AVIN SPECIALIZED REPORTS

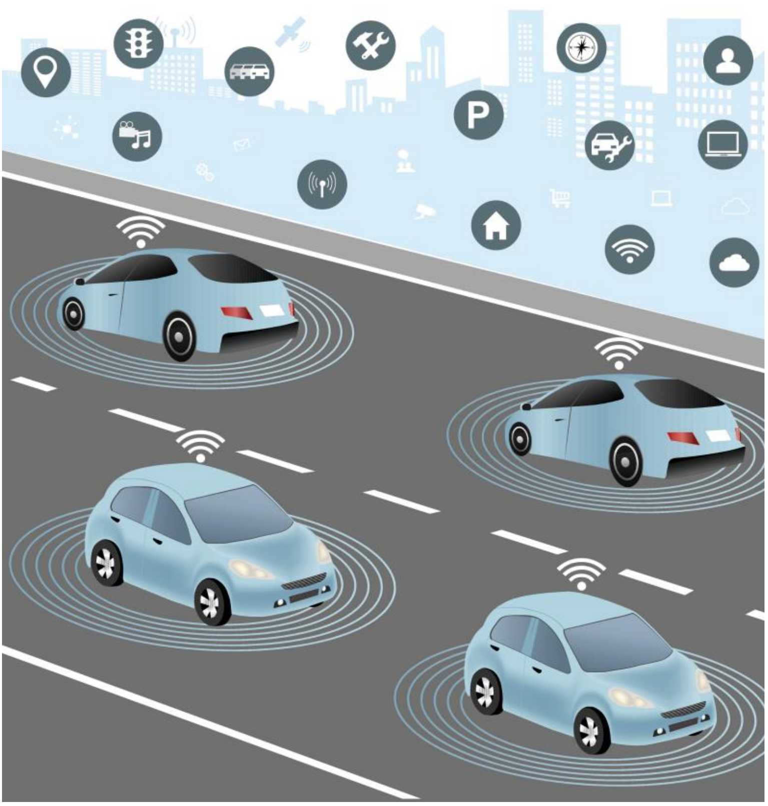
JULY 2019

OPPORTUNITIES FOR CONNECTED VEHICLES BEYOND TRANSPORTATION

Ontario Centres of Excellence
Where Next Happens

TABLE OF CONTENTS

INTRODUCTION



To reduce the number of road fatalities and augment safety on roads, connected vehicles (CVs) have been introduced to the automotive market. Through the exchange of safety alerts, CVs can have better awareness of their surroundings, resulting in avoided collisions and fewer fatalities on roads. Furthermore, through the exchange of traffic condition messages, CVs can alleviate congestion and avoid undesirable road events, resulting in better driving experiences and environmental impacts.

With their features and in-vehicle resources, CVs have become of particular interest to researchers and developers in the automotive and information technology sectors. Consequently, **remarkable use cases of CVs beyond safe and convenient transportation have emerged.**

Some of these use cases utilize the array of in-vehicle sensors, in addition to the vehicle mobility and ubiquitous availability, for enabling a wide scope of **mobile sensing** applications and services.

With wireless connectivity brought to the vehicular environment, CVs are considered major **data relays** and **mules**. They can facilitate moving data between themselves and other connected entities, either in the direct vicinity or remotely.

Other use cases utilize the abundance of data processing and storage resources available in CVs through their on-board computing units. The "**Vehicular Cloud**" paradigm has emerged as a result of relevant research and innovation.

With the availability of positioning systems on board, CVs can be also utilized for **locating objects** that are lost or cannot identify their own location.

Realizing the amount of time spent daily in vehicles, original equipment manufacturers (OEMs) and automotive developers have been actively introducing e-payment capabilities to the vehicle compartment bringing a wide scope of **e-commerce** applications to vehicle occupants. This emerging use case of CVs has brought diverse opportunities for retailers and financial services corporations to gain profits through purchases initiated and completed inside the vehicle compartment on the go. Keeping safety in mind, voice assistants have been widely utilized in this regard.

Motivated by the wide and diverse benefits that can be obtained through utilizing the abundant capabilities of CVs, **this report delineates the various applications and service domains in which CVs can be utilized beyond solely using them for safe transportation**. The report mainly discusses the use of CVs in mobile sensing, data relaying and transferring, cloud computing, localization, as well as in e-commerce. This is followed by some highlights of relevant research activities happening in Ontario. We conclude the discussion underlining some design and operational imperatives, such as data privacy and cybersecurity, that should be rigorously considered for the successful adoption of such scopes of use.

It is worth noting that the concepts and use cases covered in this report have emerged from worldwide research activities. Relevant industry developments, except for the e-commerce scope of use, are pending sufficient deployments and availability of connected vehicles and vehicular communication technologies.

MOBILE SENSING

To boost safety levels on roads, CVs are equipped with an array of sensors to enable monitoring of vehicle surroundings and providing relevant input to the in-vehicle systems. Examples of these sensors and the applications they support have been discussed in an earlier AVIN report[1].

With the ongoing activities in the automotive sector, researchers and developers have become very perceptive to the broad capabilities and uses of CV sensors. This has resulted in **taking vehicular sensing to broader scopes** beyond only the initial safety targets. Some use cases have emerged utilizing the sensors that have been initially embedded in CVs for the safety objectives, but for other applications that can benefit from this sensory data. Other use cases have entitled adding more sensors to CVs, widening the scope of applications that can benefit from the mobility and ubiquitous availability of vehicles.

Generally speaking, this concept of generating sensory data by moving entities, vehicles in the context of this report, is know as "mobile sensing[2]."

[1] Autonomous Vehicle Innovation Network. (2018). Data in the Context of CAVs - Types and Operational Opportunities. Retrieved from https://tinyurl.com/y9kkwlqy

[2] Abdelhamid, S., Hassanein, H., Takahara, G. (2014) Vehicle as a mobile sensor. Elsevier Procedia Computer Science. Retrieved from https://www.sciencedirect.com/science/article/pii/S1877050914008801

Examples of mobile sensing applications that can **make use of the pre-existing sensors in CVs** include **monitoring parking availability** and **detecting road conditions**. These two applications can utilize the in-vehicle **camera** for extracting relevant data from captured images. While on-the-move, CVs can capture images of roadsides, analyze these images to detect vacant parking spots, and, with input from the on-board positioning system, share real-time information about the locations of these vacant spots with other vehicles. If the detecting CVs are connected to the Internet, they can send this parking information to a central entity that can share it with other users via a software application. If a detecting CV is not equipped with an Internet connectivity, it can utilize its vehicle-to-vehicle and vehicle-to-infrastructure communication capabilities to disseminate such information[3]. Being very dynamic, this parking information should be distributed with a rational expiry time. The on-board camera can also be utilized for detecting road conditions. For example, through image processing techniques, wet and snowy roads can be detected based on analysis of the polarization and texture levels in captured camera images[4]. Different road anomalies can also be detected through other types of sensors. For example, data from in-vehicle **accelerometers** can be analyzed and utilized for detecting potholes and bumps in the road based on the variations in the captured vibration data [5]. Information about the locations and severity of these detected road anomalies can be reported by the detecting CVs to road authorities for maintenance support. This vehicle-based road monitoring approach is much more cost- and time-effective than the traditional techniques that involve sending dedicated personnel to scan the roads.

The other category of vehicular mobile

[3] **Korosec, K. (2019). Volvo cars in Europe will be able to warn each other about hazardous road conditions. Retrieved from** https://techcrunch.com/2019/04/15/volvo-cars-in-europe-will-be-able-to-warn-to-each-other-about-hazardous-road-conditions/

[4] **Yamada, M., Ueda, K., Horiba, I., Sugie, N. (2001). Discrimination of the road condition toward understanding of vehicle driving environments. IEEE Transactions on Intelligent Transportation Systems. Retrieved from** https://ieeexplore.ieee.org/abstract/document/911083

[5] **Eriksson, J., Girod, L., Hull, B., Newton, R., Madden, S., Balakrishnan, H. (2008). The pothole patrol: Using a mobile sensor network for road surface monitoring. Retrieved from** http://nms.csail.mit.edu/papers/p2-mobisys-2008.pdf

sensing applications targets **expanding the scope of information services supported by CVs through equipping them with additional sensors** and utilizing the mobility of CVs for collecting a wide scope of environmental data through these sensors. Examples of these applications include **measuring pollution and noise levels** in streets by equipping vehicles with relevant sensors and collecting this data from the vehicles via their on-board connectivity. Some road conditions are difficult to detect through analyzing camera images. **Ice on roads** is an example of such challenging road conditions. In this regard, researchers have proposed other detection techniques that can be facilitated by equipping CVs with extra sensors. An example of these techniques is to use a transducer to analyze the ultrasonic noise of friction between vehicle tires and streets and detect the availability of ice accordingly[6].

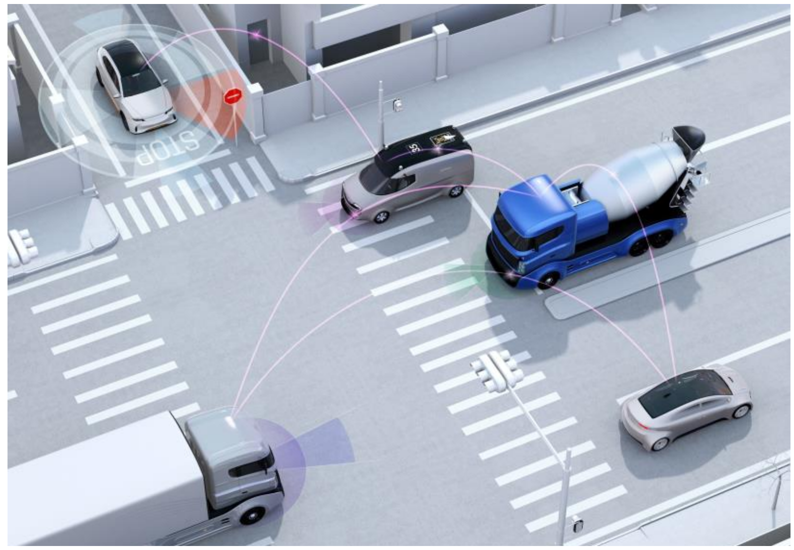
Realizing the safety benefits that can be gained through utilizing CVs as mobile sensors, OEMs have considered adopting such a concept by their vehicles. For example, in 2015, Jaguar Land Rover announced a research project that targets detecting, predicting and sharing data on potholes using their vehicles[7].

Due to having well-defined, city-wide routes, **transit** CVs are the best candidates for adopting this mobile sensing concept. **Fleet and ride-hailing** CVs are other well-suited options given the wide-span of their mobility and road coverage. However, mobile sensing campaigns should also be open to the public interested in utilizing their in-vehicle resources. When **public-owned** vehicles are used in mobile sensing, two other popular terms can be used to refer to this operation; **public sensing** and **crowdsensing**.

[6] Gailius, D., Jacenas, S. (2016). Ice detection on a road by analyzing tire to road friction ultrasonic noise. Retrieved from https://bit.ly/2X36n73

[7] Jaguar Land Rover Limited. (2015). Jaguar Land Rover announces technology research project to detect, predict and share data on potholes. Retrieved from https://www.jaguarlandrover.com/news/2015/06/jaguar-land-rover-announces-technology-research-project-detect-predict-and-share-data

DATA RELAYING



CVs are equipped with communication capabilities that enable data exchange with neighboring vehicles and infrastructure. Depending on the technology level, CVs may also be able to communicate with pedestrians and other on-road devices such as connected billboards. In addition to being targeted to augment safety levels on roads, data exchange brings massive operational opportunities in a diversity of information service domains, as delineated in an earlier AVIN report[1].

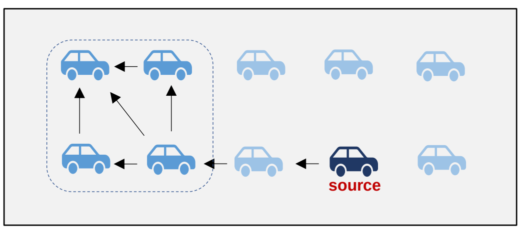
To boost the scale of benefits of such data exchange, CVs are meant also to be data forwarders/relays to transmit the data farther than just neighbor-to-neighbor communication ranges. Data relaying in CVs can follow three different **communication patterns**, depending on who and where the data destination is.

1. Geocasting:

Geocasting refers to relaying data to a group of destinations identified by their geographical locations. This communication pattern can be utilized by CVs in many different scenarios. For example, CV drivers can benefit from receiving information about how busy the traffic is at a specific point of interest (PoI), such as a gas station. Using their CVs, these drivers can issue an information request to be *geocast* towards the vehicles near to this PoI. CVs receiving the request can reply back with their real-time driving speed in that area. Since the requesters

and responders are not direct neighbors, they cannot have direct communication, and they depend on the data relaying capabilities of CVs in-between them to move the requests and replies towards their intended destinations.

> **Geocasting** refers to relaying data to a group of destinations identified by their geographical locations.

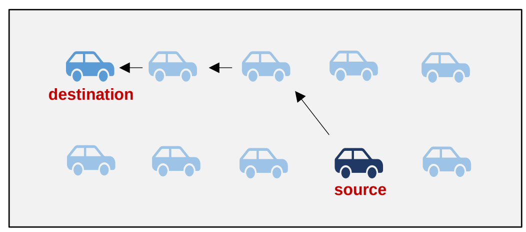


2. Unicasting:

Unicasting refers to sending data to a single, specific destination. For example, in the data harvesting scenario described above, the data reply carrying the driving speed at the PoI needs to be sent to only its corresponding requester. Therefore, the data reply is *unicast* towards the requesting CV, relayed using intermediate CVs moving between the source and destination vehicles.

In another scenario, when a CV occupant is interested in accessing a specific piece of media, but the CV does not have an Internet connection, the vehicle-to-vehicle and vehicle-to-infrastructure communication and data relaying capabilities can be utilized for obtaining such information. The CV can unicast a request to the closest road-side unit (RSU), which can download the requested media item and unicast it back to the requesting CV over other intermediate CVs.

> **Unicasting** refers to sending data to a single, specific destination.

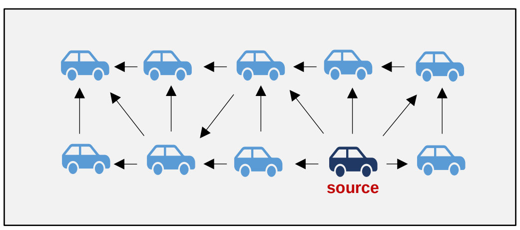


3. Information Dissemination:

Information Dissemination refers to flooding the surrounding area with information. Information can go farther than the limits of the direct communication range of the disseminating vehicle through the communication and data relaying capabilities of neighboring vehicles.

A CV can follow this communication pattern when it detects a critical on-road event and decides to share it with all the surrounding vehicles. For example, when a CV, using its in-vehicle sensors, detects a pothole that can cause severe damage to passing vehicles, this detecting CV can share information about the location and severity of this pothole with all vehicles in the surrounding area to avoid later encounters with it.

Information Dissemination refers to flooding the surrounding area with information.



In addition to sharing road-related data, the data relaying capabilities of CVs can be utilized for other purposes such as **commercialization**. For example, CVs can be utilized to relay and disseminate store and restaurant advertisements or offers while being on-move. This can be a source of paid rewards to the participating vehicles by the owners of the advertised services.

The data relaying capabilities of CVs can be also a savior in the cases of **emergencies** or **natural disasters** when other communication infrastructures are down because of their reliance on communication wires. In such cases, vehicle-based information dissemination can be used for relaying critical data to/from the crisis management authorities, and for guiding emergency vehicles and staff through the best available routes.

DATA MULES

CVs are equipped with computing capabilities through their on-board units (OBUs). In-vehicle OBUs usually come with an abundance of data storage and processing resources, with some OBUs designed to be more powerful than personal computers. In terms of storage capabilities, some OBUs can have **terabytes of available data storage**.

Being endowed with such abundant data storage resources, CVs can work as data mules moving data from one point to another. This can be helpful when it is very costly to transfer large volumes of data over a communication network, or when communication links between the two points cannot be established. In such cases, point A (the sender) can directly load a CV with the data to be moved to and downloaded at point B (the destination). An example of such data-moving paradigm is utilizing CVs for moving data to rural areas with no/limited access to broadband connectivity. Vehicle-based data muling can also be utilized in harsh and/or crisis-subject environments where communication networks cannot be expanded. In such environments, driver-less CVs can be utilized for data delivery.

Another approach for utilizing CVs as data mules is to let CVs store the data they collect on their way, either data generated by their in-vehicle sensors or acquired from other vehicles or infrastructure. This data can be carried by the holding CVs as long as their expiry time has not been reached. While being carried by CVs, such data can be advertised by its owners and harvested by interested entities, while taking proper data privacy, deidentification, and cybersecurity practices into consideration. For example, CVs, on their way, can detect road anomalies and store relevant data to be reported later to interested authorities. CVs can also store information about the vehicle crashes they encounter. Such carried information can be harvested later through requests from police or insurance agents, for example, upon receiving a consent from the involved parties.

VEHICULAR CLOUDS

As highlighted in the previous section, CVs are equipped with abundance of storage and processing resources through their OBUs. Researchers have realized that these computing capabilities exceed the needs of the basic automotive applications and are likely to be underutilized. This claim, supported by the availability of communication capabilities in CVs, was a motivation to **take vehicles to the cloud**[8]; in other words, having abundance of idle computing resources in CVs pushed for using these vehicles as computing clouds and coming up with the concept of “vehicular clouds”. The computing resources, both storage and processing, of CVs on roads or at parking lots can be **rented out** to users in need, the same way conventional cloud computing is offered and utilized. With collaboration between multiple CVs, their computing resources can be combined resulting in a giant computing hub on wheels.

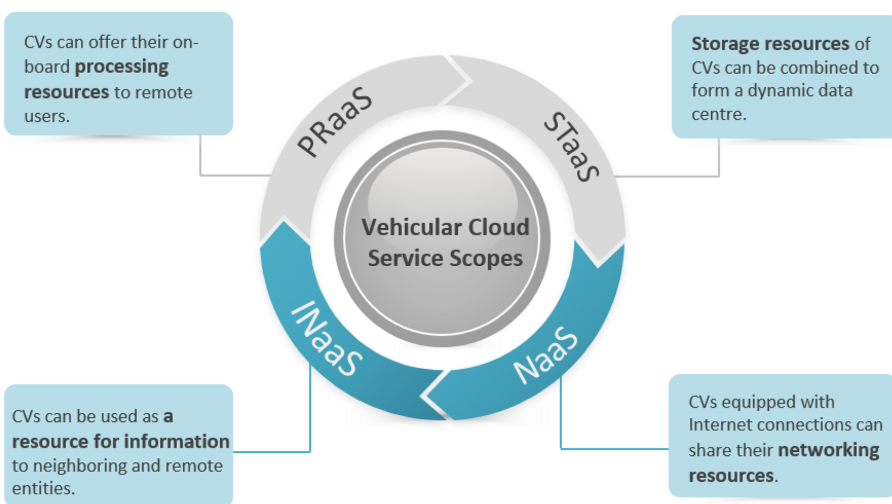
---

[8] **Olariu, S., Eltoweissy, M., Younis, M. (2011). Towards autonomous vehicular clouds. Retrieved from** https://bit.ly/2Rz7Sc1

A **vehicular cloud** is a pool of in vehicle computing resources offered dynamically and on demand by connected vehicles to users in need of performing a computing task.

As mentioned above, vehicular clouds (VCs) share similarities with the conventional cloud computing paradigm, mainly through the concept of renting out idle computing resources on-demand to users in need through business and pricing models. However, being mobile, VCs bring unique advantages compared to the conventional fixed clouds. Facilitated by the pervasive reach of vehicles, VCs can bring ubiquitous computing on wheels[9], not restricted by fixed deployment locations. VCs can also be utilized in environments where Internet connectivity is restricted or unavailable, compared to conventional cloud computing that is mainly reliant on Internet access.

Researchers have highlighted that VCs can provide different scopes of service[8,10]. *Processing as a Service* (PRaaS), *Storage as a Service* (STaaS), *Network as a Service* (NaaS), and *Information as a Service* (INaaS), are major categories of these service scopes. In **PRaaS**, VCs can offer their on-board processing resources to remote users to either access software pre-installed on the OBU, or to migrate



[9] Abdelhamid, S., Benkoczi, R., Hassanein, H. S. (2016). Vehicular Clouds - Ubiquitous Computing on Wheels. In Emergent Computation. New York, NY: Springer. Retrieved from https://www.researchgate.net/publication/312003991_Vehicular_Clouds_Ubiquitous_Computing_on_Wheels

[10] Whaiduzzaman, M., Sookhak, M., Gani, A., Buyya, R. (2014). A survey on vehicular cloud computing. Retrieved from https://www.sciencedirect.com/science/article/pii/S1084804513001793

a virtual machine to run on vehicular platforms (i.e., moving an external software platform temporarily to run on the OBU of an available CV).

In **STaaS**, storage resources of CVs can be combined to form a dynamic data centre offering data storage services on-demand to remote users, same as offered by conventional clouds. Given the mobility of vehicles, CVs can bring a unique advantage using them for STaaS as mules moving data, as discussed in the previous section.

As a unique feature of VCs compared to conventional clouds, CVs equipped with Internet connections can share their networking resources. These CVs can be used as mobile hot spots providing **NaaS** to neighboring third parties in need of Internet access.

Lastly, a CV can be used as a resource for information providing **INaaS** to neighboring and remote entities. This category of services is facilitated by the floods of data and information that CVs collect from their in-vehicle sensors, other vehicles or RSUs, and/or through access to the Internet.

Many visionary applications of VCs have been proposed by researchers[7]. A popular example is the use of storage resources of **CVs parked at an airport as a giant data centre**[11]. The argument behind this application is that such CVs are left idle for days, and sometimes for months. Instead of wasting these parked resources, recommendations have been made to dynamically offer them for remote users as an on-demand STaaS. Storage resources of these vehicles can be allocated to requesters based on the travel schedules and access consents of the CV owners. To enable such access and usage, these parked vehicles need to be plugged into a power supply and equipped with an Ethernet connection, which can be offered by the airport for a fee. Based on the same argument of the idle resources of parked vehicles, another suggested application is **crowdsourcing computing resources by a company**

[11] Arif, S., Olariu, S., Wang, J., Yan, G., Yang, W., Khalil, I. (2012). Datacenter at the airport: Reasoning about time-dependent parking lot occupancy. IEEE Transactions on Parallel and Distributed Systems. Retrieved from https://ieeexplore.ieee.org/document/6143927

utilizing the parked CVs of its employees. Instead of outsourcing computing facilities or purchasing computers, companies can remotely access the computers of CVs in their parking lots, subject to the consent of the vehicle owner. The employees owning these vehicles can be paid for their accessed resources, making profit instead of having their vehicles left idle at the parking lot.

Moving CVs have been also widely considered in the use cases of VCs. A popular suggested application is utilizing the computing resources of CVs towards adopting **dynamic traffic management**. In this use case, CVs at intersections can be used to collect data about the number of vehicles waiting at each road segment connected to the intersection. A coordinating vehicle can be elected to form a VC with the vehicles collecting the count data, and to generate and convey a proper schedule for the intersection traffic lights based on the collected data. Another example is utilizing CVs as **mobile laboratories** in areas where fixed or Internet-accessed facilities cannot be secured. This use case highlights an advantage of VCs compared to conventional clouds.

LOCALIZATION

Localization refers to the ability to determine the location of an object. With the navigation, positioning, and communication technologies CVs have on-board, they are considered key enablers for providing localization for objects missing their location information, and for locating missing objects on roads.

Sometimes, the satellite-based navigation systems fail to accurately locate their vehicles, especially in cities with tall buildings obstructing clear communications with the satellite providing the needed information. To **improve the accuracy of the navigation systems** in such environments, CVs can depend on data exchange with one another and utilize the strength and direction of the received signals for applying mathematical localization techniques to accurately compute their location[12].

One of the prominent uses of CVs in this regard is using them for **locating sensor nodes**[13]. In harsh environments that cannot or not safe to be

[12] **Circuit Cellar. (2014). Triangulation, Trilateration, or Multilateration? Retrieved from** http://circuitcellar.com/ee-tips/triangulation-trilateration-or-multilateration-ee-tip-125/

[13] **Ibrahim, W. M., Abu Ali, N. A., Taha, A. M., Hassanein, H. S., (2014). Side localization to increase localization accuracy. Retrieved from** http://www.queenstrl.ca/uploads/4/6/3/1/4631596/2014_side_localization_to_increase_localization_accuracy.pdf

accessed by humans, sensor nodes needed to monitor such environments are usually deployed by dropping them from a helicopter. Because those sensor nodes are deployed from a distance, it is hard to predict their ground location. However, when data is reported by these sensors, it needs to be geotagged with the exact location where it is generated (i.e., the location of the generating sensor node) to be able to take informed actions. One of the efficient solutions proposed to solve this dilemma is to use **CVs as mobile anchors** continuously sharing their location while moving near the area where there are sensor nodes to be located. After receiving location data from passing vehicles at different time instants, the receiving sensor nodes can utilize such data to compute their own location by applying mathematical localization techniques.

Another potential use case of CV localization is using CVs to **locate stolen vehicles**. While CVs are moving, they scan their surroundings. Using their on-board camera, they can detect the license plate number of the vehicles they encounter and store this information tagged with the location and time of encounter. Whenever a vehicle is stolen, police agents can start to harvest this information from CVs and use it to locate and track the stolen vehicle(s).

E-COMMERCE

One of the emerging use cases of CVs is engaging them in e-commerce. With the extended time many people spend in their vehicles, CVs have attracted the interest of retailers to start providing an e-commerce experience inside the vehicle compartment.

Motivated by the market interest and the large profits that can be made through vehicular e-commerce, many OEMs have been striving to bring e-commerce applications and e-payment services to their vehicles. In 2016, Volkswagen Financial Services AG acquired PayByPhone, a Vancouver-based parking payment company, with the aim to become a global leader in mobile parking payment[14]. In 2017, Daimler Financial Services acquired PayCash Europe aiming to introduce the Mercedes Pay service[15].

[14] **Brach, B. (2016). Vancouver-based PayByPhone app acquired by German auto giant. Retrieved from** https://www.cbc.ca/news/canada/british-columbia/vancouver-based-paybyphone-app-acquired-by-german-auto-giant-1.3914358

[15] **Otto F., (2017). ePayment investment: Daimler Financial Services acquires PayCash Europe SA. Retrieved from** https://media.daimler.com/marsMediaSite/en/instance/ko/ePayment-investment-Daimler-Financial-Services-acquires-PayCash-Europe-SA.xhtml?oid=15310294

In 2017, General Motors (GM) announced the GM Marketplace platform that allows vehicle occupants to order food and drinks en route and make restaurant reservations[16]. In 2018, Chevrolet partnered with Shell to offer the ability to pay for Shell fuel purchases through the in-vehicle Marketplace application[17].

Realizing the vehicular e-commerce hype, global financial services corporations have also been actively seeking and establishing partnerships with automotive technology developers. For example, in 2018, **Mastercard** announced a partnership with SAP focusing on their Connected Vehicles Network platform and aiming to offer consumers the ability to place in-vehicle payments for parking, fuel, and ordering food[18]. In the last few years, **Visa** has also been actively establishing collaborations with OEMs and automotive platform providers to enable in-vehicle e-payment. For example, since 2016, Visa has been working with Honda to build and enhance the in-vehicle payment experience of Honda's vehicles[19].

Such availability of in-vehicle e-payment capabilities facilitates a wide span of **consumer applications**. In addition to the parking, fuel, and food e-payment capabilities highlighted earlier, connectivity and online shopping can bring all the retailers offering e-shopping options to the vehicle compartment. By accessing the vehicle location and the occupant(s)' purchase preferences, the in-vehicle e-commerce applications can proactively display items of interest for purchase on-the-go. Orders can be placed in the vehicle, and items can be picked up on the way or automatically shipped to a saved address.

To enable these **personalized shopping feeds**, data privacy should be strictly taken into consideration, communicating the data collected to its owner for having full awareness and giving digital consent a priori.

---

[16] **General Motors Co. (2017). GM lets customers order their morning coffee with their car. Retrieved from** https://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2017/dec/1205-marketplace.html

[17] **Chevrolet Press. (2018). Chevy and Shell deliver fuel payment from the comfort of the driver's seat. Retrieved from** https://media.chevrolet.com/media/us/en/chevrolet/news.detail.html/content/Pages/news/us/en/2018/apr/0418-shell.html

[18] **Wyper S., (2018). Powering payments from the driver's seat. Retrieved from** https://newsroom.mastercard.com/2018/02/27/powering-payments-from-the-drivers-seat/

[19] **Visa. Road ahead: Connected cars coming to a lot near you. Retrieved from** https://usa.visa.com/visa-everywhere/innovation/connected-car.html

In-vehicle payments can also be utilized to purchase over-the-air software/firmware updates offered by OEMs and equipment manufacturers to enhance the driving experience and bring further convenience to the vehicle occupants.

For safety considerations, use of in-vehicle e-commerce applications is provided to CV drivers via **voice assistance**, whereas screen-based options can be provided to the non-driving occupants. A study by Juniper Research[20] forecasts that over 370 million in-vehicle digital voice assistants will be accessed by 2023. The study also anticipates that the total spending over CV e-commerce platforms will reach $265 billion by 2023.

[20] **Juniper Research. (2018). Connected cars: How 5G, connected commerce & blockchain will disrupt the ecosystem. Retrieved from** https://www.juniperresearch.com/document-library/white-papers/connected-cars-how-5g-connected-commerce

HIGHLIGHTS FROM ONTARIO

WESTERN UNIVERSITY

Department of Computer Science
Ivey Business School

Researchers at Western University have collaborations with worldwide researchers to work on topics such as object localization using parked vehicles, emergency message propagation, and in-vehicle laboratories.

Links: http://www.csd.uwo.ca/faculty/bauer/

https://www.ivey.uwo.ca/faculty/directory/joe-naoum-sawaya/

UNIVERSITY OF WATERLOO

Department of Electrical and Computer Engineering

Researchers at the Broadband Communications Research Lab and the Waterloo Centre for Automotive Research have been working on diverse research activities utilizing connected vehicles for a wide scope of services, including using vehicles for disaster management, data delivery for smart grids, and vehicular cloud computing.

Links: https://uwaterloo.ca/broadband-communications-research-lab/

https://uwaterloo.ca/centre-automotive-research/

QUEEN'S UNIVERSITY

School of Computing

Researchers at the Telecommunications Research Lab introduced the concept of Vehicle as a Resource (VaaR), outlining the various scopes of information services a connected vehicle can provide on the road or at parking lots.

The research group has been also active in relevant research areas including resource allocation in vehicular clouds, recruitment models for vehicular public sensing, and data caching in vehicular networks.

Link: http://www.queenstrl.ca/

UNIVERSITY OF OTTAWA

School of Electrical Engineering and Computer Science

Researchers at the University of Ottawa have been actively proposing solutions to improve the performance of data relaying and path planning in connected vehicles and vehicular crowd sensing.

Links: http://www.nsercdiva.com/

CONCLUSIONS

In this report, we have discussed various uses of CVs beyond their basic use for safe and convenient transportation. First, the use of CVs for mobile/public/crowd sensing have been delineated, highlighting how the in-vehicle sensors, connectivity, and ubiquitous availability can be utilized for provisioning sensing-based environmental services. Second, the benefits that CVs can bring through using them as data relays and mules have been delineated highlighting some relevant informational, commercial, and emergency use cases. Considering the abundant processing and storage resources in CVs, the emerging vehicular cloud paradigm has been deliberated, shedding light on the differences to the conventional cloud computing paradigm and the various service scopes that can be offered by such a promising paradigm. Furthermore, the use of the CV navigation and positioning capabilities for locating other objects have been touched upon. We have also shed light on the emerging vehicular e-commerce paradigm discussing some of the ongoing efforts by OEMs and financial services corporations bringing e-payment and online shopping capabilities to CVs.

To be able to successfully adopt these prominent use cases of CVs, some development and operational considerations should be taken into account[21,22]. First, sharing CV resources with others brings data **privacy** and **cybersecurity** issues to the forefront. Stringent privacy by design and cybersecurity practices should be adopted in the whole CV system lifecycle to protect the data of the CV owners offering their in-vehicle resources to external parties.

[21] **Abdelhamid, S., Hassanein, H. S., Takahara, G. (2015). Vehicle as a Resource (VaaR). Retrieved from** http://www.queenstrl.ca/uploads/4/6/3/1/4631596/2015_vehicle_as_a_resource_(vaar).pdf

[22] **Autonomous Vehicle Innovation Network. (2019). Data in the Context of CAVs - Challenges and Recommendations. Retrieved from** https://bit.ly/2ZHkUar

Using CVs as information providers necessitates taking the **quality of information** into consideration. Whenever information is collected from CVs, it should be assessed and validated first before using it for making informed decisions and/or sharing it with the public.

The **dynamic availability** of vehicles is another concern to be considered when accessing CV resources. Vehicles involved in a mobile sensing campaign or in a vehicular cloud might leave the area of interest before finishing the assigned task. Therefore, the spatial and temporal availability of vehicles should be considered before allocating tasks to them. Migration of tasks from a CV to another is an option to deal with such a challenge.

To urge CV owners to utilize their vehicles in the different use cases highlighted in this report, **incentives** should be guaranteed to be received in return. Such incentives can take on different forms including receiving free services, payments, parking and/or express way vouchers.

As the CV technologies evolve, their use opportunities will be further realized and more scopes of service and applications will emerge, bringing much efficiency, convenience, and quality of experience not only to vehicle occupants, but also to remote end users.

MEET THE AVIN TEAM

Raed Kadri
Director, Automotive Technology and Mobility Innovation
(416) 861 1092 x9-7400
raed.kadri@oce-ontario.org

Sherin Abdelhamid
Technical Data and Global Trends Analyst
(416) 861 1092 x 9-1097
sherin.abdelhamid@oce-ontario.org

Mona Eghanian
Senior Manager, Automotive and Mobility
(416) 861 1092 x 9-1076
mona.eghanian@oce-ontario.org

Daniel Graham
Manager, Automotive and Mobility Portfolio
(416) 861 1092 x1107
daniel.graham@oce-ontario.org

Martin Lord
Senior Sector Manager, Automotive and Mobility Portfolio
(905) 823 2020 x9-3236
martin.lord@oce-ontario.org

Dan Ruby
Business Development and Commercialization Manager
(866) 759 6014 x9-3249
dan.ruby@oce-ontario.org

Shane Daly
Automotive and Mobility Team Coordinator
(416) 861 1092 x9-5017
shane.daly@oce-ontario.org

ABOUT AVIN

The **Autonomous Vehicle Innovation Network (AVIN)** initiative is funded by the Government of Ontario to support Ontario’s competitive advantage in the automotive sector and to reinforce its position as a North American leader in advanced automotive and mobility technologies, including transportation and infrastructure systems.

This initiative capitalizes on the economic potential of connected and autonomous vehicle (CAV) technologies by supporting the commercialization of best-in-class, made-in-Ontario solutions that create jobs, drive economic growth and enhance global competitiveness. AVIN also helps Ontario’s transportation systems and infrastructure adapt to these emerging technologies.

AREAS OF FOCUS

AVIN programs focus on supporting the development and demonstration of CAV technologies in light vehicles (e.g., cars, trucks and vans), heavy-duty vehicles (commercial vehicles, trucks, buses and RVs), transportation infrastructure, intelligent transportation systems (ITS) and transit-supportive systems.

AVIN is administered on behalf of the Government of Ontario by Ontario Centres of Excellence (OCE). The initiative comprises five distinct programs and a central hub. The AVIN programs are:

- AV Research and Development Partnership Fund
- WinterTech
- Talent Development
- Demonstration Zone
- Regional Technology Development Sites

The AVIN Central Hub is a dedicated team that supports delivery and administration of AVIN programming, and provides the following key functions:

- Connect & Coordinate - a focal point to help coordinate activities among industry, academia, research organizations and governments, and connect interested stakeholders and members of the public;
- Opportunity Identification - knowledge translation, research, data/information, trend analysis, and acting as a bridge between technology and policy; and
- Awareness & Education - promote AVIN programs and Ontario's AV testing pilot and build awareness of Ontario's growing CAV community.

AVIN has five Objectives:

We would like to thank the Government of Ontario for supporting AVIN programs and activities.

We would also like to thank the partner organizations that work with OCE to deliver AVIN programs, including the Regional Technology Development Sites and the Demonstration Zone.