routes et transports

PUBLICATION DE L'ASSOCIATION QUÉBÉCOISE DES TRANSPORTS

VOL 46 NUM 2, OCTOBRE 2017

Le transport du futur sera électrique, autonome et partagé!

AUTONOMIE, CONNECTIVITÉ OU **ÉLECTRIFICATION DES VÉHICULES,** le Québec vibre d'énergie positive pour l'environnement

MONTRÉAL, **UNE VITRINE** pour les technologies associées à l'électromobilité

L'ÂGE D'OR **DE L'ÉCONOMIE DU TRANSPORT** aux États-Unis ou la mobilité redéfinie

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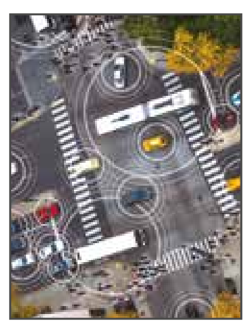
L'expertise en transport

En couverture



L'AQTr remercie MM. Mouhamed Abdulla et Ke Wu qui ont bien voulu l'autoriser à utiliser la photo de leur article *5G Connected Vehicules: The Missing Link to Highly Autonomous Vehicles* (à lire en page 123).

RÉDACTRICE EN CHEF
Emmanuelle Royer

AUTEURS
Mouhamed Abdulla
Jean-Pierre Arcoragi
François Bélisle
François Bellavance
Ilham Benyahia
Frédéric Blas
Sylvain Boisvert
Sylvain Boucher
Giancarlo Colmenares
Luc Couillard
Stéphane Duquet
Ryan Falconer
Melissa Felder
Nicolas Hautière
Lisa Jerram
Catherine Kargas
Amanda Lam
Pierre Lavigueur
Antoine Malo
Thomas Massin
Fabien Menant
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Pegah Nouri
Alexandra Ouimet
Yves Provencher
Pascal Renaud
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Arya Rohani
Nicolas Saunier
Alexandre Savard
Rod Schebesch
Habib Shamskhou
Martin Thibault
Jean-François Tremblay
Martin Trépanier
Gregory Wielinsky
Ke Wu

RECHERCHE DE COLLABORATEURS ET D'AUTEURS
Laszlo Dankovics, Lynn Dumont, Rafika Lassel,
Zineb Mabrouki et Line Rousseau

COORDINATION
Margaux Andrieu, Julie Harnois

MONTAGE GRAPHIQUE
AQTr

RÉVISION LINGUISTIQUE
Muriel Dérogis, ER Translations et Youssef Megharfi

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Publiée deux fois par an, la revue *routes et transports* s'adresse à tous ceux qu'intéresse le domaine du transport. Sa liste de distribution comprend des représentants des autorités gouvernementales, paragouvernementales et municipales, des entreprises privées, des bibliothèques, des institutions d'enseignement, des médias, de même que tous les membres de l'AQTr.
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ABONNEMENT
L'abonnement annuel est de 30 $ + taxes pour le Canada et de 60 $ pour les autres pays. Frais d'expédition en sus. Prière de s'adresser au secrétariat.

ÉDITRICE
Présidente-directrice générale de l'AQTr

PUBLICITÉ
Anne-Julie Robitaille : 514 523-6444, poste 313

IMPRIMERIE
Imprimerie l'Empreinte

INDEXÉE PAR REPÈRE
Dépôt légal, Bibliothèque nationale du Canada, ISSN 0319-3780

ENVOI DE PUBLICATION
Poste-publications
Convention nº : 40038871
Port de retour garanti

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PARUTIONS 2017

	Thème	Parution
VOL. 46 Nº1	Ville, vision, vitalité	Printemps 2017
VOL. 46 Nº2	Le transport du futur sera électrique, autonome et partagé!	Automne 2017

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SUÈDE

En milieu urbain, une interconnectivité performante, entre les véhicules et tous les autres usagers de la route, repose sur des exigences techniques pointues. À lire en **page 123**.

FRANCE

La route peut s'électrifier et recharger les véhicules qui l'empruntent. Apprenez-en davantage sur la Route de 5e Génération (R5G) en **page 115**.

ARGENTINE

Le déploiement des véhicules autonomes (VA) ne sera pas le même pour tout le monde, tout comme les progrès de la mobilité intelligente.
À lire en **page 109**.

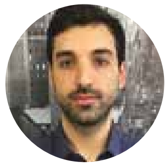
LISA JERRAM

Principal Research Analyst
Navigant Research

Lisa Jerram is a principal research analyst contributing to Navigant Research's Transportation Efficiencies program.

She analyzes emerging markets for new vehicle technologies for cars, trucks, and buses, electric vehicle charging equipment, innovative urban mobility solutions such as carsharing and ride-hailing, and fuel cells for transportation.

Mme Jerram étudie l'impact de l'arrivée des véhicules autonomes dans nos villes et les changements potentiels qui affecteront le paysage urbain.
À lire en **page 104.**



FRÉDÉRIC BLAS

Gérant
AC&A

Frédéric Blas est ingénieur civil et urbanisme de l'INSA de Lyon, et détient un master en mobilité urbaine (UPM et URJC, Madrid) et un MBA (UCEMA, Buenos Aires).

Possédant une expérience de plus de 10 ans, il a participé et dirigé de nombreux projets en infrastructure, en économie et en planification de systèmes de transports.

Il est actuellement gérant du département Études et planification d'AC&A (Argentine).

Il est également professeur des Facultés d'Ingénierie de l'Université catholique argentine (UCA) et de l'Université de Buenos Aires (UBA).

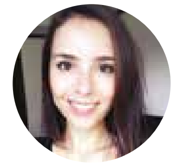
THOMAS MASSIN

Consultant

Thomas Massin est docteur en urbanisme et aménagement du territoire. Il a une expérience de dix ans dans le domaine des mobilités urbaines, acquise au sein de l'Institut pour la ville en mouvement et de l'Institut d'aménagement et d'urbanisme de la région Île-de France.

Il a également été conseiller politique du président de la Région Île-de-France pour la thématique des transports et chargé de cours à l'Université de Buenos Aires.

Actuellement, il travaille comme consultant pour la Mission de préfiguration de la métropole de Buenos Aires, dans le cadre d'un financement de la BID.



FLORENCIA RODRÍGUEZ

Consultante
AC&A

Florencia Rodríguez est sociologue de la UBA, et détient un master en économie urbaine (UTDT, Buenos Aires) et un MSc. en transport et planification urbaine de la University College London.

Elle est spécialiste en mobilités urbaines et a acquis son expérience professionnelle aussi bien dans le secteur public national que dans le secteur privé, au sein d'AC&A, où elle travaille depuis 2014.

Elle est également assistante technique à la Fondation Métropolitain, à la Fondation Études en Transport et pour le groupe de recherche MetroLab de la UBA.

MM. Blas et Massin et Mme Rodriguez nous éclairent sur les disparités qu'aura le déploiement des véhicules autonomes (VA), selon les régions du monde, les pays et les types de territoires concernés.
À lire en **page 109**.

NICOLAS HAUTIÈRE

Adjoint au directeur
du Département COSYS
IFSTTAR

Nicolas Hautière est adjoint au directeur du département Composants et Systèmes de l'Institut français des sciences et technologies des transports (IFSTAR), de l'aménagement et des réseaux, depuis janvier 2017.

En 2005, il obtient un doctorat, puis, en 2011, une habilitation à diriger des recherches en vision par ordinateur.

Formé en 2012 à l'École nationale des ponts et chaussées aux enjeux de politiques publiques pour le développement durable, il prend alors la direction du projet Route 5e génération.

FABIEN MENANT

Responsable de projet en
auscultation des routes
IFSTTAR

Fabien Menant est ingénieur de recherche et développement au sein du Laboratoire auscultation, modélisation et expérimentation des Infrastructures de transport à l'Institut français des sciences et technologies des transports, de l'aménagement et des réseaux (IFSTAR).

Depuis 2010, ses travaux portent sur la conception et le développement de systèmes innovants pour l'auscultation de surface des réseaux routiers.

En 2014, il obtient un doctorat en sciences pour l'ingénieur dont le sujet porte sur l'utilisation de capteurs bas-coût embarqués dans des véhicules traceurs, pour surveiller l'état des infrastructures routières.

MM. Hautière et Menant nous explicitent comment l'avènement de véhicules électriques, autonomes et partagés, adaptés aux enjeux de société, façonnera la route de 5e génération. À lire en **page 115**.

MOUHAMED ABDULLA

Marie-Curie Individual Fellow
Chalmers University
of Technology
Sweden

Mouhamed Abdulla is an EU Marie-Curie Individual Fellow at Chalmers University of Technology in Sweden. Until 2015, he was an NSERC Fellow with the Electrical Eng. Dept. of the University of Quebec.

He was with IBM Canada as a Senior Technical Specialist for 7 years.

He holds several awards from international organizations, the government, academia and the industry.

He was an IEEE Executive Committee member of the Montreal Section, where he was the Secretary in 2013 and Treasurer in 2014-2015.

KE WU

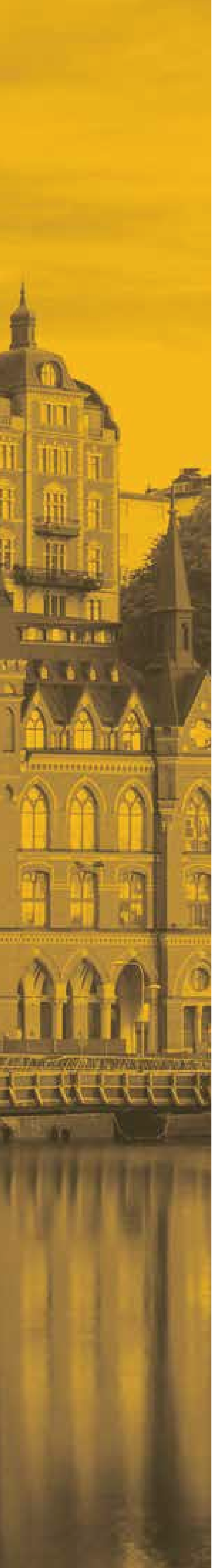
Professor
University of Montreal

Ke Wu is a Professor of Electrical Engineering at the University of Montreal. He is also the NSERC-Huawei Industrial Research Chair, Tier-I Canada Research Chair (2002-2016) and the Director of the Poly-Grames Research Center (2008-2014).

He was the President of the IEEE Microwave Theory/Techniques Society in 2016. He has been the recipient of many awards, including the Thomas W. Eadie Medal of the Royal Society of Canada in 2009, the Queen Elizabeth II Diamond Jubilee Medal in 2013 and the Marie-Victorin Prize (the highest distinction in engineering in Quebec) in 2014.

MM. Abdulla et Wu traitent des exigences techniques indispensables à une interconnectivité performante, en milieu urbain, entre les véhicules et tous les autres usagers de la route.
À lire en **page 123**.

SUÈDE



Suède

5G Connected Vehicles: The Missing Link to Highly Autonomous Vehicles

Mouhamed Abdulla & Ke Wu

Today, there is a clear convergence between technologists, visionaries, corporations, academics, and policymakers on the expected trend of Intelligent Transportation Systems (ITS). The related infrastructure and vehicles of the future will essentially have four key attributes, which are (a) electric (i.e. sustainable), (b) autonomous (i.e. convenient), (c) connected (i.e. safe), and (d) shared (i.e. rely on smart mobility utilization).

Present day autonomous vehicles are primarily founded on light detection and ranging (LiDAR) technology, where the objective of this sensing capability is to navigate on road infrastructures while avoiding collisions with likely obstacles, such as other vehicles, cyclists, pedestrians, animals, and random objects. Despite being a remarkable milestone in this vehicular ecosystem, critical information is not being shared locally to the cloud and the transportation management system for the purpose of dynamic cooperation, remote access control, and network optimization. With time, as the volume of active cars and traffic increases, interconnectivity among vehicles will be necessary for greater safety, traffic efficiency, intelligent resource utilization, and smart energy consumption.

In fact, autonomous vehicles with sensing capabilities are constrained by line-of-sight and thus cannot detect a likely collision with a fast-moving vehicle driving towards an urban junction, for instance. Moreover, harsh weather conditions, such as fog, sunbeams, heavy rain and snow, significantly deteriorate the quality of sensing technology. Evidently, vehicle-to-everything communications is the prime alternative technology that can overcome the shortcomings of LiDAR-based autonomous vehicles. According to a European Commission study, vehicle-to-vehicle (V2V) communications have the potential to prevent up to 35% of serious casualties from road accidents. In other words, it is of the utmost importance to have both sensor capabilities and communications technology, as they complement each other and also serve as sources for supplemental system redundancy, added security and greater awareness of the vehicle's surroundings.

Evidently, communications need not only be limited to other vehicles; it could be an all-encompassing vehicle-to-everything (V2X) connectivity. For instance, vehicle-to-infrastructure (V2I) has the prospect for making traffic flow more fluid and dynamic through direct communications with nearby traffic signs. Vehicle-to-pedestrian (V2P) communications could automatically alert a car of an unnoticeable pedestrian presence on the road ahead.

The same also applies for enhancing the safety of cyclist maneuvering in a busy city. Since these changes on the road occur in split seconds, the vehicle's computer system will automatically and proactively control and steer the car to avoid such accidents. As for vehicle-to-network (V2N) communications, it essentially keeps a vehicle in a continuous and direct communication link with a radiofrequency (RF) network infrastructure (i.e. similar to a tower used nowadays for mobile communications), such as an LTE Advanced Pro (Rel.13, 14) or the much anticipated 5th generation wireless network (5G). V2N will enable greater spatial coverage; so for instance, it could notify a driver in real-time of a heavy traffic jam a few kilometers ahead and dynamically reroute the traffic to reach the destination with minimal travelling distance and time.

To enable communication between vehicles manufactured by different companies, standardization is required for interoperability. Direct short-range communication (DSRC) is a standard ready for utilization at an operating frequency of 5.9 Gigahertz. This standard, which was formally known as IEEE 802.11p, sets the communication protocol for local information transmission in an ad hoc vehicular configuration. The disadvantage of this protocol is the lack of dynamic information sharing of the many hours of driving history with the transportation management system. As an alternative, cellular-based 5G communications, which is under development and is expected for gradual deployment in 2020, essentially inherit the distributed features of DSRC with the added benefit of centralized coordination by the transportation management system. Undoubtedly, the capabilities of

Figure 1
Connected vehicles are an integral part of future smart cities.

the 5G alternative is more convenient for the purpose of highly autonomous vehicles, particularly since it will deliver ultra-reliable, low-latency, and fast communications for complex vehicular networks.

Evidently, networks related to cars are commonly known as vehicular ad hoc networks (VANET). Because vehicles are in constant movement, a certain VANET is quickly formed in a particular geographical area over a limited time frame. After a short time period, the network dissolves and a new VANET is formed. This keeps repeating over and over again throughout the vehicle's travel route. For such distributed, complex, and dynamically-changing networks, V2X capabilities are indispensable. In fact, the objective of smart future ITS is to ensure fast connectivity that is seamlessly interweaved with a cascading combination of V2V, V2I, V2P, and V2N networks. For such very complex networks, where data is routed across different devices and critical infrastructures, and where interoperability among the diverse units is a basic necessity, various critical metrics within the 5G requirement are fundamental, namely: ultra-reliability, low-latency, high-capacity, variable-mobility, and elevated traffic-density. Evidently, evaluating, assessing, and designing the parameters of the communication link for a V2X network with unpredictable traffic status will be of critical concern for future roads populated by highly autonomous vehicles.

The reliability metric alone is immensely complicated to fulfill. For instance, a packet reliability of 99.999% is generally feasible for semi-autonomous vehicles with a driver-in-the-loop. Whereas, for fully autonomous, where no human intervention is required, a reliability of 99.9999999% is expected. Communication latency is yet another element of concern where extremely low values in the range of 2~3 milliseconds are desired. As for data capacity, a communication of multi-Gigabits per second, up to 8 Gbps, is anticipated in order to share on-route information with other vehicles in the region and the network cloud.

Despite the densification of the vehicular network, the quality of service ought to remain in constant communication with ultra-high reliability. In other words, in an urban setting, it is estimated that there are roughly 1,000 vehicles per square kilometer; in the suburbs, it is estimated at 500 vehicles/km^2, and on highways, the values are even fewer than these numbers. Moreover, reliability must be preserved up to a communication range among vehicles in the order of 100-200 meters on roads, and 500 meters on highways.

It is of the utmost importance to have both sensor capabilities and communications technology, as they complement each other and also serve as sources for supplemental system redundancy, added security and greater awareness of the vehicle's surroundings

Achieving these constraints and requirements altogether is a recipe for immense challenges. To tackle this undertaking, it is of the utmost importance for the electrical engineering community advancing the 5G network for the ITS ecosystem to work together and in cohesion, both at the fundamental and experimental research tracks. There are various overlapping concepts in different sub-systems that demand a holistic understanding and fluency, and thus cross-pollination of expertise is required to optimize a complex communication network for highly autonomous vehicles. Different areas of radiofrequency engineering (i.e., communications, microwaves, propagation, and antenna systems) must collectively work the technical intricacies that are of extreme interdependence in order to predict and eliminate the potential sources of road accidents.

Extensive research on many fronts is required, including (i) network modeling based on real-world vehicular traffic, (ii) connectivity and throughput analysis founded on average performance assessed by measurable data, and fine-grained performance accessed by meta-distribution techniques, (iii) mobility concerns and robustness to Doppler effect, say up to 300 kilometers per hour, (iv) temporal aspects of traffic variability, (v) empirical propagation channel measurements and modeling over high frequencies, (vi) modulation schemes and network access, (vii) system design and spatial diversity, (vii) antenna design issues with single and multiple antenna elements, and (viii) antenna position on the vehicle, directivity, beamforming, etc.

The eventual future of smart cities with intelligent transportation for road safety and traffic efficiency is inevitable. Everything that should be connected must be connected; this includes the seamless connectivity of vehicles, cyclists, pedestrians, etc. Bringing this eventuality of a data rich environment to fruition will require creative engineering solutions to intercorrelated challenges, which are expected to result in opportunities and gains for society at large. This article attempted to underscore the complementary need of both sensors and connectivity for highly autonomous vehicles. Technical requirements for vehicular interconnectivity and overall system performance under the anticipated 5G communications were discussed. Open challenges that will require extensive research by the scientific engineering community before real-world mass deployment of highly autonomous vehicles were also highlighted. ■