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Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication in a heterogeneous wireless network – Performance evaluation ☆

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ABSTRACT

Connected Vehicle Technology (CVT) requires wireless data transmission between vehicles (V2V), and vehicle-to-infrastructure (V2I). Evaluating the performance of different network options for V2V and V2I communication that ensure optimal utilization of resources is a prerequisite when designing and developing robust wireless networks for CVT applications. Though dedicated short range communication (DSRC) has been considered as the primary communication option for CVT safety applications, the use of other wireless technologies (e.g., Wi-Fi, LTE, WiMAX) allow longer range communications and throughput requirements that could not be supported by DSRC alone. Further, the use of other wireless technology potentially reduces the need for costly DSRC infrastructure. In this research, the authors evaluated the performance of Het-Net consisting of Wi-Fi, DSRC and LTE technologies for V2V and V2I communications. An application layer handoff method was developed to enable Het-Net communication for two CVT applications: traffic data collection, and forward collision warning. The handoff method ensures the optimal utilization of available communication options (i.e., eliminate the need of using multiple communication options at the same time) and corresponding backhaul communication infrastructure depending on the connected vehicle application requirements. Field studies conducted in this research demonstrated that the use of Het-Net broadened the range and coverage of V2V and V2I communications. The use of the application layer handoff technique to maintain seamless connectivity for CVT applications was also successfully demonstrated and can be adopted in future Het-Net supported connected vehicle applications. A long handoff time was observed when the application switches from LTE to Wi-Fi. The delay is largely due to the time required to activate the 802.11 link and the time required for the vehicle to associate with the RSU (i.e., access point). Modifying the application to implement a soft

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handoff where a new network is seamlessly connected before breaking from the existing network can greatly reduce (or eliminate) the interruption of network service observed by the application. However, the use of a Het-Net did not compromise the performance of the traffic data collection application as this application does not require very low latency, unlike connected vehicle safety applications. Field tests revealed that the handoff between networks in Het-Net required several seconds (i.e., higher than 200 ms required for safety applications). Thus, Het-Net could not be used to support safety applications that require communication latency less than 200 ms. However, Het-Net could provide additional/supplementary connectivity for safety applications to warn vehicles upstream to take proactive actions to avoid problem locations. To validate and establish the findings from field tests that included a limited number of connected vehicles, ns-3 simulation experiments with a larger number of connected vehicles were conducted involving a DSRC and LTE Het-Net scenario. The latency and packet delivery error trend obtained from ns-3 simulation were found to be similar to the field experiment results.

1. Introduction

A robust wireless communication network is the foundation for connected transportation systems. Reliable and seamless vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data communication is the critical component of Connected Vehicle Technology (CVT) applications. Though there are several communication technologies/options available, such as Wi-Fi, WiMAX, LTE, and DSRC, not all can support low latency, accuracy, and the reliability of data transmission required for CVT safety applications (RITA, 2015a). While Dedicated Short-Range Communication (DSRC) provides low latency, fast network connectivity, highly secure and high-speed communication for safety applications, reliance on DSRC only may prove detrimental to diverse CVT applications. As a result, research efforts for wireless technologies that can enhance V2V and V2I communications for diverse applications have been undertaken. The wireless communication research community has been exploring combinations of DSRC with Wi-Fi, WiMAX and LTE communication technologies to provide a robust next-generation communication network for connected vehicles (Dar et al., 2010). Moreover, it is expected that DSRC roadside units will be installed at key locations such as intersections and interchanges. Thus, the limited coverage of DSRC (approximately 300 m) and integration of existing Wi-Fi, WiMAX, and LTE network creates a heterogeneous wireless network (Het-Net) for CVT applications.

For continuous connectivity, the shift from one communication network to another relies on the successful handoffs between the networks that ensure optimal utilization of available communication options (i.e., eliminate the need of using multiple communication options at the same time) and corresponding backhaul communication infrastructure requirements depending on the connected vehicle application requirements. In this study, the authors investigated the potential of a Het-Net to provide connectivity for V2V and V2I communications with optimal network resource allocation based on the connected vehicle application requirements. The objectives of this research were to evaluate the performance of Het-Net for (i) V2I communications for collecting traffic data, and (ii) V2V communications for a collision warning application. For field experiments, the authors utilized the Clemson University Wi-Fi network, and the National Science Foundation (NSF) sponsored Science Wireless Network (SciWiNet) infrastructure at Clemson, South Carolina that supports WiMAX, 3G and LTE, and DSRC infrastructure installed in test vehicles and roadsides. SciWiNet project supports a mobile virtual network operator (MVNO) for academic research communities (Martin et al., 2015). In additional, an ns-3 simulation experiment was conducted to evaluate Het-Net performance when there are larger numbers of vehicles within close proximity, and validate field test findings.

2. Previous studies

Various wireless technologies have been used to support the data transfer requirements of diverse intelligent transportation system (ITS) applications (Ma et al., 2009a). The selection of wireless communication option relies on the accessibility and feasibility of a wired communication option and wireless communication options (Wi-Fi, WiMAX, LTE), and data transfer requirement of particular applications (Ma et al., 2009a; Goodwin, 2003; Dey et al., 2015a; Haseman et al., 2010; Zhou et al., 2013). While existing ITS applications are infrastructure-based (i.e., installed at roadside locations), the next major deployment of wireless technologies within the transportation grid is the high speed wireless communication between moving vehicles and transportation infrastructures (V2V and V2I). V2V and V2I communication supported CVT safety applications require fast acquisition, fast message delivery (i.e., low latency) with high reliability, and the highest security and privacy standards (Watfa, 2010). To meet these particular requirements of CVT applications, the Federal Communications Commission (FCC) assigned 75 MHz bandwidth between 5.850 GHz and 5.925 GHz frequency in the US, which is known as Dedicated Short-Range Communication (DRSC). DSRC based V2V communication has been developed, evaluated and demonstrated under the supervision of the USDOT and the auto-manufacturers coalition for multiple safety applications (Lukuc, 2012).