Wireless Interference and Regulatory Frameworks for Frequency Allocation in V2X Communication Systems

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Abstract. Intelligent Transportation Systems (ITS) and Vehicle-to-Everything (V2X) communication technologies are revolutionizing the transportation sector by enhancing traffic efficiency, safety, and overall user experience. However, the performance of these systems can be significantly hindered by various types of interference. This paper provides a comprehensive overview of the regulatory framework for frequency allocation in V2X communication, identifies the types of interference affecting these systems both co-channel and adjacent channel, and explores strategies for managing and mitigating such interference. It includes an overview of current frequency allocations in the USA, EU/United Kingdom, China, Australia, Japan, South Korea, and Singapore, and discusses the implications of interference on ITS/V2X. The findings underscore the need for robust regulatory frameworks to ensure the successful deployment and operation of ITS and V2X communication systems worldwide.

Keywords: V2X · Interference · U-NII-4

1 Introduction

Intelligent Transport Systems (ITS) and Vehicle-to-Everything (V2X) communication technologies are transforming the interaction between vehicles and their surroundings to enhance road safety, traffic efficiency, and overall transportation sustainability. The cornerstone of ITS and V2X functionality is the allocation of spectrum that the designated radio frequencies are essential for wireless communications. Globally, the spectrum allocation varies, with different countries and regions dedicating specific frequency bands according to their unique regulatory environments and technological needs. The primary band for ITS services, including V2X communications, is the 5.9 GHz band, recognized in many parts of the world and specifically in the United States and Europe. Because V2X is supposed to be a globally harmonized technology in the 5 GHz spectrum

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(except for Japan's 760 MHz technology [19]), the Unlicensed National Information Infrastructure (U-NII) [25] labeling has been adopted for V2X spectrum to standardize nomenclature. U-NII designation is heavily used by various countries to harmonize frequency bands for unlicensed device usage. This band supports both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Additionally, the 5.8 GHz band is utilized in parts of Asia for ITS applications, often serving as a supplementary or overlapping band to the 5.9 GHz allocations. Figure 1 shows the United States U-NII-4 interference from low-cost U-NII-4 devices in Ch. 177. Additionally, the 5.8 GHz band is utilized in parts of Asia for ITS applications, often serving as a supplementary or overlapping band to the 5.9 GHz allocations.

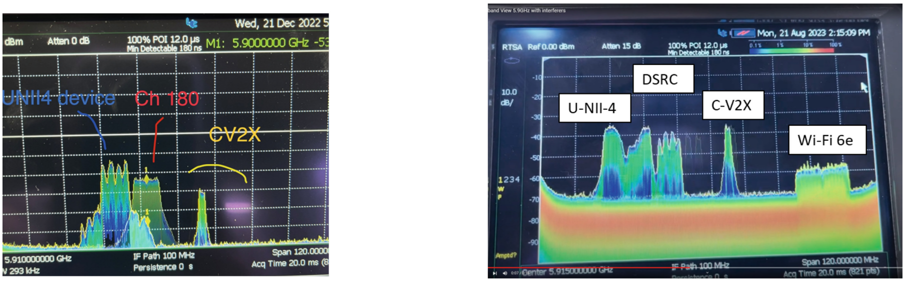

Fig. 1. U-NII-4 Interference on DSRC in the United States.

1.1 EU/United Kingdom 5855–5925 MHz

In the EU/UK, the frequency arrangement is established in 10 MHz blocks. The 5855–5875 MHz frequency band is allocated for non-safety road ITS applications, whereas the 5875–5935 MHz range is reserved for safety-related ITS uses. Within this designated spectrum, the segment 5875–5915 MHz is specifically prioritized for road-ITS, and the 5915–5925 MHz segment is assigned for rail-ITS applications, with the 5925–5935 MHz range exclusively reserved for rail-ITS. Both on-board units (OBUs) and roadside units (RSUs) are allowed to operate under license exemption in these bands. According to the European Commission's Decision (EU) 2020/1426, the 5875–5935 MHz frequency band is dedicated to safety-related Intelligent Transport Systems (ITS/V2x). This decision particularly emphasizes the prioritization of road ITS applications below 5915 MHz, aiming to enhance road safety and traffic efficiency. The 5925–5935 MHz band is mainly allocated for urban rail ITS, allowing shared use and coordination with fixed services to support efficient and safe urban rail operations. Technical specifications set a maximum spectral power density of 23 dBm/MHz and a total transmit power of 33 dBm with a 30 dB transmit power control range. The spectrum in the 5855–5875 MHz frequency range is not protected against interference because it is designated for non-critical uses, such as non-safety related road-ITS and non-specific short-range devices. The updated COMMISSION IMPLEMENTING DECISION (EU) 2019/1345 of 2 August 2019 [9], amending Decision 2006/771/EC, ensures efficient operation and prevention of interference for short-range devices across the EU [1,10].

As of the COMMISSION IMPLEMENTING DECISION (EU) 2019/1345 of 2 August 2019, amending Decision 2006/771/EC, the European Commission has updated the harmonized technical conditions for the use of radio spectrum by short-range devices. This decision ensures that short-range devices operate efficiently and without causing interference across the EU Short-range devices refer to a category of radio devices designed to operate over short distances at low power this naturally encompass all of V2X/ITS. Member states are not allowed to impose additional technical parameters or usage restrictions beyond those specified in the decision. This prohibition ensures that all short-range devices across the EU follow the same technical standards, preventing discrepancies that could lead to interference or inefficiencies one of the things it dose i regulates the maximum spectral power, density. The density refers to the highest amount of power that can be transmitted per unit of frequency. It is a measure of how much power is distributed across the frequency spectrum by a device. This is important for ensuring that devices do not emit excessive power within any narrow band of frequencies, which could cause interference with other devices operating in the same or adjacent frequencies. However Vehicle-to-vehicle (V2V) communications for road-ITS will be permitted at 5915–5925 MHz once spectrum-sharing solutions for the protection of rail-ITS have been developed at ETSI. In the absence of such sharing solutions for the protection of rail-ITS, the EU permits infrastructure-to-vehicle (I2V) communications for road-ITS at 5915–5925 MHz subject to coordination with rail-ITS [3,18].

1.2 USA 5895–5925 MHz

In the USA, the Federal Communications Commission (FCC) has revised the utilization of the 5.9 GHz radio frequency band, initially designated in 1999 for ITS [26]. The updated policy is (5.895–5.925 GHz) specifically for ITS to support traffic safety functions. This modification was prompted by the growing demand for Wi-Fi, aligning the part of the band now open to Wi-Fi with other frequencies already utilized for similar purposes, thus enhancing the strength and reliability of internet services. Conversely, the segment retained for ITS focuses on promoting vehicle-to-vehicle and vehicle-to-infrastructure communications, crucial for improving road safety and managing traffic effectively. This decision reflects the FCC's intent to balance the imperative needs of robust traffic safety systems with the public's escalating demand for broader and better wireless connectivity. Additionally, the FCC's approach considers international standards, aligning the 30 megahertz reserved for ITS with global practices to standardize technology and minimize costs, thereby preparing for future advancements in traffic safety communication technologies [12].

1.3 Japan 5770–5850 MHz/750–764.5 MHz

In Japan, ITS utilizes specific frequency bands to enhance vehicular communications, thereby improving safety and efficiency in transportation [2]. The spectrum is segmented into two principal parts: the ITS Connect band (755.5–764.5 MHz) supporting V2V, V2I, and I2I communications for safety applications, and the ETC/ETC 2.0 band (5770–5850 MHz) used for Electronic Toll Collection systems, including the advanced ETC 2.0 that integrates additional data services. Seven Frequency Division Duplexing (FDD) channels within the ETC/ETC 2.0 band manage communications at toll booths and support broader ETC 2.0 applications. Notably, in the U.S., the 755.5–764.5 MHz frequency range is not part of the traditional UNII bands and is typically allocated for other services, whereas the 5770–5850 MHz corresponds to the UNII-3 band [27].

1.4 Singapore 5875–5925 MHz

In Singapore, the Infocomm Media Development Authority (IMDA) redefined the framework for ITS in 2017 by allocating specific segments of the 5.9 GHz band (5875 MHz–5925 MHz) for various ITS functions [16]. The spectrum divisions are meticulously categorized: 5875–5885 MHz is earmarked for vehicle-to-vehicle (V2V) safety protocols, 5885–5895 MHz for control communications and WAVE Short Message Protocol (WSMP) operations, and 5895–5905 MHz alongside 5855–5875 MHz are allocated as multifunctional service channels for both governmental and private use. The 5905–5915 MHz range is designated for road pricing initiatives, and 5915–5925 MHz is allocated primarily for long-range communications, mostly for governmental applications. All devices using these bands must strictly adhere to IMDA's specified technical standards, which dictate emission power limits and modifications to the IEEE standards to ensure reliable, swift communications. Furthermore, Singapore's spectrum policy allows vehicular on-board units (OBUs) to operate without licenses, while other installations might require specific licenses, with fees adjusted based on whether the usage is shared or exclusive [5].

1.5 Australia 5855–5925 MHz

In Australia, the regulatory set by Australian Communications and Media Authority (ACMA) for V2X technologies is currently under development, with no specific mandate in effect yet [20]. Guidance and alignment of transport policies across the nation are provided by Austroads, a government advisory body comprising members from all Australian states and New Zealand. The Australian Road Research Board (ARRB) supports these efforts through research aimed at enhancing road safety and efficiency. The Australian Communications and Media Authority (ACMA) has made available radio frequency spectrum in the 5.9 GHz band for use by ITS in Australia through the ITS Class License. The ACMA specifies the use of the 5855–5925 MHz spectrum band for ITS under the Radio communications (Intelligent Transport System) Class License 2017. This spectrum is segmented into seven 10 MHz channels, with 5855–5875 MHz allocated for non-safety ITS applications, 5875–5895 MHz for safety-related applications, and 5905–5925 MHz reserved for future uses. Each ITS station operating within these bands must comply with the ETSI Standard EN 302 571 and adhere to a maximum EIRP of 23 dBm/MHz, allowing some flexibility for minor modifications. This structured yet adaptable approach aids in integrating advanced vehicular communication technologies within Australia's regulatory landscape [5].

1.6 South Korea 5855–5925 MHz

In South Korea, the Telecommunications Technology Association (TTA) documented Dedicated Short-Range Communications (DSRC) in the 5.8 GHz band between Road-Side Units (RSUs) and On-Board Units (OBUs) back in 2006. Building on this foundation, the Ministry of Science and Information and Communications Technology (MSIT) allocated the 5855–5925 MHz band for Cooperative Intelligent Transport Systems (C-ITS) applications in 2016. This strategic allocation was segmented into seven 10 MHz channels to optimize the spectrum for various uses. Specifically, the 5895–5905 MHz segment serves as the Control Channel (CCH), responsible for managing and coordinating communication flows within the C-ITS network. The other channels function as Service Channels (SCH), supporting a mix of safety and non-safety applications. The spectrum policy in South Korea is notably technology-neutral, allowing the use of any radio technology that meets the established standards. The specific allocations within the 5855–5925 MHz range include 5855–5875 MHz for LTE-V2X, 5875–5895 MHz as the guard and experiment band, and 5895–5915 MHz for DSRC. This approach ensures that the spectrum use is efficient and adaptable to various transportation and communication needs [5].

1.7 China 5905–5925 MHz

In China, the frequency spectrum specifically al-located for Intelligent Transport Systems (ITS) comprises 20 MHz in the 5.9 GHz band, focusing on the 5905–5925 MHz range [4]. In 2018, the Bureau of Radio Regulation (BRR), in collaboration with the State Radio Regulation of China (SRRC) and the Telematics Industry Application Alliance (TIAA), undertook comprehensive studies to develop a detailed ITS spectrum policy. Differing from other nations, China has opted for Cellular Vehicle-to-Everything communications C-V2X as the sole technology for ITS safety applications. This decision was solidified after extensive research and trials, leading to the Ministry of Industry and Information Technology (MIIT) regulating this frequency band specifically for the Internet of Vehicles (IoV), utilizing LTE-V2X technology to significantly enhance vehicular communication and safety. The MIIT's Bureau of Radio Regulation (BRR) plays a crucial role in the ongoing planning and evaluation of spectrum needs for ITS services, ensuring the coexistence of various systems and effective spectrum management. This strategic approach facilitates advanced vehicular communications while ensuring compatibility and efficiency across different technological platforms [5].

2 Obscure Technologies Operating in the V2X Band

Each country manages its spectrum differently, allowing for a variety of applications that can coexist within the designated V2X frequency bands. This introduction sets the stage for a detailed country by country discussion, exploring how various regions accommodate these lesser-known uses of the V2X spectrum.

2.1 EU/UK

The frequency band 5855–5935 MHz allocated for V2X communication has obscure technology operating in its band. **Fixed-Satellite Service (FSS)** operate between 5850 MHz–5925 MHz bandwidth. FSS refers to a type of satellite communication service where satellite systems and ground stations (known as Earth stations) are used in fixed locations on the Earth's surface to communicate with satellites in orbit. This service is specifically designated for Earth-to-space communications, meaning it primarily involves transmissions from Earth stations up to the satellites. Guidance for the harmonized use and coordination of **Maritime Broadband Radio (MBR)** systems on board ships and offshore platforms operating within the frequency bands 5852–5872. MBR is where high-speed digital communication and data transfer are essential for effective and safe operations. In addition the Frequencies 5900–5950 kHz has been allocated with additional permissions, meaning it has primary allocations, but other services can also use it under certain conditions. **Fixed Service (in all three ITU Regions)**: This service typically involves communications between fixed points and is allowed globally in this frequency band. **Land Mobile Service (in Region 1)**: This refers to services used by vehicles or portable units on land. **Mobile except Aeronautical Mobile (R) Service (in Regions 2 and 3)**: This covers mobile services excluding aircraft-based communication [13].

2.2 USA

The frequency band 5895–5925 MHz allocated for V2X communication has obscure Technology operating in its band regulations governing the use of certain frequency bands by the **non-Federal Fixed-Satellite Service (FSS)** [15]. With the 5850–5925 MHz (Earth-to-space): This band is used for communications from Earth stations to satellites. Within the 5650–5925 MHz band The military has been given permission to use **Radio Location Service** this is a type of radio service used for determining the position, velocity, or characteristics of objects, by means of the propagation properties of radio waves. Radiolocation involves technologies such as radar and can be utilized for a range of applications including navigation, air traffic control, and maritime vessel tracking [11].

2.3 Japan

In exploring the current utilization of the 5770–5850 MHz and 755.5–764.5 MHz frequency bands, it becomes evident that their usage extends beyond V2X applications. Notably, the **FIXED-SATELLITE (Earth-to-space) services** within these bands are allocated for communications from Earth to satellites. This illustrates the diverse technological implementations within the same frequency spectrum, showcasing a blend of terrestrial and extraterrestrial communication capabilities [27].

2.4 Singapore

In Singapore 5875–5925 MHz frequency bands are predominantly dedicated to ITS and C-V2X technologies. However, there is potential for overlap with **satellite communication services** [1].

2.5 South Korea

In South Korea, the 5855–5925 MHz V2X frequency bands are predominantly dedicated to ITS and C-V2X technologies. However, there is potential for overlap with **satellite communication services**. In addition the applications for this technology is done in a neutral manner, meaning, any radio technology can be used in this spectrum as far as the technology complies with the corresponding regulations [1].

2.6 China

In China 5905–5925 frequency bands are predominantly dedicated to ITS and C-V2X technologies. However, there is potential for overlap with satellite communication services. China has given the allocation of the 6425–7125 MHz frequency band for International Mobile Telecommunications (IMT), which includes 5G/6G [6,22].

3 Technologies in Adjacent Band that Can Cause Interference on V2X

Adjacent bands are crucial for spectrum management as they can influence or be influenced by the operations within the primary band due to their proximity. Effective management of adjacent bands is essential to prevent interference, ensuring that each service within these bands operates efficiently without disrupting nearby spectrum users. This involves implementing technical measures, such as guard bands or specific transmission limits, to maintain clear and reliable communication channels across different services and technologies.

3.1 EU/UK

In the European Union, the frequency band designated for ITS is 5855 MHz to 5925 MHz. The adjacent bands to this ITS-dedicated spectrum are generally used as follows: Lower Adjacent Band (Below 5855 MHz) 5725–5855 MHz: This band is commonly utilized for **Wi-Fi and other Radio Local Area Network (RLAN) applications** under the regulations for unlicensed use. It supports various wireless communications technologies that require broad bandwidth and are essential for consumer and commercial connectivity. The Upper Adjacent Band (Above 5925 MHz) is 5925–6425 MHz: Recently, this range has been opened up for the new **Wi-Fi 6E** standard in many parts of the world, including the EU. Wi-Fi 6E extends existing Wi-Fi into the 6 GHz band, providing additional spectrum to alleviate congestion in existing bands, offering wider channels, and improving data throughput rates with less interference [3].

3.2 USA

In the lower band the FCC has reallocated the lower 45 MHz 5850–5895 MHz of the 5.9 GHz band for unlicensed uses, such as **Wi-Fi**. This means that this portion of the spectrum can be used for various wireless communications that do not require a license, which includes Wi-Fi networks. The unlicensed operations are allowed indoors with specific power and technical limitations to prevent interference with other services using adjacent frequencies. In the upper band recently, this range has been increasingly considered for **Wi-Fi 6E** deployment, which extends Wi-Fi into the 6 GHz band. The FCC has opened up the lower part of the 6 GHz band (5925–6425 MHz) for unlicensed use, which allows for more robust indoor and outdoor Wi-Fi applications. The spectrum from 6425 MHz up to 7125 MHz is also under consideration for additional unlicensed use as well as other potential future broadband services [8,21,24].

3.3 Japan

In Japan, the ITS band is specifically allocated around 5.9 GHz, particularly from 5770–5850 MHz for Electronic Toll Collection (ETC) and related ITS communications and 755.5–764.5 is related to more standard ITS. Here's how the adjacent bands are generally utilized: Lower Adjacent Band (Below 5770 MHz) 5725–5770 MHz: This segment is typically used for applications such as **Wi-Fi and other radio local area network (RLAN) services**. It is part of the spectrum allocated for unlicensed use, supporting various consumer and business wireless applications [27].

3.4 Australia

In Australia, the ITS band allocated from 5855 MHz to 5925 MHz. Lower Adjacent Band (Below 5855 MHz) 5825–5855 MHz: This segment is often used for **wireless access systems and other similar applications**. It may also be allocated for additional wireless communication services, depending on the specific national spectrum plan. Upper Adjacent Band (Above 5925 MHz) 5925–6425 MHz: This range is increasingly being considered for the expansion of Wi-Fi services under the new **Wi-Fi 6E** specifications, which extend Wi-Fi into the 6 GHz band, allowing for more extensive channels and higher throughput with reduced interference. The 5725–5850 MHz and 5925–6425 MHz bands mentioned refer to frequency ranges allocated for Radio Local Area Networks (RLANs) under the IEEE 802.11 series of standards, which include Wi-Fi technologies [14].

3.5 Singapore

In Singapore, the frequency bands adjacent to the 5875–5925 MHz range, used for ITS, are utilized as follows: Lower Adjacent Band (5725–5875 MHz) ISM Band: This band is designated for **Industrial, Scientific, and Medical (ISM) applications**. ISM bands are typically used for various unlicensed purposes that include industrial controls, scientific experiments, and medical equipment. In some regions, this band also supports Wi-Fi networks under specific conditions, such as reduced power limits to minimize interference. Higher Adjacent Band (5925–6425 MHz): **Wi-Fi 6E**. The segment from 5925 MHz onwards is part of the newly allocated spectrum for Wi-Fi 6E in Singapore [7].

3.6 South Korea

In South Korea, the ITS band is allocated in the 5.9 GHz range, specifically from 5850 MHz to 5925 MHz. Lower Adjacent Band (Below 5850 MHz): Typically used for other communication services, which may include additional allocations for **mobile services or fixed satellite services**, depending on South Korea's spectrum planning. Upper Adjacent Band (Above 5925 MHz): Increasingly considered and allocated for expanded Wi-Fi capabilities under the **Wi-Fi 6E** standard, extending into the 6 GHz band. This allows for broader channels and higher throughput with less interference, benefiting both consumer and industrial applications [23].

3.7 China

In China, the adjacent bands to the 5905–5925 MHz segment, which is part of the 5.9 GHz range allocated for ITS, are as follows: Lower Adjacent Band (below 5855 MHz): This range typically includes other communication services, such **mobile services and fixed satellite services**. Specific allocations can vary, often including portions reserved for governmental and military uses, depending on the country's spectrum planning policies. Upper Adjacent Band (above 5925 MHz): This band is increasingly being considered for expanded Wi-Fi capabilities under the **Wi-Fi 6E** standard, which extends into the 6 GHz range. The Wi-Fi 6E standard allows for additional channels at higher frequencies [17].

4 Mitigation Techniques Against U-NII-4 Interference

To address U-NII-4 interference in a realizable way that road authorities could implement immediately, we performed two studies, one that recommends a guard band spacing, another that recommends retrofitting RF in-line hardware.

4.1 Rechannelization/Gaurd Band Spacing

This study investigates the effects of increasing the guard band size of the lower 5.9 GHz DSRC band on the adjacent channel interference from Unlicensed National Information Infrastructure 4 band (U-NII-4) devices and to try and see if there is a significant decrease in the interference level. In this study, two different modes of DSRC communication were used to measure packet reception rate (PRR). The first mode was V2I communication. This was done by using an on-board unit OBU) and having it send dummy packets to a roadside unit (RSU). The second mode of communication used in the study was I2V communication. As opposed to the OBU sending the packets to the RSU, the RSU sent dummy packets to the OBU. Both the RSU and the OBU were controlled from a host computer. The Unlicensed National Information Infrastructure 4 band (U-NII-4) interferes used to cause the interference were all controlled by a custom interference management application (IMA) on the same host computer. Figure 2 shows the in-lab measurements.

Fig. 2. In lab testing with low-cost U-NII-4 interferers

In the IMA software, the central frequency and bandwidth of the interferer transmissions was able to be manipulated. The results from experimentation

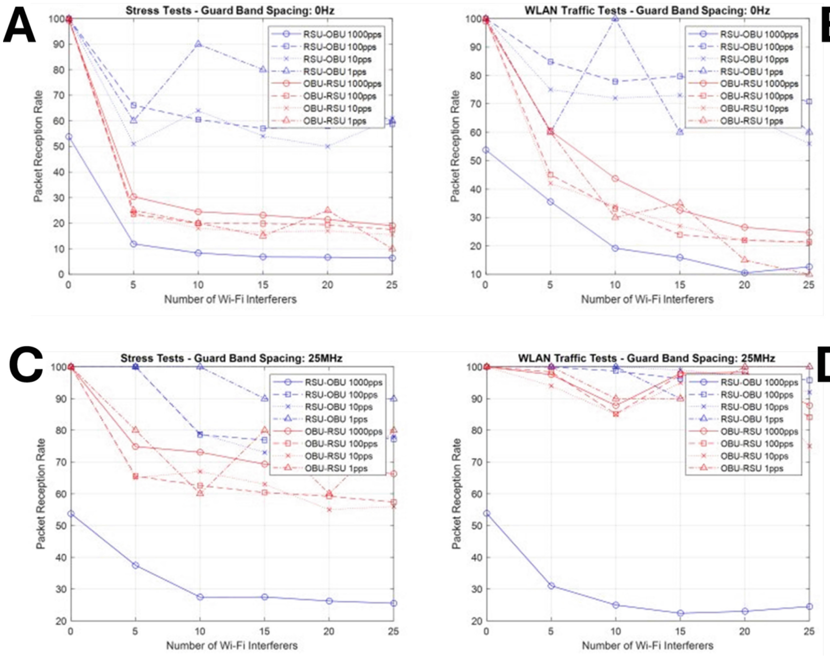

Fig. 3. I2V and V2I PRR when the DSRC band does not have a guard band. (A) Stress Test, (B) Emulated WLAN; I2V and V2I PRR when the DSRC band has a guard band of 25 MHz. (C) Stress Test, (D) Emulated WLAN;

can be shown to support the goal of this study. When comparing the results for the different guard band sizes tested the average packet reception rate is shown to have increased. The minimal guard band size is suggested to be 15 MHz to achieve above 80% PRR. Future works involving this study may focus on increasing the number of U-NII-4 devices used in experimentation or looking at the C-V2X band and trying to mitigate interference there. In Fig. 3 we show our findings.

4.2 In-Line RF Hardware

Past research has proved that interference by adjacent bands can result in thirty percent drop-in Packet Reception Rate (PRR) for I2V, and seventy percent for V2I. This results in less than ideal communication, raising concern for the safety of everyday travel. This study seeks to answer: What measures could be taken, using existing RF Technologies in line with the stock RSU antennas, to restore PRR of both I2V and V2I? This study finds possible solutions through RF filter design, and in-line attenuation techniques. Tested Infrastructure-to-Vehicle (I2V) and Vehicle-to-Infrastructure (V2I). This study finds possible solutions through attenuation integration. Attenuation increases PRR of V2I, while impacting range and I2V PRR. However, circulators can be used to bypass the

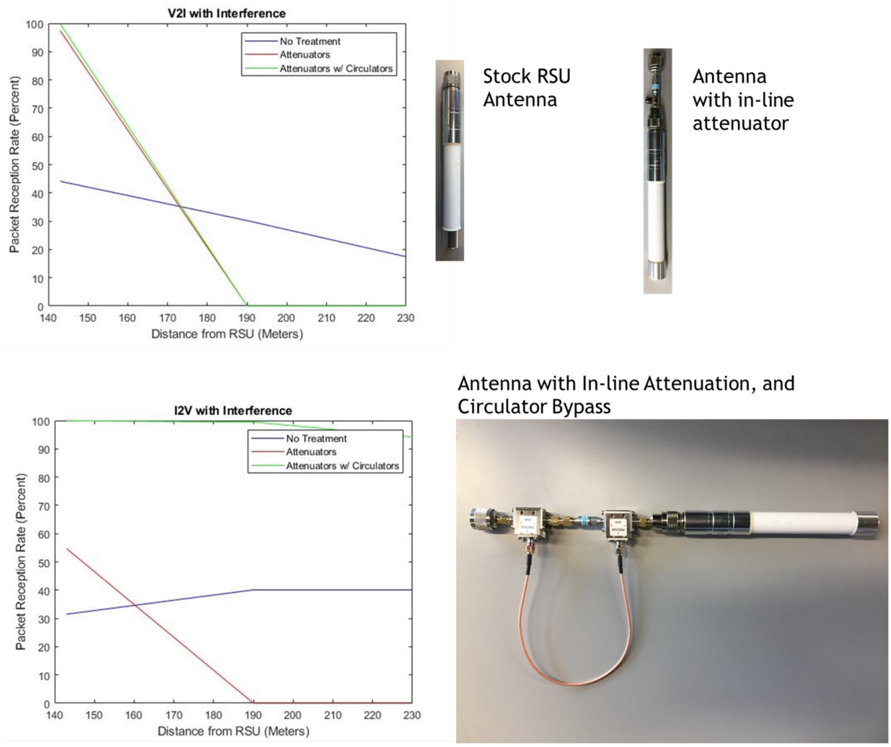

Fig. 4. Field distance measurements for V2I and I2V both with and without RF in-line mitigation treatments.

attenuation and result in higher I2V PRR. Contrary to expectations, V2I benefited from the surrounding interference, having higher PRR ratings. This study finds possible solutions through RF filter design, and in-line attenuation techniques. Future work will search for a cheap to fabricate RF filter solution. In Fig. 4 we show our findings.

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