Guest Editorial Advanced Signal Processing for Local and Private 5G Networks

THIS IEEE Journal of Selected Topics in Signal Processing (J-STSP) special issue (SI) aims to provide a comprehensive overview of the state-of-the-art advances and a view of emerging research challenges and opportunities for *Advanced Signal Processing for Local and Private 5G Networks*. This SI describes the latest advances in emerging private 5G networks from the perspective of signal processing to advance its theoretical underpinnings and practical applications.

Some enterprises, factories and other potential users have stringent communications performance requirements in terms of throughput, latency, reliability, availability, and device density, which cannot be met by 4G long term evolution (LTE) radio features. Instead, 5G new radio (NR) has the potential to deliver on such requirements, and shape both the industrial world as well as our daily lives, by providing spectrum flexibility, multi-Gbps peak data rates, ultra-low latencies, high reliability, and massive connectivity. By building dedicated networks with complete control over every aspect of the network, local and private 5G NR networks can provide further optimized services securely and privately, with better performance over the controlled area than that of any public 5G NR deployment. To do so, a local and private 5G NR network must tailor its end-to-end radio behavior towards its performance goal by deploying many new features such as its flexible physical layer and protocols, flexible numerology, short transmission times and mini-slots, self-contained sub-frames, asynchronous HARQ, lean carrier, distributed multiple-input multiple-output (MIMO), mmWave operations, connected inactive states, grant-free access, and importantly spectrum usage flexibility. Moreover, by leveraging system-level network slicing (NS), radio cloud, edge computing, and improved security and privacy, such a local and private 5G NR network can simultaneously provide different performance profiles for a variety of user needs within its area of service. To deploy these features, it is necessary to take into account the local statistics including channel state information, communication and spectrum resources, along with the heterogeneous environment. All of the above can be very different in the context of private networks, as compared to the context of public networks.

I. Summary of the Papers in This SI

This SI starts with a guest editor-authored survey paper that summarizes concepts, architectures, and the research landscape of private 5G networks. This survey is followed by nine contributed papers. These papers cover a range of important research topics, described as follows.

The first paper, entitled "*Dynamic Scheduling for Heterogeneous Federated Learning in Private 5G Edge Networks*," designs a dynamic scheduling policy to explore the spectrum flexibility for heterogeneous federated learning (FL) in private 5G edge networks. Particularly, the authors formulate a heterogeneity-aware dynamic scheduling problem to minimize the global loss function, with the consideration of straggler and limited device energy issues. By solving the formulated problem, the authors propose a dynamic scheduling algorithm (DISCO) to make an intelligent decision on the set and order of scheduled devices in each communication round.

The second study, "*Offset Learning Based Channel Estimation for Intelligent Reflecting Surface-Assisted Indoor Communication*," presents a neural network for channel estimation of intelligent reflecting surface (IRS)-assisted MIMO systems. To estimate the indoor channels with an affordable piloting overhead, the authors propose an offset learning-based neural network for channel estimation without any prior knowledge of the IRS-assisted channel structure or indoor statistics.

The third contribution, which is entitled "*A Markov Chain Approach for Myopic Multi-hop Relaying: Outage and Diversity Analysis*," proposes a new cooperative protocol over a multi-hop network with finite buffers at the relay nodes based on a myopic coding strategy. A complete theoretical framework for the analysis that includes outage probability is investigated by modeling the evolution of the considered network as a state Markov chain (MC). The authors also derive an expression for the achieved diversity-multiplexing tradeoff by using the state transition matrix and the related steady state of the MC. Simulation results demonstrate that the proposed protocol outperforms the conventional multi-hop relaying scheme in terms of outage probability and diversity gain.

The fourth paper, which is entitled as "*A Novel NOMA Solution with RIS Partitioning*," presents a novel downlink non-orthogonal multiple access (NOMA) solution with reconfigurable intelligent surface (RIS) partitioning to enhance the system spectral efficiency. The authors propose an efficient physical resource distribution scheme to improve the ergodic rates and outage probabilities while maximizing the user fairness. Simulation results reveal the superiority of the proposed system over the considered benchmark systems in terms of ergodic rate, outage probability, and user fairness.

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The fifth paper, "*Blockchain-Enabled Electrical Fault Inspection and Secure Transmission in 5G Smart Grids*" integrates the consortium blockchain (CB) technique to construct an automatic secure and efficient electrical fault inspection system. To maximize the signal transmission utility and network security, the authors propose a two-step optimization scheme. Based on an actual city topology and YouTube video service data statistics, the superiority of the presented solution is demonstrated from the aspects of network performance and transmission security.

The sixth contribution addresses the issues of "*Fresh, Fair and Energy-Efficient Content Provision in a Private and Cache-Enabled UAV Network*," by presenting a private and cache-enabled unmanned aerial vehicle (UAV) network architecture and formulating a joint caching, UAV trajectory, and transmit power optimization problem to maintain the freshness of arriving data. To solve the formulated problem, the authors propose a novel algorithm by leveraging the Lyapunov optimization framework and the successive convex approximation (SCA) technique. Simulation results verify that the presented algorithm can provide fresh content files for users and is 22.11% more energy-efficient and 70.51% fairer than other benchmark algorithms.

The seventh paper, namely "*Data-Driven Adaptive Network Slicing for Multi-Tenant Networks*," presents a two-stage optimization framework for allocating network slices to users, which could be used in a private network. The optimal subset of network slices to be (de)activated is first found by maximizing the long-term expected utilities of tenants. At shorter timescales, slices within the previous subset of slices are activated according to the time-varying user traffic demands and channel states to maximize resource isolation at minimum cost. Convex approximation is used to relax the non-convex problem formulations, and novel iterative algorithms are proposed to solve them. Simulation results verify the efficiency of the proposed solution with respect to a state of the art method.

The penultimate paper entitled "*Cognitive Opportunistic Navigation in Private Networks with 5G Signals and Beyond*," proposes an architecture for a cognitive receiver that can extract navigation observables from 5G NR signals without requiring knowledge of the corresponding reference signals. To exploit the full ranging accuracy, the receiver estimates the reference signals from multiple 5G base stations and employs them for navigation. In the acquisition stage, a sequential detection problem is formulated for the detection of the number of active base stations and their corresponding reference signals, as well as the Doppler frequencies. Further, tracking loops refine and maintain the estimates provided in the acquisition phase. Experimental results demonstrate the performance of the proposed receiver by using off-the-air 5G signals on ground and aerial platforms.

The closing paper, titled "*Secret Key Generation Using Short Blocklength Polar Coding over Wireless Channels*" belongs to the broader area of physical-layer security mechanisms. Specifically, it deals with the problem of secret key generation over wireless channels using polar codes. The authors treat the regime of short blocklengths, which is relevant for 5G networks that include Internet-of-Things connectivity, such as private industrial networks. Besides the treatise of short blocklengths with polar codes, another original aspect of the paper is the use of correlated Gaussian sources for secret key generation. The numerical results demonstrate the gain in key rate of the proposed code constructions compared to the corresponding basic polar codes as well as LDPC-based protocols in the short blocklength regime.

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APPENDIX: RELATED ARTICLES

[A1] M. Wen *et al.*, "Private 5G networks: Concepts, architectures, and research landscape," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3137669.

[A2] K. Guo, Z. Chen, H. H. Yang, and T. Q. S. Quek, "Dynamic scheduling for heterogeneous federated learning in private 5G edge networks," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3126174.

[A3] Z. Chen *et al.*, "Offset learning based channel estimation for intelligent reflecting surface-assisted indoor communication," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3129350.

[A4] A. Nicolaides, C. Psomas, and I. Krikidis, "A Markov chain approach for myopic multi-hop relaying: Outage and diversity analysis," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3128810.

[A5] A. Khaleel and E. Basar, "A novel NOMA solution with RIS partitioning," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3127725.

[A6] Z. Ning, H. Chen, X. Wang, S. Wang, and L. Guo, "Blockchain-enabled electrical fault inspection and secure transmission in 5G smart grids," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, 10.1109/JSTSP.2021.3120872Z.

[A7] Yang, K. Guo, X. Xi, T. Q. S. Quek, X. Cao, and C. Liu Fresh, "Fair and energy-efficient content provision in a private and cache-Enabled UAV network," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3121878P.

[A8] N. Reyhanian and Z.-Q. Luo, "Data-driven adaptive network slicing for multi-tenant networks," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3127796.

[A9] M. Neinavaie, J. Khalife, and Z. M. Kassas, "Cognitive opportunistic navigation in private networks with 5G signals and beyond," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3119929.

[A10] H. Hentilä, Y. Y. Shkel, and V. Koivunen, "Secret key generation using short blocklength polar coding over wireless channels," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, Jan. 2022, doi: 10.1109/JSTSP.2021.3129624.

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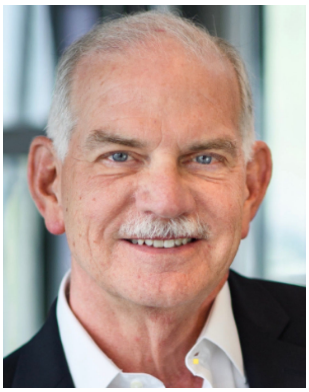

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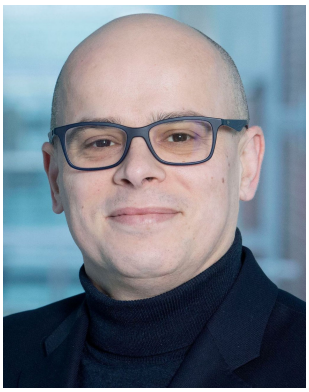

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