Spectrum for Connected Vehicles

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1 Introduction

This ongoing research has been exploring wireless technologies and spectrum policies to determine how to effectively and efficiently meet the communications needs of connected and autonomous vehicles. This includes choosing an amount of spectrum for connected vehicles, a technology, and a set of coexistence rules.

In the midst of the one-year period coved under Project 322, U.S. spectrum policy regarding connected vehicles took a dramatic new turn, when the Federal Communications Commission (FCC) adopted a new set of rules regarding Intelligent Transportation Systems (ITS) spectrum. This move makes our ongoing research into spectrum policy for connected vehicles more important than ever, but it has changed the nature of that research. Proponents of connected and automated vehicles are now scrambling to determine whether requirements can be met under the new rules, and if so, how.

Until this year, the U.S. had allocated 75 MHz of spectrum to connected vehicles in the ITS band, had selected Dedicated Short-Range Communications (DSRC) as the only technology allowed in this spectrum band, and was in the midst of experiments to assess sharing between DSRC-based connected vehicles and unlicensed devices in a manner designed to protect safety-critical connected vehicle communications. Thus, as the year began, our research was addressing questions such as whether DSRC was the best technology, whether 75 MHz was the right amount of spectrum to allocate for ITS, and whether the 75 MHz ITS band should be shared. We made useful advances, as will be discussed below.

In new rules (which the Commission first voted on in Dec. 2020 and officially adopted in May 2021 when they were published in the federal register), the FCC decided to phase out DSRC and replace it with cellular vehicle-to-everything (C-V2X), reduce the amount of spectrum dedicated exclusively for connected vehicles by 60%, from 75 MHz to 30 MHz, and abandon consideration of the two leading spectrum-sharing proposals. Since the FCC has been transitioning to new leadership during the 2020-21 year, there is still a chance that they will revisit some of these decisions, but this is currently the official policy of the U.S.

In the wake of the recent FCC proceeding, the most important issue for connected vehicles is the extent to which needs can be met with a 30 MHz ITS band, and what to do if this is not the case. Some in the industry have concluded that only a portion of anticipated connected vehicle communications can be supported, and have begun the difficult process of prioritizing.[1] As discussed below, in response to this new policy, we have begun the process of considering ways to expand capacity for connected vehicle communications beyond these 30 MHz, in part through spectrum sharing.

Finally, the manner in which the FCC changed its policies for connected vehicles over the explicit objections of the Department of Transportation revealed a failure in the spectrum policy-making process, regardless of whether the final decision was a good one or a bad one. We have proposed ways to improve this process. This too will be discussed below.

[1] ITS America, The Future of V2X: 30 MHz Application Map, 2021.

The following three sections summarize contributions in these three areas. Section 2 describes a simulation study of C-V2X and DSRC based on application layer metrics. Section 3 describes a simulation study of traffic that is carried over a combination of spectrum exclusively allocated for connected vehicles and spectrum that is shared with other devices. Section 4 describes contributions to the policy-making process, including a new proposal. Our contributions to transportation workforce development are summarized briefly in Section 5. Section 6 shows that products of this work include publications and presentations within the last year [1 - 9], which build on our previous products such as [10 - 24].

2. Assessing C-V2X and DSRC with Application-Layer Metrics

Problem

To determine which technology is better between DSRC, C-V2X mode 3, and C-V2X mode 4, and to determine how much spectrum to allocate, a regulator needs to understand how these two decisions will affect real-life outcomes. Past researchers have typically tried to define network-layer quality of service metrics that they assume must be met for all applications. For example, if some safety applications require a packet loss rate of 1%, some require a latency of 100 ms, and some require a range of 300 meters, then the system must support a 1% loss rate and 100 ms latency at a distance of 100 ms. We believe this method is inherently misleading, and have been seeking alternatives, with an initial focus on use of such metrics for selecting the best technology.

Approach

Our focus for these comparisons was on application-layer outcomes. Some people argue that the most important outcomes relate to roadway safety, e.g. crash prevention. Thus, our approach was to use extensive simulation to determine how spectrum decisions affect the ability of select important safety-related applications to prevent crashes. We focused initially on Forward Collision Warning application (FCW). This application warns a driver when she is at risk of hitting the car immediately in front. An application can provide this warning without any sensors as long as vehicles exchange information about position, velocity and acceleration. When network-level quality-of-service is poor, this causes warning lights to turn on at suboptimal times, which in turn affects driver behavior and ultimately crash probability. We can therefore explore how spectrum policy decisions affect this application's ability to prevent crashes.

Methodology

Our method was to develop and use simulation software, which in this case can mimic the behavior of the three major connected vehicles communications protocols: DSRC, C-V2X mode 3, and C-V2X mode 4. In addition to simulating the transfer of packets, we simulate the movement of cars along a road, the behavior of applications that exchange packets over DSRC and C-V2X and use the results to warn drivers about dangers, and the reaction of drivers. To achieve the latter, this software is fed by data collected from previous connected-vehicle deployments and from emulators used by real human subjects, so that we can incorporate into the simulation reasonable models of driver behavior under normal steady-state conditions and when confronted with the risk of collision. The simulation is also fed by data on the real movement of cars derived from trials conducted in Michigan with support from the Department of Transportation.

We consider a connected vehicle system to be working well when a driver using this system responds to warnings of impending danger at about the same time as the driver of a car that has perfect information, where perfect means that packets are transmitted with zero loss and zero latency. The more loss and latency occur, the more this will affect a driver's assessment of collision risk.

Findings

In scenarios simulated to date, we have seen better application-layer performance with C-V2X than with DSRC in some scenarios, and little difference in others, where good application-layer performance means the application has sufficiently recent information to assess collision risk reasonably well. However, the differences we observe do not necessarily translate to significantly better safety outcomes. When distances between cars is small, network-layer quality of service is similar for both technologies. When distances are great, we see greater differences in network-layer performance, and thus greater differences in risk assessments, but this matters less at the application layer because larger distances generally mean low risk of crash anyway. We presented these results at a Transportation Research Board (TRB) Transit Safety and Security Conference [4].

Conclusions

At least for Forward Collision Warning, we found C-V2X to be as good or better than DSRC in all scenarios considered, which is an argument to adopt C-V2X. However, the advantages of C-V2X that we observed are more modest than other researchers have reported, because we have considered the benefits at the application layer where it actually matters for safety, rather than at the network layer.

Recommendations

Our results are consistent with the FCC's recent decision about technology, although the safety implications of that decision may be overstated, at least in the scenarios we considered. Had the FCC not selected a technology, we would recommend making a similar comparison with other applications and in other scenarios. In the wake of that recent selection of C-V2X, our most important recommendation is that application-layer quality of service metrics should be among the assessment criteria used in the future when making these important decisions regarding both wireless technology and spectrum policy more gnerally.

3. The Potential Role of Spectrum Sharing

Problem

As the spectrum available for connected vehicle communications in the U.S. falls from 75 MHz to 30 MHz due to the FCC's recent decision, assuming that decision is not reversed, there is a risk that not all communications can be supported at the desired quality of service. This could adversely affect roadway safety, as well as other goals for connected vehicles, including reduction in traffic congestion, energy consumption, and environmental impact, as well as provision of new value-added services to drivers and passengers, and future support for connected vehicles.

Approach

We have already shown that connected vehicles can share spectrum with unlicensed devices such as Wi-Fi quite well in some cases, at least for non-safety-critical communications for which throughput is the most important measure of quality of service [19, 21]. This is especially true for in-door Wi-Fi, but sharing was also efficient for out-door fixed Wi-Fi. (Mobile Wi-Fi is more problematic.) This is an important result by itself for non-safety-critical traffic, and it suggests there may even be opportunities for safety-critical traffic when there are no outdoor Wi-Fi hotspots nearby. Thus, we expect that there will be some times and locations when the more important safety-critical communications must occur in the ITS band, but possibly other times and locations when shared spectrum can be quite useful as well.

Of course, this same challenge of advancing connected vehicles with appropriate policies is not unique to the United States. This year the PI also presented our results to date on spectrum sharing between unlicensed devices and non-safety-critical connected vehicle communications internationally, as an invited keynote speaker at a workshop of the International Telecommunications Union (ITU), which is the telecom arm of the United Nations [3, 27].

Our approach beginning this year and continuing beyond will be to consider C-V2X systems that supplement the 30 MHz ITS band with other spectrum bands, where some of those other bands may be shared with other kinds of wireless systems. Shared bands can be used for communications traffic that is able to tolerate more interference while still meeting quality of service objectives, and traffic for which failure to meet quality of service requirements is less significant (i.e. does not affect crash prevention).

Methodology

We have begun the process of developing simulation tools to assess these new kinds of spectrum arrangements. We will simulate the movement of vehicles around a city, the transmission of packets from vehicle to vehicle via C-V2X, the more important safety applications that run over C-V2X, and novel approaches for deciding which packets and packet streams will be carried in the ITS band or one of the alternative spectrum bands.

Conclusions

The FCC may have been premature when it abandoned its study of spectrum sharing with connected vehicles, although after the recent decision it would now have to shift those experiments from DSRC to C-V2X. More research is needed.

4 A New Approach for Policy Advancement

Problem

Many government agencies are involved in establishing policies for connected vehicles. At the federal level, this includes the Federal Communications Commission, the Department of Transportation, the National Telecommunications and Information Administration, and sometimes the White House. State and local government agencies are also critically important, since they are likely to be responsible for much of the infrastructure. The automotive and telecommunications industries are both important as well. Most of those voices were not heard in this process.

In this case, the FCC chose a spectrum policy over the loud objections of the Department of Transportation (DoT), and with limited involvement from other players. The FCC argued that this decision was in the best interests of the telecommunications sector, since it would clear a path for the next generation of Wi-Fi. DoT argued that the decision was contrary to the goal of safe and efficient transportation. The American people care about both telecommunications and transportation, not either one in isolation, but no single agency seemed to weigh both of these objectives with the seriousness that they deserve. Moreover, both agencies put forth very limited evidence in support of their respective cases [23]. The nation needs a process that considers what is in the broader public interest from all perspectives, and that is evidence-based.

Approach

We considered how the federal government has addressed other issues that transcend the mission and authority of a single federal agency, from construction of the U.S. National broadband Plan, to the post-9/11 formation of communications systems for federal, state and local first responders, to the debate over spectrum for global positioning systems (GPS). We sought lessons from both successes and failures of the past.

Recommendations

We have proposed a new process by which effective policies can be produced. Rather than allowing different players such as the FCC and the DoT to develop policies related to connected vehicles piecemeal, we believe the federal government should establish an interagency task force with multiple federal agencies. This task force would then convene players who are not part of the federal government, including state and local governments, the automobile industry, the telecommunications industry, consumer protection and privacy groups, and outside experts. This task force would establish a vision of applications that will be supported for both connected and autonomous vehicles, select a standard, develop an infrastructure strategy including the roles for both government agencies and commercial operators, create appropriate spectrum rules, and seed deployment. A paper describing this approach [1] was published as part of the *Day One Project,* which showcases promising technology policies for the coming years. It has also been presented publicly [7], and discussed in the press [25].

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 a graduate course on Wireless Policy at Carnegie Mellon University, and in a seminar for students and faculty at multiple universities along with other researchers [7]. This research has also involved one current Ph.D. student at Carnegie Mellon University, and one former Ph.D. student at Carnegie Mellon University.

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