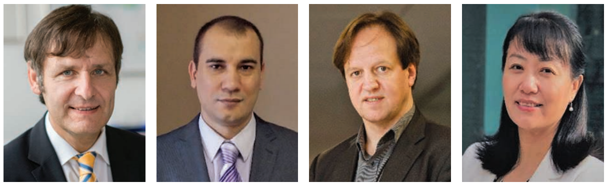

Klaus David, Anwer Al-Dulaimi, Harald Haas,
and Rose Qingyang Hu

6G Fabric Compiles Microdomains for Sophisticated Service Delivery

While the industry is exploring the key drivers and future needs of 6G cellular communication systems, 6G research is in full swing, globally supported by large programs. As a result, many new technologies are being proposed. This could be noticed in various fora and publications that convey new visions for the verticals that 6G would serve and the key elements that could make this happen. New radio and optical wireless access technologies for 3D coverage, new waveforms, artificial intelligence (AI) and machine learning (ML), edge–cloud supported by AI, joint communication and sensing, optical fiber networks, nonterrestrial network (NTN) integration, new network architectures, trusted computing platforms, quantum communications, and digital twin provisioning systems are some of many technology enablers for 6G. However, 6G will support many more vertical industries. This requires defining a new model for network infrastructures that builds on 5G architectures and designs, especially private networks and open networking. This means that operating minor networks independently at their local domains and allowing separated domains to handle services without centralized management may become more mainstream. AI and ML will become important enablers for future network management and control. This segregation within the mobile network architecture allows AI-driven components to maximally utilize resources at their local domain. In addition, minor domains would be able to decompose service requests to reduce operational cost incurred by the network. This network modeling takes advantage of fully automated elements and services that could be onboarded upon user demand for more efficient networks that fully utilize resources in a cost-efficient manner. Therefore, operators and vendors need to work closely with network planning engineers and academia to bring such designs into reality.

Digital Object Identifier 10.1109/MVT.2023.3238481
Date of current version: 2 March 2023

The cycle for 6G development, from the conceptual level to field trials and final deployment, will take many years to come, and we will probably see the first 6G live network by 2030. However, it is very important to start defining the new technologies that could define the pillars for 6G and what could be the new technical 6G standard. Since we are looking at the next wave of digitization, future standard committees need to be more diverse and bring together experts from telecom, cloud, software, and application developer industries. To this point, academics and technology visionary specialists could also contribute to 6G standards through their ideas and solutions. Given the significant progress that humanity made with cellular communications during the past 40 years, it is important to remain adventurous and bold in terms of new visions. It is important to get all experts around the table to define how we could develop a carbon-efficient, secure, trustworthy, and user-friendly network that unleashes digital economies around the emerging trends of fully autonomous systems, the metaverse, and future digital twins. 6G could be a turning point for societies from every social and industrial aspect, and we need to combine the right ideas with technical elements to demonstrate new advanced communication networks. IEEE Future Networks created various projects, such as the Connecting the Unconnected Challenge, a 5G/6G testbed, and many others, to gather passionate researchers who are willing to contribute to 5G/6G evolutions. This series in *IEEE Vehicular Technology Magazine* is one of the most prominent activities to document how to develop, launch, and maintain 6G networks.

This is the third special issue in the "IEEE Future Networks Series on 6G Technologies and Applications" series by *IEEE Vehicular Technology Magazine*. This special issue includes nine technical articles that focus on research aspects and industrial challenges of 6G communications. In the following, we present a summary of the accepted articles.

The first article, "Reconfigurable Holographic Surface: A New Paradigm to Implement Holographic Radio," is by Ruoqi Deng et al. [A1]. The article studies a new holographic radio concept for ultramassive multiple-input, multiple-output (MIMO), where numerous tiny and inexpensive antenna elements are integrated to realize high directive gain with low hardware cost. The authors analyze a prototype of a reconfigurable holographic surface radio system that was built to verify the performance of the technology. The authors highlight the potential to achieve high directive gain with low hardware cost, low power consumption, and simple circuits.

The second article, "AI-Based Time-, Frequency-, and Space-Domain Channel Extrapolation for 6G: Opportunities and Challenges," is by Zhen Zhang et al. [A2]. The article uses AI to divide the channel extrapolation into time, frequency, and space domains according to different application scenarios. Various AI models are used to characterize the channel propagation that affects the extrapolation of each domain, such as the spatial consistency property, partial reciprocity, and spatial nonstationarity. The authors show how a cross-domain extrapolation strategy based on transfer learning can accelerate the training process of the AI model and improve the channel extrapolation accuracy.

The next article, "Positioning and Sensing in 6G: Gaps, Challenges, and Opportunities," is by Ali Behravan et al. [A3]. The authors provide a selected set of 6G use cases and determine their positioning and sensing requirements to identify the gaps against state-of-the-art technologies. Focusing on positioning, the article shows that between the three key performance indicators (KPIs) (accuracy, latency, and availability), there is a significant gap between the 5G capability and the 6G requirements. Similarly, sensing analysis shows gaps in certain KPIs (accuracy and resolution) between current and future sensing requirements. The authors also present a framework for positioning in future 6G radios, considering technical enablers and predefined challenges in real deployments.

The fourth article, "Artificial intelligence-Assisted Network Slicing: Network Assurance and Service Provisioning in 6G," is by Jiadai Wang et al. [A4]. The authors provide a comprehensive review of AI-assisted 6G network slicing for network assurance and service provisioning. The article aims to show the typical characteristics of 6G network slicing, analyze the feasibility of AI implementation in various network domains, and include a new system framework. The article provides a case study on AI-assisted bandwidth scaling and, finally, summarizes the main challenges and open issues for its future developments.

The fifth article, "Aligning the Light for Vehicular Visible Light Communications: High Data Rate and Low-Latency Vehicular Visible Light Communications Implementing Blind Interference Alignment," is by Máximo Morales Céspedes et al. [A5]. This article focuses on the use of blind interference alignment (BIA) for vehicular visible light communications (V-VLC), considering a reconfigurable photodetector to provide linearly independent channel responses. The authors show that BIA solves the issues of MIMO techniques and meets the main requirements for 6G V-VLC. The article demonstrates that vehicles are potential platforms for implementing a reconfigurable photodetector. The article raises the issues of BIA implementation in V-VLC and showcases a road map for further investigations.

The sixth article, "Recent Advances of Ultramassive Multiple-Input, Multiple-Output Technologies: Realizing a Sixth-Generation Future in Spatial and Beam Domains," is by Rui Feng et al. [A6]. The authors address 6G ultramassive MIMO techniques in both spatial and beam domains, focusing on channel parameter estimation algorithms, channel characteristics, and channel models to evaluate future physical layer technology designs. The given analysis emphasizes the transitions of data processing in the spatial domain to demonstrate the efficiency tradeoff between accuracy and complexity. The article shows the need for further studies on new ultramassive MIMO to characterize overall system performance.

The seventh article, "Futuristic 6G Pervasive On-Demand Services: Integrating Space Edge Computing With Terrestrial Networks," is by Zeqi Lai et al. [A7]. The authors propose space edge computing (SEC), which combines advanced computational features with networking and storage elements for satellite platforms. The goal for this merging of technologies is to enable pervasive and performant on-demand services in 6G. The authors investigate the technical features of SEC and integrated satellite cloud architecture that support "space edges" and "terrestrial clouds" enabling on-demand services anytime, anywhere. The article also provides performance analysis and discusses new directions for future research.

The eighth article, "Multicasting Over 6G Non-Terrestrial Networks: A Softwarization-Based Approach," is by Claudia Carballo González et al. [A8]. The article analyzes service delivery over multicast/broadcast aided by softwarization and resource allocation mechanisms. This is driven by Internet of Things deployment and extended reality multimedia application scenarios. The article considers these services to be delivered through NTNs. NTNs can be used to extend mobile access networks, leading to new research directions on 6G architectures employing smaller domains.

The final article, "Semantic Communication for the Internet of Vehicles: A Multiuser Cooperative Approach," is by Wenjun Xu et al. [A9]. The article studies a cooperative semantic-aware architecture to convey essential semantics from connected users to servers to reduce the exchanged traffic. The authors propose the idea of semantic-aware content delivery in the

Internet of Vehicles (IoV), with a special focus on the successful transmission of essential semantics of the source data. To demonstrate performance, the authors provide a case study of the image retrieval task for vehicles in intelligent transportation systems. The article proposes an architecture that consumes fewer radio resources to improve IoV connectivity given increasingly limited spectrum resources.

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Appendix: Related Articles

[A1] R. Deng, Y. Zhang, H. Zhang, B. Di, H. Zhang, and L. Song, "Reconfigurable holographic surface: A new paradigm to implement holographic radio," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 20–28, Mar. 2023, doi: 10.1109/MVT.2022.3233157.

[A2] Z. Zhang, J. Zhang, Y. Zhang, L. Yu, and G. Liu, "AI-based time-, frequency-, and space-domain channel extrapolation for 6G: Opportunities and challenges," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 29–39, Mar. 2023, doi: 10.1109/MVT.2023.3234169.

[A3] A. Behravan et al., "Positioning and sensing in 6G: Gaps, challenges, and opportunities," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 40–48, Mar. 2023, doi: 10.1109/MVT.2022.3219999.

[A4] J. Wang, J. Liu, J. Li, and N. Kato, "Artificial intelligence-assisted network slicing: Network assurance and service provisioning in 6G," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 49–58, Mar. 2023, doi: 10.1109/MVT.2022.3228399.

[A5] M. M. Céspedes, B. G. Guzmán, V. P. Gil Jiménez, and A. G. Armada, "Aligning the light for vehicular visible light communications: High data rate and low-latency vehicular visible light communications implementing blind interference alignment," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 59–69, Mar. 2023, doi: 10.1109/MVT.2022.3228389.

[A6] R. Feng, C.-X. Wang, J. Huang, and X. Gao, "Recent advances of ultramassive multiple-input, multiple-output technologies: Realizing a sixth-generation future in spatial and beam domains," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 70–79, Mar. 2023, doi: 10.1109/MVT.2022.3231711.

[A7] Z. Lai et al., "Futuristic 6G pervasive on-demand services: Integrating space edge computing with terrestrial networks," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 80–90, Mar. 2023, doi: 10.1109/MVT.2022.3221391.

[A8] C. C. González, S. Pizzi, M. Murroni, and G. Araniti, "Multicasting over 6G non-terrestrial networks: A softwarization-based approach," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 91–99, Mar. 2023, doi: 10.1109/MVT.2022.3232919.

[A9] W. Xu, Y. Zhang, F. Wang, Z. Qin, C. Liu, and P. Zhang, "Semantic communication for the internet of vehicles: A multiuser cooperative approach," *IEEE Veh. Technol. Mag.*, vol. 18, no. 1, pp. 100–109, Mar. 2023, doi: 10.1109/MVT.2022.3227723. ***VT***

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