Top Level Newsletter: Connected Vehicle

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Editor-in-Chief: Kay Das, IEEE Life Member,
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Vol 40: This issue includes articles relevant to the 6G future of connected vehicles:

1. Open Radio Access Network (O-RAN) is an emerging paradigm…
2. Toward 6G Vehicle-to-Everything Sidelink
3. Integrating Terrestrial and Non-Terrestrial Networks: 3D Opportunities and Challenges

General Notes
This series of newsletters is intended to provide the IEEE member with a top level briefing of the many different subjects relevant to the research, development and innovation of the connected vehicle.

The objective is to provide a platform for fast learning and quick overview so that the reader may be guided to the next levels of detail and gain insight into correlations between the entries to enable growth of the technology. Intended audiences are those that desire a quick introduction to the subject and who may wish to take it further and deepen their knowledge. This includes those in industry, academia or government and the public at large. Descriptions will include a range of flavors from technical detail to broad industry and administrative issues. A (soft) limit of 300 to 600 words is usually set for each entry, but not rigorously exercised.

As descriptions are not exhaustive, hyperlinks are occasionally provided to give the reader a first means of delving into the next level of detail. The reader is encouraged to develop a first level understanding of the topic in view. The emphasis is on brief, clear and contained text. There will be no diagrams in order to keep the publication concise and podcast-friendly. Related topics in the case of Connected Vehicle technology, such as 5G cellular and the Internet of Things will be included. The terms Connected Vehicle and Automated Driving will be used inter-changeably. Articles from other published sources than IEEE that add to the information value will occasionally be included.

This newsletter forms part of the regional Advanced Technology Initiative (ATI) of which connected vehicles form a constituent part. Technical articles solely from IEEE journals/magazines are referred to by their Digital Object Identifier (DOI) or corresponding https link. The link for each article is provided. Those readers who wish to delve further to the complete paper and have access to IEEE Explore (www.ieeexplore.ieee.org) may download complete articles of interest. Those who subscribe to the relevant IEEE society and receive the journal may already have physical or electronic copies. In case of difficulty please contact the editor at kaydas@mac.com. The objective is to provide top level guidance on the subject of interest. As this is a collection of summaries of already published articles and serves to further widen audiences for the benefit of each publication, no copyright issues are foreseen.

Readers are encouraged to develop their own onward sources of information, discover and draw inferences, join the dots, and further develop the technology. Entries in the newsletter are normally either editorials or summaries or abstracts of articles. Where a deepening of knowledge is desired, reading the full article is recommended.

1. Information-to-Model Matching for AI in Open Radio Access Networks (by Jorge Martin Perez et al)

Published in: IEEE Communications Magazine (Volume: 61, Issue: 4, April 2023) **Page(s):** 58 - 63

DOI: https://doi.org/10.1109/MCOM.003.2200401

Abstract:
Open Radio Access Network (O-RAN) is an emerging paradigm, whereby virtualized network infrastructure elements from different vendors communicate via open, standardized interfaces. A key element therein is the RAN Intelligent Controller (RIC), an Artificial Intelligence (AI)-based controller. Traditionally, all data available in the network has been used to train a single AI model to be used at the RIC. This article introduces, discusses, and evaluates the creation of multiple AI model instances at different RICs, leveraging information from some (or all) locations for their training. This brings about a flexible relationship between gNBs. In 5G, a gNodeB is responsible for radio communication with UEs in its coverage area, known as a cell. A gNodeB may be a physical entity, such as a tower, or the AI models used to control them, and the data such models are trained with. Experiments with real-world traces show how using multiple AI model instances that choose training data from specific locations improve the performance of traditional approaches following the hoarding strategy.

Conclusion:

We have proposed and analyzed a new approach to the integration of AI in O-RAN scenarios, allowing to assign different model instances to each gNB of the network, and independently *choose* the data each instance is trained on. Our approach deviates from the state of the art in that it does not seek to train one model instance for the whole network and to train it using all available data; therefore, it provides more flexibility than fully-centralized and fully-distributed approaches.

Our performance evaluation, leveraging real-world traces, shows how our approach yields very attractive trade-offs between training time and learning effectiveness, by combining data from different sources in a flexible manner. Future research directions stemming from our work include characterizing *a priori* the usefulness of data for AI training, trade-offs between data transfer delays and AI training time, and the impact of AI accuracy over the performance of concrete applications.

2. Toward 6G Vehicle-to-Everything Sidelink: Nonorthogonal Multiple Access in the Autonomous Mode (by Alessandro Bazzi et al)

Published in: IEEE Vehicular Technology Magazine (Volume: 18, Issue: 2, June 2023)
Page(s): 50 - 59

Abstract:

The cellular vehicle-to-everything (C-V2X) sidelink technology, specified in the long-term evolution (LTE) and further improved in the 5G new radio (NR) standards to facilitate direct data exchange between vehicles, will play a crucial role in revolutionizing transportation systems. However, the demand for very high reliability and ultralow latency services especially challenges the sidelink resource allocation mechanism when performed by distributed vehicles, in the so- called autonomous mode. One of the major causes of performance degradation is the resource allocation mechanism, which was designed for orthogonal multiple access (OMA) and can generate interference and collisions under high load conditions. In this context, here we argue in favor of the use of non-OMA (NOMA) as a game changer for the sidelink in the upcoming 6G V2X, and the purpose of this article is to provide a reference for further intriguing studies in the field. Additionally, the gain achievable over conventional allocation schemes by enabling NOMA through the use of successive interference cancelation (SIC) at the receiver is measured through realistic simulations conducted when considering the latest C-V2X specifications.

NOMA has been extensively studied for 5G downlink and uplink, with specifications introduced for the LTE downlink in release 14 and a study conducted within the 3GPP for the 5G uplink in release 16. However, its adoption to the more challenging C-V2X sidelink interface has not yet been discussed in standardization and has only recently been considered in early literature works with a few of them addressing the autonomous mode.

To fill this gap, the objective of this article is to provide a general but concise view of what could be denoted as NOMA solutions, and discuss their implications and potential for the specific scenario of the C-V2X sidelink, exhibiting peculiar features. NOMA is indeed not a single but a number of different techniques; it can be realized in the power domain or code domain, grant-based or grant-free, single or multislot, and also in a cooperative manner. Such techniques can be differently shaped in the V2X context and may all contribute to the evolution of a sidelink toward a more robust, efficient, and reliable 6G air interface. Toward this aim, we provide a review of the latest research and, additionally, we show through original simulations conducted in realistic large-scale scenarios the significant improvement achieved just by the application of the main NOMA enabler, i.e., SIC, on top of the legacy C-V2X sidelink autonomous mode operation.

Introduction:

The automotive and transportation sectors are the key areas that demonstrate the breakthroughs of the 5G NR communication system. In such a context, providing 5G connectivity over the sidelink of a vehicular user equipment (VUE), such as a car or a truck, is a pivotal enabler of a plethora of applications targeting cooperative automated driving (CAD). Unlike the conventional uplink/downlink, the sidelink interface supports direct short-range V2X communications between vehicles, or between vehicles and pedestrians, roadside units, and other stationary or moving road elements in the vehicle surroundings.

Sidelink communication has been one of the main focuses of the latest efforts of the Third Generation Partnership Project (3GPP) aimed at enhancing the cellular system with V2X connectivity support, under the umbrella term of *C-V2X*. Studies started from release 14 with the LTE-V2X technology. The recent NR-V2X sidelink specifications in release 16 and the enhancements in release 17 represent a step forward, but still cannot fully match the challenging reliability and latency requirements of CAD applications.

Sidelink communication is aimed at avoiding interference among simultaneously transmitting vehicles by selecting nonoverlapping resources, based on an OMA to the channel. Due to imperfect channel sensing and vehicle coordination, resource orthogonality cannot always be assured. This is especially true when sidelink resources are selected by vehicles without the support of the base station (BS), in the so called *autonomous* mode (as well as mode 4 in LTE-V2X and mode 2 in NR-V2X). The limitations of half-duplex (HD) transceivers on board, vehicle mobility, and hidden terminal phenomena can cause resource collisions, leading to system performance limited by interference. The situation becomes worse as the number of transmitting VUEs or the channel load increases. Such a scenario is expected in the near future, with the higher penetration rate of the C-V2X technology and because of bandwidth-hungry and information-rich CAD applications, e.g., cooperative sensing and maneuvering. Solutions targeting straightforward enhancements may not be sufficient to address the above scalability and capacity demands, and more disruptive techniques are required.

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3. Integrating Terrestrial and Non-Terrestrial Networks: 3D Opportunities and Challenges (by Giovanni Ceraci et al)
Published in: IEEE Communications Magazine (Volume 61, Issue 4, April 2023), pages 42-48.

Abstract:
Integrating terrestrial and non-terrestrial networks has the potential of connecting the unconnected and enhancing the user experience for the already-connected, with technological and societal implications of the greatest long-term significance. A convergence of ground, air, and space wireless communications also represents a formidable endeavor for the mobile and satellite communications industries alike, as it entails defining and intelligently orchestrating a new 3D wireless network architecture. In this article, we present the key opportunities and challenges arising from this revolution by

presenting some of its disruptive use cases and key building blocks, reviewing the relevant standardization activities, and pointing to open research problems. By considering two multi-operator paradigms, we also showcase how terrestrial networks could be efficiently re-engineered to cater for aerial services, or opportunistically complemented by non-terrestrial infrastructure to augment their current capabilities.

Introduction:

A mobile connection is our window to the world. The current social, economic, and political drive to reach global wireless coverage and digital inclusion acknowledges connectivity as vital for accessing fair education, medical care, and business opportunities in a post-pandemic society. Sadly, nearly half of the population on Earth remains unconnected. Indeed, rolling out optical fibers and radio transmitters to every location on the planet is not economically viable, and reaching the billions who live in rural or less privileged areas has remained a chimera for decades. The long-overdue democratization of wireless communications requires a wholly new design paradigm to realize ubiquitous and sustained connectivity in an affordable manner.

The authors present key opportunities and challenges arising from this revolution by presenting some of its disruptive use cases and key building blocks, reviewing the relevant standardization activities, and pointing to open research problems, Meanwhile, in more urbanized and populated areas, even 5G may eventually fall short of satiating our appetite for mobile internet and new user experiences. Life in the 2030s and beyond will look quite different from today's: hordes of network-connected uncrewed aerial vehicles (UAVs) will navigate 3D aerial highways - be it for public safety or to deliver groceries to our doorstep - and flying taxis will re-shape how we commute and, in turn, where we live and work. The bold ambition of reaching for the sky will take the data transfer capacity, latency, and reliability needs for the underpinning network to an extreme, requiring dedicated radio resources and infrastructure for aerial services.

In a quest for anything, anytime, anywhere connectivity - even up in the air - next-generation mobile networks may need to break the boundary of the current ground-focused paradigm and fully embrace aerial and spaceborne communications. To this end, the wireless community has already rolled up its sleeves in search for technology enhancements towards a fully integrated terrestrial plus non-terrestrial network (NTN) able to satisfy both ground and aerial requirements. At first glance, terrestrial networks (TNs) could be:

- Re-engineered and optimized to support aerial end-devices
- Complemented by NTN infrastructure such as low Earth orbit (LEO) satellite constellations or aerial base stations (BSs) to further enhance performance.

Cost-related factors may advocate for a progressive roadmap. In the present paper, we discuss the great opportunities and challenges lying behind a 3D integrated TN-NTN from a new standpoint. We begin by providing examples of disruptive use cases, an overview of the building blocks of an integrated TN-NTN architecture, and an up-to-date summary of the relevant 3rd Generation Partnership Project (3GPP) standardization activities. We then place the spotlight on aerial services, and introduce novel case studies for a conventional terrestrial operator pursuing aerial connectivity through two plausible choices:

- Deploying dedicated uptilted cells - or partnering with a specialized aerial operator doing so - reusing the same spectrum;

- Leasing infrastructure or solutions from a LEO satellite operator.

We conclude by reviewing the main hurdles that still stand in the way to an integrated TN-NTN and pointing out key open problems worthy of further research.

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