

Sheridan Institute of Technology

From the SelectedWorks of Mouhamed Abdulla, Ph.D., MIEEE

Fall October 1, 2017

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

Dr. Mouhamed Abdulla, *Chalmers University of Technology, Göteborg, Sweden*

Prof. Ke Wu, *University of Montréal, Québec, Canada*

Creative Commons License
This work is licensed under a Creative Commons CC_BY International License.



Available at: <https://works.bepress.com/mouhamed-abdulla/19/>

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

AILLEURS DANS LE MONDE,
transport et infrastructure riment avec intelligence

AQT

L'expertise en transport



Canada

ACTIVE-AURORA : TRANSFORMER LES TRANSPORTS AU CANADA

Rod Schebesch et Martin Thibault
page 83

THE VALUE PROPOSITION OF MOBILITY SERVICES: OPPORTUNITIES AND CHALLENGES FOR SUSTAINABLE OPERATIONS

Ryan Falconer & Melissa Felder
page 88

HOW CAN ORGANIZATIONS BECOME A PART OF THE SHARED MOBILITY EVOLUTION?

Amanda Lam
page 93



États-Unis

BUILDING MOMENTUM FOR A NEW ERA OF TRANSPORTATION MOBILITY AT GOMENTUM STATION, CALIFORNIA

Habib Shamskhou & Arya Rohani
page 99

AUTOMATED VEHICLES AND THE CHANGING URBAN TRANSPORTATION LANDSCAPE

Lisa Jerram
page 104



Argentine

LES VÉHICULES AUTONOMES (ET PARTAGÉS), L'ÉTALEMENT URBAIN ET LES SYSTÈMES DE TRANSPORT PUBLIC DANS LES VILLES D'AMÉRIQUE LATINE

Frédéric Blas, Thomas Massin
et Florencia Rodriguez
page 109



France

LA ROUTE DE DEMAIN SERA- T-ELLE AUSSI ÉLECTRIFIÉE, AUTOMATISÉE ET PARTAGÉE ?

Nicolas Hautière et Fabien Menant
page 115



Suède

5G CONNECTED VEHICLES: THE MISSING LINK TO HIGHLY AUTONOMOUS VEHICLES

Mouhamed Abdulla & Ke Wu
page 123

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 Vehicles: The Missing Link to Highly Autonomous Vehicles* (à lire en page 123).

RÉDACTRICE EN CHEF

Emmanuelle Royer

AUTEURS

Mouhamed Abdulla
 Jean-Pierre Arcoragi
 François Béïsle
 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 Lavigne
 Antoine Malo
 Thomas Massin
 Fabien Menant
 Catherine Morency
 Gheorghe Munteanu
 Pegah Nouri
 Alexandra Ouimet
 Yves Provencher
 Pascal Renaud
 Florencia Rodriguez
 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 Dérégis, ER Translations et Youssef Megharfi

ORIENTATION

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. Les opinions exprimées dans la revue *routes et transports* n'engagent que la responsabilité de leurs auteurs et ne reflètent pas nécessairement les positions de l'Association québécoise des transports. Tous les articles de *routes et transports* peuvent être reproduits sans autorisation, à condition d'en mentionner la source et de faire parvenir un exemplaire de la publication au secrétariat de l'Association québécoise des transports.

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 n°: 40038871

Port de retour garanti

GRANDS PARTENAIRES**PARTENAIRES PRESTIGE**

Aéroports de Montréal, Association québécoise du transport intermunicipal et municipal (AQTIM), Axor Experts-Conseils Inc., Englobe Corp., Groupe S.M. international, Les services EXP, Norda Stelo, Pricewaterhouse Coopers s.r.l./s.e.n.c.r.l., Réseau de transport de la Capitale (RTC), Société de transport de Montréal (STM), Tetra Tech QI Inc., Ville de Québec



Partenaire principal de l'AQTr

PARUTIONS 2017

	Thème	Parution
VOL. 46 N°1	Ville, vision, vitalité	Printemps 2017
VOL. 46 N°2	Le transport du futur sera électrique, autonome et partagé!	Automne 2017

Articles

Nous attendons vos propositions d'articles. Pour connaître les dates de remise des textes, veuillez consulter notre site Web à AQTr.com.

Publicité

Pour réserver votre espace publicitaire et offrir une visibilité incomparable à votre entreprise, contactez Anne-Julie Robitaille au 514 523-6444, poste 313.

Profil d'entreprise

Faites connaître votre entreprise en réservant le prochain Profil d'entreprise, un publireportage comprenant deux pages de contenu rédactionnel.

Des nouvelles de nos partenaires

Faites-nous connaître vos dernières réalisations. Contactez-nous à communication@AQTr.com.

Suggestions

Faites parvenir vos suggestions à communication@AQTr.com.



FRANCE

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



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](#).



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](#).

A wide-angle, golden-yellow photograph of Stockholm's Old Town (Gamla Stan) at sunset. The image captures a dense cluster of historic buildings, including several with prominent towers and spires, all reflected in the calm water of a canal in the foreground. The sky is filled with warm, hazy clouds.

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 interwoven with a cascading combina-

tion 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 99.999999% 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/km², 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.

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.

**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**

nel measurements and modeling over high frequencies, (vi) modula-

tion schemes and network access, (vii) system design and spatial diversity, (viii) antenna design issues with single and multiple antenna elements, and (ix) 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. ■

Nous transformons activement l'avenir des transports

**Actively transforming the
future of transportation**



Imaginer et réaliser dans l'intérêt commun
stantec.com