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Millimeter-wave communicating-radars for enhanced vehicle-to-vehicle communications

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ABSTRACT

To be effective, safety relevant applications based on wireless communications between vehicles need a minimum rate of vehicles equipped with communication devices. Although this minimum rate of vehicles could be relatively low, it is still difficult to obtain starting from a nonequipped vehicles situation. However, Long and short range radars are becoming very popular these days for cruise control, obstacle detection, parking assistance and pre-crash sensing. These radars are active sensors that produce significant radiofrequency power in wide allocated frequency bands. They also integrate a sensitive receiver. To accelerate the vehicle-to-vehicle communications penetration rate, this paper evaluates the possibility of enhancing vehicle-to-vehicle communications by using communicating-radars working at millimeter-wave. Current allocated frequencies for both vehicle-to-vehicle communication and radars are presented. Short-range and long-range radar radiofrequency parameters are analyzed to verify that existing automotive radar radio standards are consistent with communication. At grazing angles above the road, the characteristics of the communicating-radar propagation channel are theoretically and experimentally studied and compared to a more conventional 5.9 GHz channel. An analysis of Ultra Wide Band radio communication providing simultaneous access to vehicles in the same communication area is presented. Lastly, relevant architectures for communicating-radars are discussed.

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1. Introduction

Improving traffic efficiency, reducing congestion on roads and reducing accidents as well as damage cost are challenging tasks in most regions of the World. To put the problem into context, annual damage cost caused by accidents in the EU alone is approximately 100 Billion euro. This can be potentially minimized by using new information and communication technologies. Among these technologies, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications are good

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candidates to improve the current situation. In this way, connecting vehicles between themselves or with the infrastructure by a wireless radio link enables a new range of applications and the improvement of existing applications (Jin and Recker, 2006).

V2V communications have drawn much attention in recent years and will constitute an integral part of future Intelligent Transportation Systems (ITS). A recent standard for V2V in the 5.9 GHz has emerged. It is based on the IEEE 802.11p Wireless Access in Vehicle Environments (WAVE) protocol. This 5.9 GHz V2V communication protocol has a growing interest and constitutes the current car industry baseline solution.

The aim of this paper is to evaluate if upgraded millimeter-wave short range radars (SRR), which we will call communicating-radars, can be an effective, complementary V2V communications solution. The reason for this study is that driver assistance and collision avoidance applications, which could have a significant impact in reducing accidents, generally require a significant penetration rate. Since V2V communication resources will be installed progressively on board the vehicles, this sufficient penetration rate seems difficult to obtain when introducing the ITS application. Thus, the full benefit could only appear later.

However, automotive radars are widely in use and vehicle safety has already substantially improved in the last decades with the use of new safety technologies. Radar sensors for driver-assist systems help improve safety and comfort functions in Brake-Assist and Pre-Crash applications providing object detection (Groll and Detlefsen, 1997; Jones, 2001). For several years, Adaptive Cruise Control radars (ACC), long-range radars (LRR) and SRR have been commercial on-the-shelf facilities. In Europe, using a temporary frequency allocation valid until 2013, narrow-band SRR operate at 24 GHz. After 2013, SRR have to migrate to 79 GHz using an already allocated much wider 4 GHz bandwidth. Consequently, a new generation of SRR has to be developed by the industry. Moreover, SRR are intended to operate like a virtual safety belt, going 360° around the vehicles, using several radars and, to perform the basic radar function, SRR integrate a powerful transmitter and a sensitive receiver. Thus, SRR transmit and receive signals to and from every part of the equipped vehicle. Therefore, if we can modify, at marginal cost, the next generation of SRR to also allow communication, then we can facilitate the emergence of V2V communications, as well as provide an additional, very different communication link, which can improve the overall V2V communication reliability.

This paper will study some complementary aspects of these two V2V communication means.

To start the evaluation, we first consider current ITS frequency allocation regarding V2V communications and automotive radars. Then, we analyze SRR and LRR radiofrequency operating parameters to verify if current automotive radar standards are consistent with V2V communications. Next, we theoretically and experimentally consider the propagation channel characteristics at millimeter-wave, at grazing angles over the road and, at 5.9 GHz, above the vehicles on the road. At 5.9 GHz and at 79 GHz, very different, decorrelated and therefore complementary communication channels are obtained. Since radar allocated frequency bands are very wide, typically wider than 500 MHz, Ultra Wide Band (UWB) radio communication is justified for V2V communications. This bandwidth reduces the impact of the frequency selective fading which can be a problem at this frequency. To communicate simultaneously with several surrounding vehicles inside a platoon, specific multiple access radio techniques have to be developed. To provide this multiple access capability, specific Modified Gegenbauer Functions (MGF) UWB waveforms having interesting orthogonality properties are analyzed, compared and combined to a more conventional Code Division Multiple Access (CDMA) technique. Finally, we consider current automotive radar sensor architectures and propose modifications in order to upgrade them to communicating-radars.

Some years ago, Heddebaut et al. (2000) discussed the idea of using a multifunctional automotive radar and communication system. Roberton and Brown (2003) then presented an integrated radar and communications unit based on chirped spread-spectrum techniques. Heddebaut et al. (2005) refined the idea of using long-range radars to support communication between vehicles. Xu et al. (2006) presented an integrated radar and communication system based on a Direct Sequence Ultra Wide Band (DS-UWB) radio technology, and Saddik et al. (2007) described an Ultra Wide Band multifunctional communications radar system. In its final report dated September, 2007, the eSafety (2007) working group on communications indicated that the secondary use of automotive radars for V2V communications can complement other technologies.

Therefore, two main advantages are expected from such an evolution:

- When both are installed in a vehicle, 5.9 GHz WAVE communications and communicating-radars can cooperate and support communication over two very different propagation channels, thus providing an extended frequency diversity communication system. This offers a low common mode failure probability for V2V safety scenario applications.
- In the coming years, it is expected that radars will be fitted to more and more vehicles, with a significant growth rate. They are paid for by the customers to provide different services, such as: obstacle detection, parking assistance, pre-crash sensing, etc. If a communication capacity can be factory-built at marginal cost, using the radar front-end as a secondary use, then this communication resource, ready to use, can be used solely to provide communication to vehicles equipped with radars but not yet with a dedicated communication resource. This could increase quite significantly the communication system penetration rate and reduce the delay to obtain the full benefit of V2V communications.

This paper is organized in six sections. In Section 2, the European ITS allocation process and its new status will be briefly explained and put into context among existing regulations in the United States and Japan. Both 5.9 GHz V2V and radar allo-

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