Sharing Connected Vehicle Infrastructure for Safety Applications, Smart City and Internet Access

FINAL RESEARCH REPORT

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1 Problem Description

Safety vehicle-to-infrastructure (V2I) applications could prevent many fatalities and injuries, but this requires extensive deployment of infrastructure. States and localities may lack the funds for deployment and operation of these roadside devices, which could cost billions of dollars. Communications infrastructure is also needed for smart city applications, e.g. to allow low-power sensors embedded in bridges to send their stress readings back to city collection sites. It might be possible to greatly reduce the infrastructure cost paid by government if some of the same infrastructure used to improve vehicular safety and support smarty city applications is also used to provide Internet access over DSRC-based vehicular networks.

There is no reason why passengers cannot use the capacity of vehicular networks to browse the web or stream movies when (and only when) that capacity is not needed for safety-related applications. Whenever this DSRC connectivity is available, it is a far less costly Internet access option than a cellular network. Indeed, with data from mobile devices doubling every 18 months, cellular providers are actively seeking new ways to offload traffic from macrocells when possible. However, use of vehicular networks for Internet access is only possible if roadside infrastructure exists that can serve as a gateway between the vehicular network and the Internet. Infrastructure for Internet access is different from infrastructure deployed for safety purposes, but perhaps similar enough to allow cost-effective sharing.

If the benefits of sharing infrastructure, then multiple policies and business arrangements become possible: (i) government can deploy infrastructure for safety and smart city purposes, and charge commercial Internet service providers (ISPs) that use it, (ii) government can get some of the infrastructure it needs at lower cost by leasing access from commercial ISPs, or (iii) government and commercial ISPs can establish public-private partnerships to manage shared infrastructure. Today, no one knows whether such arrangements would be cost-effective. The PI has previously addressed similar partnership opportunities for government agencies that must provide communications capabilities for firefighters, police, and other public safety purposes, e.g. (Hallahan and Peha, 2011; Peha, 2013). His research at CMU demonstrated that many billions of dollars could be saved through different forms of infrastructure sharing. Later, he co-authored the plan to turn this proposal into reality. Congress passed legislation to allocate $7 billion for this approach in 2012. However, that technology was quite different, so this approach may or may not work for transportation.

Infrastructure is not the only costly resource needed for connected vehicles. There is also spectrum. At the time 75 MHz of spectrum was first allocated to Intelligent Transportation Systems, (ITS) demand was relatively low for spectrum at those high frequencies. That is no longer the case. Other industries would now like to reclaim some of the ITS spectrum entirely, to share the ITS spectrum with connected vehicles, or a bit of both. The Federal Communications Commission (FCC) has an ongoing proceeding in which it is considering several such plans. We began consideration of spectrum decisions in this project.

2 Approach

The first objective was to determine cost savings from infrastructure sharing, when it is deployed by government agencies and shared with private parties. We considered a base-case scenario where the U.S. Department of Transportation (DOT) mandates vehicles to be equipped with connected vehicle technology for safety purposes, and the technology they choose is DSRC. Both assumptions are consistent with 2016 DOT proposals, although we may revisit these assumptions in future work. In our analysis, local and state governments deploy infrastructure of roadside units (RSUs) for safety, and those RSUs can be shared with Internet Service Providers (ISPs) for a fee, perhaps through some form of public-private partnership. ISPs have typically provided Internet access for users in vehicles via macrocellular networks. The volume of data from mobile Internet has been increasing sharply, and connected vehicles using V2V/V2I links could carry some Internet data at a lower cost than macrocellular networks can (Ligo et al. 2017). Therefore, ISPs could reduce cost by taking advantage of roadside units (RSUs) that serve as Internet gateways, rather than deploying cell towers alone. ISPs could deploy their own RSUs, or ISPs could share the ones deployed by governments, resulting in cost savings for the government.

Alternatively, governments may widely deploy other types of infrastructure that could be shared. In this project we considered the deployment of "smart" streetlights with communications capability, such as those used to aid services such as public safety, air quality monitoring, etc. Those streetlights may provide cheap access to power, poles and communications backhaul. They are typically available in more locations than safety RSUs.

A second specific objective of the project was to determine what pricing strategies governments should adopt to share their infrastructure. By sharing safety RSUs or streetlights, governments might charge adopt pricing strategies either to maximize either government savings or social welfare. In our model, we quantified the increase in overall social welfare by providing Internet access through shared RSUs, as well as the reduction in taxation needed to finance government infrastructure, and provided guidance to government agencies seeking to maximize either of these objectives, or some combination.

Another specific objective was to investigate the robustness of the results above with respect to the assumptions that are most likely to vary, are most uncertain or have the most impact. Some of those assumptions are expected to change over time, such as rates of Internet data and DSRC penetration in vehicles. With sharing of either safety RSUs or streetlights, we have found that nationwide social welfare plus the reduced burden of taxation are significantly higher than base estimates if either data rates or penetration increases as expected. Uncertainty in assumptions such as the cost of cell towers may also have an impact on results. The more expensive the cost of a tower, the higher is the cost savings to provide Internet access over DSRC RSUs. For example, land and legal costs can be major components, which vary by location.

A final objective was to assess how much spectrum should be made available for vehicular communications. The U.S Federal Communications Commission (FCC) has allocated 75 MHz of spectrum in 5.9 GHz (the so-called "ITS band") for DSRC V2V and V2I communications (Lansford, Kenney, and Ecclesine 2013; U.S. Federal Communications Commission 2004). The question of whether all that spectrum should be used exclusively by DSRC devices is hotly debated. For example, it has been proposed that part of the ITS band should be used exclusively by DSRC devices while unlicensed devices are allowed in the other part (Qualcomm 2013). For our analysis, we considered the scenario in which DSRC-based safety messages are transmitted over spectrum that is not shared for other types of communications, while additional spectrum is used to transmit DSRC-based communications other than safety (i.e., Internet data). First, we determined how much spectrum should be allocated to ITS, assuming the spectrum is only used for connected vehicles. For this, we sought to understand the social welfare obtained from ITS spectrum as a function of bandwidth, and how this compares to the opportunity cost of using the spectrum for something else. Second, we considered the possibility of sharing the spectrum between ITS and other kinds of devices on a co-equal basis, how this might affect the performance for all systems involved, and how efficient spectrum would be used when compared to other spectrum management paradigms.

3 Method

Our method is threefold: (i) collect extensive data from a large deployed vehicular networks in Portugal, (ii) develop a detailed packet-level network simulation using this data that shows the relationship between infrastructure deployment strategies and achievable throughput, and (iii) develop extensive engineering-economic models that relate costs and revenues to achievable throughputs and infrastructure strategies. Infrastructure strategies vary in number of roadside units per square km, and extent of sharing between infrastructure for safety and infrastructure for Internet access.

We have been developing packet-level simulation software that uses location data from more than 900 vehicles from Portugal, to simulate a mesh network comprised by DSRC-equipped vehicles that connect to roadside units (RSU) to gain access to the Internet. We use this simulation to estimate the rate of Internet data that can be carried through the DSRC channels not occupied by safety messages, under different conditions. To estimate economic gain as a function of throughput, we assume that mobile devices can use either cellular services or networks of connected vehicles, and that every bit carried on the vehicular network is one less bit on the cellular network. In a capacity-limited cellular network, a reduction of data from mobile devices that must be carried in the busy hour allows each cell tower to provide adequate capacity over a larger area, thereby reducing the number of costly towers that a cellular operator needs to cover a given region. We define the benefit of offload in a given scenario as the cost savings from reducing the number of cell towers. This is compared to the costs of DSRC RSUs, which quantity is assumed to be the one that maximizes the difference between benefits and costs.

To examine the impact of infrastructure sharing, we estimate costs of deploying one infrastructure for safety and one for Internet, and compare that with costs obtained with different forms and levels of infrastructure sharing. We estimate the cost difference between an individual RSU used for safety, an RSU used for Internet access and an RSU suitable for both uses, with different assumptions about shared backhaul, shared power, and more.

To consider the impact of spectrum policy, we designed the packet-level simulation to support different amounts of spectrum and three different types of sharing: one based on coexistence, and two based on cooperation. In practice, the more spectrum allocated for intelligent transportation systems, the more likely that spectrum will be shared. In some scenarios, some or all of the spectrum used for intelligent transportation systems may also be used by devices that share without cooperation, meaning that they are sources of interference and congestion. In other scenarios, these devices cooperate, perhaps relaying a packet from a moving vehicle to a roadside unit, in accordance with the technical standard.

4 Findings

The economic impact of infrastructure sharing depends in part on the pricing strategies that government agencies adopt. We derived the optimal strategy for a variety of scenarios and policy objectives. In particular, transportation agencies must decide whether their goal is maximizing government savings, or maximizing overall social welfare, where the latter includes the benefits of cheaper Internet access. If social welfare is to be maximized, governments would require ISPs to pay a smaller portion of the shared costs, which is good for Internet users but reduces government savings. However, one of our surprising findings is that the difference is not great, i.e. agencies that maximize government savings will still achieve reasonably high social welfare.

We then quantified the government savings and social welfare gains that are possible when an effective pricing strategy is employed. We found that there are tremendous cost advantages when government transportation agencies share infrastructure with providers of Internet access. For a nationwide deployment of DSRC-based safety RSUs, government savings would be about 23% of the investment in safety RSUs, greatly reducing the burden on state and local transportation agencies. However, those savings depend on location. For some locations, government savings can be up to 80%. For others, such as sparsely-populated rural areas, no savings are possible from sharing safety RSUs.

We also considered the possibilities of sharing “smart streetlights” with commercial ISPs instead of safety RSU. The primary advantage of smart streetlights is that there are a lot more of them, so it is easier to find one at a location of maximal benefit to ISPs. We find that this did not result in much greater government savings. However, it can yield much higher social welfare, because the benefits to ISPs and Internet users are greater with smart streetlights.

Naturally, all our estimates depend on our predictions for the future of various parameters, so there is always uncertainty. We found that results are reasonably robust. For example, we found that if a macrocell costs on average half of the base assumption, government savings are significantly less, and DSRC-based Internet access might be cost-effective in fewer locations than predicted with base case assumptions. On the other hand, we found that uncertainty in factors such as the cost of an Internet-only RSU and the cost to upgrade safety RSUs or streetlights have limited effect on nationwide results.

Finally, we made progress on the spectrum issues, although further work remains. We found that there are realistic scenarios where allocating spectrum far in excess of what is used for safety enhances social welfare, and there are also realistic scenarios where the amount currently allocated is too much. We continue to analyze the factors that affect the socially optimal allocation. Another specific objective related to spectrum use is to determine whether part of the ITS band allocated exclusively for DSRC devices should be shared with unlicensed devices, such as laptops, tablets and smartphones using Wi-Fi. The FCC issued a Notice of Proposed

Rulemaking (NPRM) to permit unlicensed devices in that band (U.S. Federal Communications Commission 2013). However, to date there has been no consensus on whether to share and the rules to be adopted if such sharing is allowed (Lansford et al. 2015). So far, we are finding that sharing of at least some (although not necessarily all) ITS spectrum with Wi-Fi unlicensed devices is highly efficient. In some realistic scenarios, we have found that vehicles and unlicensed devices using separate bands might require 50-100% more bandwidth than would be required to achieve the same average throughputs in shared spectrum. We continue to explore other scenarios.

5 Conclusions

In this research, we have identified an approach to infrastructure sharing between government transportation agencies and commercial ISPs that could benefit both, as well as Internet users and tax-payers. If DSRC technology becomes widespread, as it would under federal policies promulgated by the U.S. Department of Transportation in 2016, then the sharing strategies we propose could cover roughly a quarter of the cost of safety infrastructure, making the adoption of this potentially life-saving technology far more affordable, which may expand deployment and reduce the burden on tax-payers. In some regions, this approach can cover as much as 80% of the cost, while in others (i.e. rural areas), it is of little value. Such results inform policy, and are important when developing local, state and federal budgets. Of course, since the 2016 rules have not been adopted so far, government agencies cannot accept our results at face value, but they are illustrative of what is possible,

In addition, we have explored the pricing policies that government agencies might adopt in such arrangements, quantified the trade-offs implicit in pricing, and shown how optimal pricing varies from urban areas to rural areas. Our results will be of help to any government agencies who choose to share infrastructure.

In the federal level, our research has impact on the current debate about the use of spectrum for Intelligent Transportation Systems. While it has been recently proposed that spectrum is shared between vehicular and unlicensed devices, transportation authorities have concerns that such sharing may cause harmful interference to vehicular communications. Our ongoing research suggests that as long as safety messages are transmitted on exclusive spectrum, the FCC could allow vehicles and unlicensed devices to share spectrum for non-safety communications in a highly efficient way.

6 Recommendations

Based on our findings and conclusions, if the proposed plan to adopt DSRC goes forward, we recommend that government transportation agencies in urban and suburban regions actively explore partnerships with commercial ISPs before investing large amounts in infrastructure. Doing so could reduce both the cost of safety infrastructure and the cost of Internet infrastructure. We advise agencies in rural regions not to invest too much time in this endeavor.

Our results to date support the idea of sharing some (but perhaps not all) of the ITS spectrum with other kinds of devices. If such sharing leads to an unacceptable degradation of performance for connected vehicles, it appears to be more effective to allow DSRC to use spectrum currently available only to unlicensed devices than to prevent unlicensed devices from accessing spectrum available only to connected vehicles. In its proceeding, the FCC has not considered the idea of allowing DSRC devices and unlicensed devices to share both the ITS band and the adjacent unlicensed band, but our results show that this deserves consideration. Nevertheless, more research is needed in this area.

It is important to note that the research above assumes a DSRC mandate as proposed in 2016, and it is not clear whether the DSRC mandate will go forward. Further research is needed to determine whether these conclusions hold with alternative approaches, including the adoption of new C-V2X technology. Such research is inherently speculative at this point, since many critical decisions by the U.S. Department of Transportation, its state and local counterparts, and the technology standards bodies have not yet been made. The issues should be explored.

7 References

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8 Products

Published Papers

1. Alexandre Ligo and Jon M. Peha, "Cost-Effectiveness of Sharing Roadside Infrastructure for Internet of Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, Volume 19, Issue 7, July 2018, pp. 2362-2372. https://users.ece.cmu.edu/~peha/infrastructure_sharing_for_Internet_of_vehicles.pdf
2. Alexandre Ligo, Jon M. Peha, Pedro Ferreira and Joao Barros, "Throughput and Economics of DSRC-Based Internet of Vehicles," *IEEE Access*, vol. 6, pp. 7276–90, 2018. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8241368
3. Alexandre Ligo and Jon M. Peha, "Spectrum for Intelligent Transportation Systems: Allocation and Sharing," accepted to appear in *Proceedings of IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN),* Seoul, South Korea, October 2018.
4. Alexandre Ligo and Jon M. Peha, "Spectrum Policies for Intelligent Transportation Systems," *Proceedings of 45th Telecommunications Policy Research Conference (TPRC)*, Arlington, VA, September 2017. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2943688
5. Alexandre Ligo and Jon M. Peha, "Is It Cost-Effective to Share Roadside Infrastructure for Non-Safety Use?," *Proceedings of IEEE 85th Vehicular Technology Conference (VTC),* Sidney, Australia, June 2017. http://users.ece.cmu.edu/~peha/Sharing_Roadside_Infrastructure_VTC_2017.pdf

Public Presentations

1. Jon M. Peha, “Sharing Connected Vehicle Infrastructure Between Governments and Internet Service Providers,” presented at ASCE International Conference on Transportation & Development (ICTD), July 2018.
2. Jon M. Peha, “Smart City Technologies for Local Governments,” to be presented at Fall Conference of Townships, Boroughs & Authorities, Sept. 2018.
3. Jon M. Peha, “Connected Vehicles for Internet Access: Implications for Governments and ISPs,” to be presented at Traffic 21 Seminar, Oct. 2018,
4. Jon M. Peha, KEYNOTE: “Wireless Communication and Municipal Governments – Looking Forward,” Pennsylvania State Association of Boroughs, August 2017.
5. Alexandre Ligo and Jon M. Peha, "Spectrum Policies for Intelligent Transportation Systems," presented at *45th Telecommunications Policy Research Conference (TPRC)*, Arlington, VA, September 2017.

6. Alexandre K. Ligo, “Spectrum for Intelligent Transportation Systems: Allocation and Sharing,” to be presented in IEEE International Symposium on Dynamic Spectrum Access Networks, October 2018.
7. Alexandre Ligo, "Is It Cost-Effective to Share Roadside Infrastructure for Non-Safety Use?," presented at *IEEE 85th Vehicular Technology Conference (VTC),* Sidney, Australia, June 2017.