Top Level Newsletter: Connected Vehicle

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Vol 30: This issue includes survey of a special section on the safety of automated driving in Intelligent Transport Systems and a top level look at the challenges of 6G.
(1) Safety of Automated Driving in Intelligent Transportation Systems (a guest editorial with three rather theoretical summaries)
(2) Six Critical Challenges for 6G Wireless Systems: A Summary and Some Solutions

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. **Special Section on Safety of Automated Driving in Intelligent Transportation Systems [Guest Editorial], Hong Wang et al**

Published in: IEEE Intelligent Transportation Systems Magazine (Volume: 14, Issue: 2, March-April 2022), pp8-9

With the promise of safer transportation, autonomous vehicles (AVs) are expected to increase road safety by 94%. However, accidents still occur involving AVs, which attracts increasing attention from academia and industry. To achieve the maximum potential for improved transportation safety, efforts are required to seek solutions from fundamental theory, key technology, guarantee frameworks, and so on. This special section aims to provide a platform for researchers and engineers from academia and industry and policy makers to present their latest research findings and engineering experiences in developing and applying novel technologies to improve and address transportation safety. The topics cover safety of the intended functionality for intelligent vehicles, risk assessment, control of AVs and vehicle platoons, and so on.

The continuous validation of the operational design domain (ODD) of an automated driving system (ADS) and the augmentation of its adequate safe operating space employing iterative engineering seems to be a prudent approach to improve the safety performance and integrity of AVs. Three articles have been chosen.

(A) "Acclimatizing the Operational Design Domain for Autonomous Driving Systems"(pp10-23) by Chen Sun et al., proposed an ODD acclimatization framework based on the driving scenario and environment models. This article provides promising directions that display great potential for future work on ODD monitoring and applications in iterative development for an automated driving system.

Abstract: The ODD of an automated driving system (ADS) can be used to confine the environmental scope of where the ADS is safe to execute. ODD acclimatization is one of the

necessary steps for validating vehicle safety in complex traffic environments. This article proposes an approach and architectural design to extract and enhance the ODD of the ADS based on the task scenario and the corresponding requirements in the development and verification cycle. The ODD is tightly focused on a unified quantifiable environmental model in the proposed approach while overseeing the ODD extraction process by formal specifications. In addition to the acclimatization framework, an implementation of the proposed approach is examined with two learning-based agents to demonstrate its feasibility. The proof of concept has shown promising directions for future work on ODD monitoring and on the applications in iterative development for ADSs.

(B) "Human–Machine Adaptive Shared Control for Safe Driving Under Automation Degradation,"(pp53-66) by Chao Huang et al proposes a human–machine adaptive shared control method for AVs under automation performance degradation, which consists of a novel risk assessment module and an adaptive control authority allocation module. This article presents experimental validation under different driving scenarios, and the method displays great potential to ensure the safety of automated driving.

Abstract: In this article, a human–machine adaptive shared control method is proposed for automated vehicles (AVs) under automation performance degradation. First, a novel risk assessment module is proposed to monitor driving behavior and evaluate automation performance degradation for AVs. Then, an adaptive control authority allocation module is developed. In the event of any performance degradation, the control authority allocated to the automation system is decreased based on the assessed risk. Consequently, the control authority allocated to a human driver is adaptively increased and thus requires more driver engagement in the control loop to compensate for the automation degradation and ensure the vehicle's safety. Experimental validation is conducted under different driving scenarios. The test results show that the approach can effectively compensate for vehicle automation performance degradation through human–machine adaptive shared control, ensuring the safety of automated driving.

(C) "Adaptive Finite-Time Trajectory Tracking Control of Autonomous Vehicles That Experience Disturbances and Actuator Saturation,"(pp80-91 by Hongbo Gao et al present a finite-time tracking control scheme for AVs that uses a fuzzy logic system to cope with the lumped disturbance and an auxiliary system to tackle the actuator saturation. The method demonstrates the ability to guarantee finite-time error convergence, chattering elimination, and strong robustness.

Abstract: Dynamic couplings, various disturbances, and uncertainties have posed a big challenge to trajectory tracking control. This article presents a finite-time tracking control scheme for autonomous

vehicles. Trajectory tracking is difficult to control due to dynamic couplings and various disturbances and uncertainties. To cope with a lumped disturbance, a fuzzy logic system is designed. In particular, a novel adaptive algorithm is constructed to adjust the gain online, and it works well even without the prior information of the lumped disturbance bounds. An auxiliary system with a simple structure is built to tackle the actuator saturation. Moreover, the proposed control method can guarantee finite-time error convergence, chattering elimination, and strong robustness. Experiment results are presented to show the effectiveness of the control schemes. (754 words)

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2. Six Critical Challenges for 6G Wireless Systems: A Summary and Some Solutions

(Harsh Tatatia et al)

Published: IEEE Vehicular Technology Magazine (Vol 17, Issue 1, pp 16-26)

Abstract: Numerous articles are now appearing on 6G wireless systems, covering different aspects, ranging from vision, architecture, and applications to technology breakthroughs. With cellular systems in mind, this article presents six critical, yet fundamental, challenges that must be overcome before the development and deployment of 6G systems. These include opening the subterahertz spectrum for increased bandwidths and the ability to utilize these bandwidths, pushing the limits of semiconductor technologies for operation within these bands, developing transceiver designs and architectures to realize the high peak data rates, and achieving submillisecond latencies at the network level to achieve 6G key performance indicators (KPIs). Additionally, since 6G systems will not be introduced in a greenfield environment, backward compatibility with existing systems is discussed. Where possible, we present practical solutions to realize the identified challenges.

Overview: 5G new radio (5G-NR) systems are now a commercial reality. 3G Partnership Project (3GPP) releases 16 and 17 aim to serve as key enablers for the evolution of 5G-NR, capturing the interworking capabilities of enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low-latency communication (URLLC). In parallel, a leap into the future is being taken by the International Telecommunication Union-Telecommunication Standardization Sector to develop a focus group called Network 2030 which studies the capabilities of networks for 2030. We refer to these as 6G wireless systems. Disruptive technologies in response to lifestyle/societal changes are predicted, which include 1) a holographic society, where holograms/immersive reality will form a preferred means of communications; 2) a much higher connectivity for all things than with 5G; and 3) time-sensitive communications, where sensors form the end points of communication.

a rigorous discussion of the critical research challenges focused on standardization, deployment, and commercial adoption of 6G systems is precisely the focus of this article. We identify six practical, yet fundamental, challenges spanning the entire 6G system, which must be overcome before the development and deployment phases. Using cellular systems as our axis of exposition, we exemplify the following areas: efficient spectrum utilization, efficient design of radio transceivers, realization of ultralow latencies (ULLs), and an analysis on the constraints imposed by backward compatibility. (We do not neglect the importance of other challenges across multiple frequency bands, which may be as critical. Our derivation of challenges is primarily centered on an eventual standardization, commercialization, and deployment perspective.) For each challenge, we identify practical limitations imposed by the technology and draw meaningful conclusions on eventual system-level impact.

For real-time holographic and immersive communication applications, data rates of ≥1 Tb/s are quoted. This, in turn, requires the use of a spectrum that can provide the needed bandwidths. A suitable candidate band lies within the range 140–350 GHz also known as *window W1* of the subterahertz band [Naturally, not all 6G services will be viable in these bands, and the existing microwave and millimeter-wave (mmWave) bands will continue to play a vital role in striking the right balance between wide area coverage and optimizing peak data rates. Here, tens of gigahertz of bandwidth are available for use. However, utilizing the available bandwidth for a working system is a challenge. We discuss the tradeoffs involved in utilizing large bandwidths and provide a cautionary tale of its impact on system performance.

If the physical size of the transmit/receive antennas is not kept constant over frequency, subterahertz bands will pose tremendous challenges to facilitate communication. This renders the following essential: 1) array gain and 2) highly directional beamforming. To strike the performance versus implementation complexity “sweetspot” of transceivers, designs of analog, hybrid, and digital beamforming solutions have been explored. While these are currently being optimized for 5G, a large gap—as well as the terahertz gap—is open for research. In fact, the underlying architectures of mixed-signal circuits required in the up/down-conversion radio-frequency chains remain unsolved for such bands. Since a high degree of integration will be required, transceiver operations may be conducted with complete system-on-chip solutions. We discuss the challenges impacting efficient transceiver design and operation for subterahertz bands.

From a semiconductor viewpoint, though CMOS processes with a feature size of 28 nm and lower can be utilized [since they yield an f_{max} (maximum frequency where the semiconductor is able to provide power gain) well above 250 GHz], other alternatives, such as silicon germanium (SiGe) bipolar CMOS (BiCMOS), high-electron mobility transistors, gallium arsenide (GaAs), and type III–V materials must be considered. The reason is that operation above 100 GHz requires careful conditioning of the output power, phase noise, in-phase and quadrature (I/Q) imbalance, and noise figure along with the semiconductor process reliability and packaging. Therefore, one may seek a more heterogeneous base that can strike the right balance in optimizing the preceding parameters with their relative cost. We discuss the challenges associated with different semiconductor technologies and outline their respective capabilities.

Operating between 140 and 350 GHz will require up to an order-of-magnitude more elements relative to arrays deployed between 24.5 and 29.5 GHz. The design of such arrays with high radiation efficiency across wider bandwidths poses enormous challenges. Scaling of the number of elements yields narrow beamwidths, and catering to wider bandwidths is difficult since the array performance at the lower edge of the band may be substantially different from that at the higher edge. As such, steering the overall array/beamforming gain toward the user equipment (UE) poses a major challenge. We assess when it may be likely for a system to achieve terabit/second rates and provide a discussion about its challenges.

The submillisecond latencies required by the time-sensitive use cases require not only an optimized physical layer (PHY), but also higher layers. Such latencies cannot be realized by the current transport and core network architectures. As such, flattening or significant reduction of the architecture is necessary. We evaluate the contributions to the end-to-end latency and provide suggestions on how to minimize them. Even if all of these modifications were made, the requirement for 6G systems to fall back to 5G and 4G may restrict the changes that may eventually be commercialized. The challenges related to latency and backward compatibility are discussed in separate sections.

Conclusions: Naturally, there are significant challenges to be overcome before we can think of 6G deployments. The realization of terabit/second data rates requires large bandwidths. If the 5G experience is a guide, maximum carrier bandwidths are limited to 400 MHz. This leads to aggregating large numbers of carriers to create higher total bandwidths. Building radios and associated RF circuits at subterahertz bands presents significant challenges. Therefore, finding the right balance between transceiver efficiency/integration, packaging, and cost is a key issue. Assuming that transceivers can be built, achieving terabit/second rates will require ultramassive arrays. Given the low channel rank, distributed arrays will be the way forward. Time-sensitive communications need submillisecond latencies. We articulate an approach to achieve low latencies by addressing contributions from the air interface, RAN, and transport networks. 6G will not be introduced in greenfield environments; we present a 6G system architecture and demonstrate how it will be backward compatible to earlier generations. (1165 words)

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