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Report for Project #355:

Rethinking Connected Vehicles for Spectrum Scarcity

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1. Problem

In 2019 and 2020, the U.S. Government was wrestling with a difficult spectrum issue that unfortunately and sometimes needlessly pitted those who care about connected and autonomous vehicles against those who care about communications networks such as Wi-Fi and cellular. Twenty years before, 75 MHz of spectrum had been allocated to Intelligent Transportation Systems (ITS). Some of that spectrum was particularly well suited for the next generation of Wi-Fi technology (Wi-Fi 6), which would greatly benefit from primary or co-primary access to160 MHz of contiguous unlicensed spectrum. The higher data rates and lower latencies made possible by Wi-Fi 6 could be highly valuable in some sectors.

The issue could have been addressed effectively by bringing together a wide range of stakeholders and experts, as we proposed in [5, 6]. This would include federal agencies such as the Federal Communications Commission (FCC), the Department of Transportation (DoT), and the National Telecommunications and Information Administration (NTIA), as well as leaders from state and local government agencies (which play a critical role in infrastructure deployment), the cellular industry, the automobile industry, university experts, and more. Instead, the decision was made in silos, without access to all of the information and analysis that such a decision deserved [8, 9]. This is similar to the process that in recent years has led to highly problematic and unnecessary disputes over spectrum for global positioning systems (GPS), and later for airplane altimeters.

This process led to a vote of the FCC in December 2020, in which FCC Commissioners chose to meet the needs of the emerging Wi-Fi technology, over the explicit objections of DoT. In May of 2021, new U.S. spectrum regulations for ITS were officially adopted (when those regulations were published in the federal register). The U.S. reduced the spectrum allocated for ITS from 75 MHz to 30 MHz, allowed unlicensed devices in the adjacent band that may cause adjacent channel interference to connected vehicles in some situations, changed the technology allowed to use the ITS band from Dedicated Short-Range Communications (DSRC) to Cellular Vehicle-to-everything (C-V2X), and ended testing of spectrum sharing between connected vehicles and other types of technology.

It is certainly possible to meet the communications needs of both the next generation of Wi-Fi and connected and autonomous vehicles. To achieve that result, the process cannot stop with the spectrum policy changes made in 2021. This research addresses possible next steps.

Some of the next steps involve seeking new solutions to accommodate spectrum scarcity. These will be discussed in the next few sections of this report.

In addition to the potential problems posed by limited spectrum availability, there is also the problem of adjacent channel interference. These problems can be especially acute when spectrum rules change, such as when the ITS band suddenly became adjacent to an unlicensed band in 2021 as described above. This research also considered spectrum policies that deal with that problem, as is also described below. We ultimately filed formal comments with the FCC [1], which have received attention in the community and the press [2].

This is part of ongoing research at CMU that has been exploring spectrum management policies and wireless technologies for connected and autonomous vehicles, including both the actual spectrum policies for ITS spectrum and the process of creating those spectrum policies. This research will continue.

2. Approach

As of today, connected vehicles have access to the 30 MHz ITS band, 10 MHz of which must accommodate adjacent channel interference from unlicensed devices. There is debate over whether that is enough spectrum to meet the near-term needs of connected vehicles. Some industry groups have been trying to prioritize, to determine which communications traffic will be carried and which will not (e.g. [22, 23]). In the longer term, it is likely that those needs will increase as autonomous vehicles move closer to widescale deployment, and as new kinds of applications and services emerge that make use of connected vehicle technology. It is likely that one part of meeting the needs of connected and autonomous vehicles in the future will be supplementing the 30 MHz ITS band with other spectrum.

In this particular project, we focus on ways that C-V2X can share spectrum with unlicensed devices, such as Wi-Fi. This could open up several bands with useful physical properties, including but not limited to the spectrum that was recently removed from the ITS band. There is reason to believe that this approach might be able to meet the needs of both connected and autonomous vehicles and unlicensed devices will achieving high levels of spectrum efficiency. Most (but certainly not all) unlicensed devices are placed in locations from which the path loss to the closest vehicle is large. Unlicensed devices such as Wi-Fi transceivers also transmit sporadically, so there are many spatial and temporal holes in the utilization of unlicensed bands. Our research [10, 12] before the recent change in spectrum regulations has shown that sharing spectrum between an earlier version of connected vehicle technology (DSRC) and an earlier version of Wi-Fi technology is considerably more spectrally efficient than the approach that the FCC had taken, i.e. establishing entirely separate allocations for each.

However, Wi-Fi 6 is somewhat different from its predecessors, and C-V2X is entirely different from DSRC. For example, C-V2X uses semi-persistent scheduling, whereas DSRC uses a listen-before-talk (LBT) approach. These technologies would not share spectrum well as currently designed. In this project, we redesigned core resource management algorithms for these technologies in a number of ways that we hypothesize will enable efficient coexistence. In subsequent research, we will test that hypothesis be seeing which of these spectrum-sharing approaches, if any, can meet the communications needs of both connected and autonomous vehicles and Wi-Fi more efficiently than not sharing.

3. Methodology

We have begun developing simulation tools to assess these new kinds of spectrum arrangements. We are developing this simulator in MATLAB, building on an approach invented at the

University of Bologna [24]. We will simulate the transmission of packets exchanged between Wi-Fi devices, the transmission of packets between vehicle and vehicle and between vehicle and roadside infrastructure via C-V2X, the movement of vehicles around a city, the attenuation of signals, and much more. We will simulate standard versions of these technologies, and we will simulate multiple novel versions of the algorithms involved in spectrum access that we believe have the potential for effective and efficient spectrum sharing. We will run these simulations in a wide variety of scenarios. Scenarios differ with respect to population density (rural to urban), road type (e.g. dense urban grid versus interstate highway), vehicle mobility, safety and non-safety applications in use, connected vehicle penetration, autonomous vehicle penetration, cellular technology (4G or 5G), unlicensed technology, and much more.

4. Conclusions and Recommendations

Further changes in spectrum policy will be needed to meet the needs of connected vehicles. To meet long term needs, we should look to spectrum beyond the 30 MHz ITS band that is available today. One reasonable approach is to promote sharing with unlicensed devices – an approach that may have been abandoned prematurely by the FCC. It is too early to reach conclusions as to whether the new approaches we have devised in this research can meet the quality-of-service needs of both connected and autonomous vehicles and unlicensed devices. We will continue the research to find out.

In addition to the issue above, we also considered the problem of adjacent channel interference in this research. We recommended that the FCC adopt a new policy which states that at least for the next five years, any proceeding that considers a fundamental change in how a band of spectrum will be used should also consider adoption of a harm claim threshold [1, 2].

5 Expanding the Transportation Workforce

This project has sought to expand the transportation workforce by contributing to the education of engineers regarding connected vehicles. We have presented some material from this work in graduate courses at Carnegie Mellon University. This research has also provided opportunities for one Ph.D. student, one MS student, and one post-doctoral Fellow at Carnegie Mellon University to learn about connected vehicles, and related transportation issues.

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