communication Scheme

We can have three types of RSU coverage created by different combination of antenna directionalities at the RSU and the On-Board Unit (OBU) on vehicles. Omni-directional antenna configurations on both the RSU and the OBU lead to the smallest RSU coverage of R_{OO}. If either of the RSU or the OBU has directional configuration, the coverage is R_{DO}. Finally, if both have directional configuration, the coverage is the largest at $R_{DD.}$ Given the same transmission rate, $R_{DD} > R_{DO} > R_{OO.}$ Table I lists up four possible antenna configurations applied to the drive-thru context, which lead to different RSU coverages. All-Omni (AO), Half-Omni (HO), and All-Directional (AD) are analyzed in Xu *et al*. [9]. Note that the RSU coverage for Half-Omni is also R_{OO} because the (directional) DATA-ACK exchange can only occur after a successful RTS-CTS exchange that can happen only within R_{OO}. Although All-Directional is analyzed in [9], and shown to perform even worse than All-Omni [9], the more fundamental problem is that it is highly unrealistic. This configuration would require the RSU to be steered toward a vehicle before the vehicle even attempts an RTS, or to keep tracking the positions of vehicles until it attempts to send an RTS to an intended vehicle. So we will exclude it from the performance comparison below. In addition to the above three, we propose an alternative called the Quarter-Omni, where only the RTS/CTS transmission/reception at the RSU are omni-directional. The name follows from the fact that among the four frames that are exchanged (RTS-CTS-DATA-ACK) in a RSU-OBU transaction, only one (either RTS or CTS depending on the data transmission direction) is omni-directional. We assume that OBU knows the GPS location of the RSU to direct the antenna towards the RSU.

TABLE I. Four Antenna Directionality configurations

Configuration	RSU Coverage	RSU Directionality		OBU Directionality	
		DATA/ ACK	*RTS/ CTS*	*DATA / ACK*	*RTS/ CTS*
All-Omni (AO)	R_{OO}	Omni			
Half-Omni (HO)	R_{OO}	Dir	Omni	Dir	Omni
Quarter-Omni (QO)	R_{DO}	**Dir**	**Omni**	**Dir**	**Dir**
All-Dir. (AD)	R_{DD}	Dir	Dir	Dir	Dir

We use Qualnet 5.1 simulator to compare the coverage and the throughput performance of AO, HO, and QO in the IEEE WAVE environment. We model a 17km road strip, on which 340 moving vehicles are exponentially spaced and there is a single RSU at the center. The average inter-vehicle spacing is 45m. The speed of the vehicles has normal distribution with the average of 90km/h and the standard deviation of 5km/h. The vehicles attempt to download data from the Internet through the RSU when they come into its coverage. The average request packet size is 800 bytes, and the size of the average response is 34K bytes. These numbers are obtained from typical request (*e.g.* HTTP GET) message size and the corresponding size of the response from services like Facebook, Google, YouTube, Twitter, and CNN. We assume that the server responds 0.5 seconds after receiving the request. Figure 1 shows the simulation results for only the lowest and the highest 802.11p

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rates, 3Mbps and 27Mbps [1], for space reason. The horizontal axis is the request arrival rate observed at the RSU. We set the minimum contention window size CW_{min}=15 [1]. We notice that the throughput performance of the QO scheme is better than AO and HO for wide range of request arrival rates. In particular, even after the system begins to degrade due to severe contention (*e.g.* beyond 20 requests/s at 3Mbps transmission rate), the throughput performance of QO is still the highest among the three. As for the effective coverage, we define it to be the position farthest from the RSU to yield more than 10Kbps throughput. We observe that QO far outperforms the other two schemes. It is because the higher throughput we discussed above is distributed across R_{DO}. For 3Mbps, the coverages for AO and HO are strongly bounded by R_{OO}. In contrast, the coverage under QO is bounded by R_{DO}, except under very heavy load where comparable throughput (that we can see towards the rightmost end of the graph) is distributed across the entire R_{DO}. In contrast, it is confined to R_{OO} for AO and HO. For 27Mbps, the poor coverage performance for AO is because data transmission is subject to R_{OO} for 27Mbps, which is much smaller than R_{OO} for RTS/CTS at 3Mbps. In the HO scheme, however, the data transmission is directional, so it is not confined to R_{OO} for 27Mbps. Making RTS/CTS range R_{DO} at 3Mbps and DATA/ACK range R_{DD}, QO can consistently achieve the largest effective coverage.

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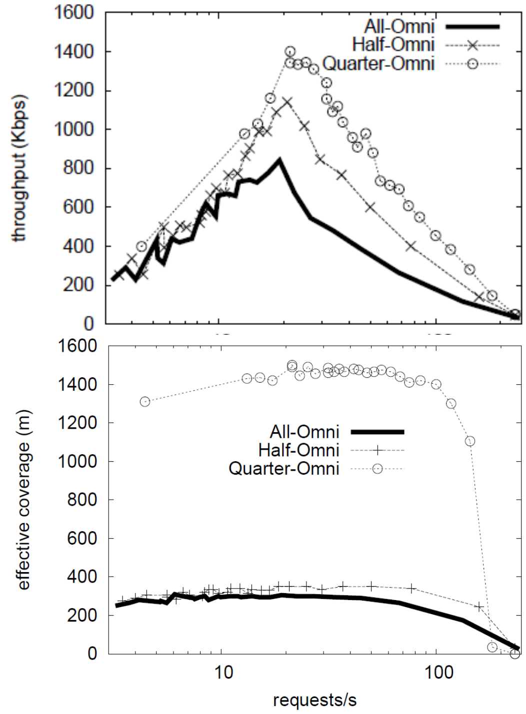
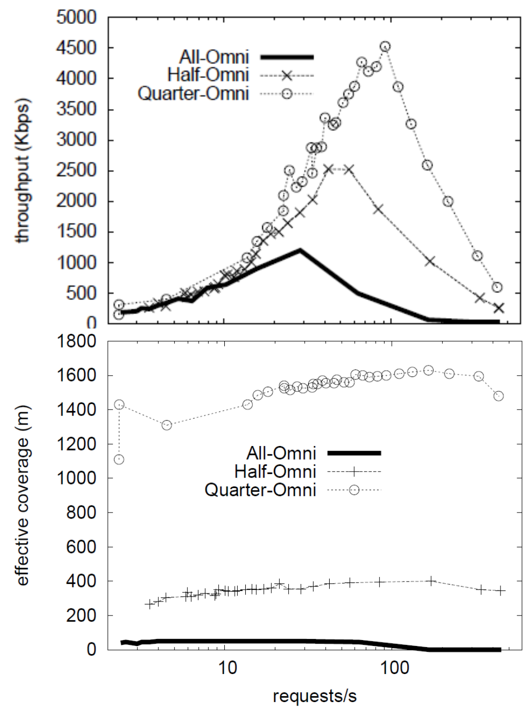


(a) At 3Mbps transmission rate



(b) At 27Mbps transmission rate

Figure 1. System throughput and effective coverage as a function of incoming request rate seen at the RSU: (a) 3Mbps and (b) 27Mbps