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EDITORIAL

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2024 EuCNC&6GS – 6G for a green and digital transition

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The 2024 European Conference on Networks and Communications & 6G Summit (EuCNC & 6GS) was held in June 2024 in Antwerp, Belgium. This Special Issue of the *EURASIP Journal on Wireless Communications and Networking*, titled **"6G for a Green and Digital Transition,"** features extended versions of selected best papers from that conference. The Technical Program Committee identified top conference papers, and the authors were invited to submit extended manuscripts. Our aim with this collection is to showcase cutting-edge 6G research that brings the 6G vision closer to reality, building upon lessons learned from 5G deployments while introducing new enabling technologies.

Turning the 6G vision into reality requires addressing not only technical challenges but also broader economic, societal, and environmental goals. Future 6G networks are expected to meet demanding requirements for connectivity, intelligence, and reliability that go beyond 5G, **all while minimizing resource consumption**—energy, spectrum, cost, and more—across devices, networks, and cloud infrastructure. In line with global digital and green objectives, this special issue emphasizes sustainable solutions that reduce power usage and greenhouse gas emissions, improving efficiency at every layer of the network. The scope of contributions spans from fundamental physical-layer advancements to network architecture innovations, artificial intelligence (AI)/machine learning (ML) for network management, time-sensitive networking, and beyond. Such breadth reflects the multifaceted approach needed to develop 6G technologies that are both high-performing and sustainable. Many of the studies in this issue are rooted in collaborative European R&D projects, underscoring the international effort to align technological innovation with societal needs in 6G development.

1 Overview of contributions

The special issue comprises nine papers that exemplify the diversity of 6G research topics. A brief overview of each contribution is given below:

1. **Ertuğrul et al. – Performance assessment of hybrid and digital irregular array configurations for beyond 100-GHz multi-user MIMO systems**: This paper assesses irregular phased array architectures (including thinned and clustered antenna arrays)

for multi-user MIMO communications beyond 100 GHz. By integrating these *irregular arrays* with hybrid (analog/digital) beamforming, the authors address the hardware challenges at sub-THz frequencies (where antenna dimensions approach chip sizes). An optimization framework is proposed to balance spectral efficiency and sidelobe levels. Notably, their results show that clustered array designs can achieve higher peak spectral efficiency than thinned arrays (e.g., ~ 4.5 vs 3.4 b/s/Hz in one configuration) with minimal performance degradation when using fully connected hybrid beamforming. This work provides insight into antenna array design for beyond-5G/6G *TeraHertz* communication, indicating that smart array configurations can push toward 6G's ambitious data rate goals.

2. **De Boni Rovella et al. – Support vector machines for optimal channel decoding**: This work explores a machine learning approach to channel decoding by leveraging support vector machines (SVMs) for forward error correction decoding. The authors identify and tackle a key scalability problem in existing SVM-based decoders—the exponential growth of classifiers and training data with code length. They introduce a novel *bit-wise SVM decoding* strategy that reduces the number of SVM classifiers from exponential to linear in the number of information bits, and drastically shrinks the required training set (to a single noiseless codeword per class). The proposed optimization framework yields a decoding rule which, under certain conditions, is **equivalent to the optimal Maximum A Posteriori (MAP) decoder** for AWGN channels. This means the SVM decoder can achieve MAP-optimal performance with much improved efficiency. The study demonstrates the potential of classical machine learning (SVMs, in this case) to attain optimal decoding, offering an alternative to deep-learning-based decoders with guaranteed convergence and robustness benefits.
3. **Giannakopoulos et al. – Key metrics for monitoring performance variability in edge computing applications**: Edge computing is crucial for low-latency services, but running applications on distributed edge resources can lead to highly variable performance. This paper presents a method to identify which system metrics best explain and predict performance variability in edge computing tasks. Using a real-world use case (single-particle analysis in electron microscopy) deployed on a Kubernetes cluster, the authors monitored hundreds of resource metrics with Prometheus. They found that when multiple tasks share resources, task round-trip times become significantly more variable. By applying correlation analysis and feature selection, they distilled over 422 collected metrics down to the **most relevant 90 metrics** (an 80% reduction) that still capture up to 87% correlation with performance variability. This reduction not only decreases monitoring overhead but also simplifies subsequent analysis for prediction and scheduling. The selected key metrics serve as robust indicators of performance interference, enabling more efficient scheduling and proactive resource management at the network edge. Their approach, supported by SHAP interpretability analysis, demonstrates how to achieve *predictable edge computing performance*—a steppingstone for dependable 5G/6G services at the network edge.
4. **Hakimi et al. – Resilient DNN for joint sub-band allocation and power control in mobile factory subnetworks**: Focusing on industrial 6G use cases, this paper addresses radio resource management in *In-X subnetworks* (small, localized 6G cells

in factories and other environments). The authors propose a **multi-task deep neural network (DNN)** that jointly performs sub-band allocation and power control for many coexisting wireless subnetworks. Importantly, the DNN is trained in an unsupervised manner and designed to be *resilient* to infrequent or delayed channel state information (CSI) updates. In dynamic factory environments, obtaining perfect, real-time CSI is challenging; this approach tolerates stale CSI while still optimizing spectrum usage. Simulation results show that the DNN achieves near-optimal performance comparable to iterative optimization methods, but with **rapid inference suitable for real-time operation**. Even when CSI is outdated, the DNN maintains robust performance, unlike conventional iterative algorithms that would require frequent re-training or re-calculation. This contribution illustrates how AI (specifically deep learning) can enable efficient and adaptive resource allocation in future 6G industrial networks, meeting strict latency and reliability requirements of mobile robotics and manufacturing lines.

5. **Chai et al. – Constant modulus constrained codebook synthesis for mmWave full-duplex ISAC devices**: This paper tackles a physical-layer challenge for **Integrated Sensing and Communication (ISAC)** devices operating in full-duplex mode at millimeter-wave frequencies. In such devices, a strong self-interference (SI) from the transmitter can overwhelm the much weaker sensing signal at the receiver. The authors propose a joint transmit–receive analog beamforming codebook design that imposes a *constant modulus (CM) constraint* on phase shifters (reflecting practical hardware limits) to maximize the signal-to-interference-plus-noise ratio (SINR) for sensing, while maintaining communication beam gain. They formulate an SINR maximization problem with constraints for SI suppression and solve it via an alternating optimization algorithm (using augmented Lagrangian and gradient descent methods). Notably, they derive an **MVDR beamforming solution as an upper bound** (when ignoring hardware constraints) and show that their proposed constrained solution comes very close to this bound in simulations. The optimized codebook effectively creates transmitter nulls to suppress near-field self-interference and adjusts the receive beam, achieving SINR levels nearly matching the ideal unconstrained case across all sensing angles. Compared to conventional codebooks or simple SI nulling, this joint TX-RX design significantly improves sensing performance while respecting the constant-modulus hardware limitations. This work advances the state of the art in full-duplex 6G transceivers, demonstrating that high-performance joint sensing/communication is feasible with careful analog beamforming design.
6. **De Vleeschauwer et al. – Application-centric congestion control**: This contribution targets the transport layer, proposing an enhancement to congestion control for modern applications (such as AR/VR) that maintain multiple simultaneous network connections. The Low Latency Low Loss Scalable Throughput (**L4S**) framework has been standardized to ensure ultra-low latency networking, but by default it gives equal bandwidth to each flow. De Vleeschauwer et al. extend L4S by enabling the *application* itself to decide how the bottleneck capacity is shared among its multiple flows. In other words, instead of every flow getting an equal rate, the application (which knows the relative importance or real-time needs of its data streams) can dynamically prioritize one flow over another—for example, giving more throughput

to the content the user is currently focusing on. Their scheme retains L4S's hallmark low latency while allowing unequal rate allocation aligned with application-level priorities. This "application-centric" congestion control is achieved by modifying the sender's reaction to congestion signals (ECN marks) on a per-flow basis, under the assumption that all flows belong to the same application (hence no fairness issues between different users). The paper presents experimental evidence that this approach yields the expected low-latency and flexible bandwidth sharing behavior. This result is significant for 5G/6G interactive services—it marries the responsiveness of L4S with the agility for applications to optimize quality of experience in real time.

7. **Trantzas et al. – Intent-driven network automation through sustainable multimodal generative AI**: This paper explores how advances in AI – particularly *large language models* (LLMs) and multimodal generative AI – can facilitate **Intent-Based Networking (IBN)** in future networks. The authors design an intent-driven automation framework aligned with industry standards for network management, with a strong focus on sustainability (cost and energy efficiency). They introduce a pipeline that translates high-level *intents*—essentially a stakeholder's description of desired network behavior or service requirements—into machine-consumable configurations that can be deployed on networking infrastructure. The framework uses multimodal generative AI models to parse not only textual descriptions of intent but also supplementary information (e.g., deployment files), producing output that interfaces with modern orchestration systems. Trantzas et al. evaluate several state-of-the-art AI models (both online services and locally hosted) for this translation task and assess the trade-offs in accuracy and resource consumption. The ultimate goal is an AI-powered NaaS (Network-as-a-Service) solution that allows even non-expert users to specify what network services they need in simple terms, and have the system automatically configure itself. The results show the approach is **feasible and accurate**, translating intents into valid network configurations while adhering to sustainability goals (minimal overhead in doing so). This work highlights a path toward more autonomous and *cognitively accessible* network management in 6G, where AI bridges the gap between human intent and network control—crucial for reducing operational complexity and energy costs in large, dynamic networks.
8. **Charpentier et al. – Utilizing the VITAL-5G platform to advance 5G standalone integration with vertical industries**: Bridging the gap between 5G technology and vertical industry applications is a key step toward 6G. Charpentier et al. present the **VITAL-5G experimentation platform**, an open and flexible testbed funded by the European Commission, which enables vertical industry stakeholders (especially in the Transport & Logistics sector) to validate 5G solutions in realistic scenarios. The paper details how VITAL-5G provides a virtualized 5G Standalone (SA) network across multiple trial sites (including port and logistics hubs), allowing third-party developers to deploy and test their 5G-enabled applications. By lowering the entry barriers (users can experiment without investing in their own infrastructure), this platform accelerates innovation and helps quantify the benefits of 5G for industry 4.0 use cases. The authors share insights from various trials conducted on the platform—for example, automated guided vehicles and

remote crane operation in smart ports—and discuss technical and operational challenges encountered by experimenters. They also identify emerging business opportunities fueled by 5G in the logistics domain, such as real-time asset tracking and smart warehouse operations. Finally, the paper outlines future developments, including extending the platform to support other verticals and to integrate evolving 6G features. This contribution underlines the importance of *open test platforms* in the 5G/6G ecosystem: By fostering collaboration between technology providers and vertical industries, it helps ensure that 6G innovations truly address practical needs and deliver economic value.

9. **Miranda et al. – A bottom-up approach for QoS-driven network slicing in TSN networks**: The final paper addresses the integration of **Time-Sensitive Networking (TSN)** with 5G/6G networks through a novel network slicing approach. TSN is a set of standards for Ethernet networks that provides deterministic latency and ultra-reliability, widely used in industrial and multimedia systems. Miranda et al. propose a "bottom-up" method to orchestrate end-to-end slices that encompass both 5G wireless and TSN wired segments, driven by Quality-of-Service (QoS) requirements. By starting from the TSN network perspective (where traffic flows have strict deadlines/priorities) and then mapping those requirements upward into the 5G slice, their approach ensures that the stringent QoS of TSN flows is preserved across the wireless domain. This work emphasizes the importance of **time-sensitive networking** in future 6G architectures, highlighting that next-generation network slices must accommodate not only the flexible, best-effort nature of 5G traffic but also the deterministic needs of industrial networks. The paper demonstrates how TSN features (like schedule-based traffic shaping) can be interfaced with 5G network slicing mechanisms in a coherent way, achieving end-to-end performance guarantees. This bottom-up slicing strategy for TSN integration showcases a pathway to support industries (manufacturing, autonomous systems, etc.) that require absolute reliability and timing precision, thereby directly contributing to 6G's goal of serving critical applications.

2 Conclusion

Together, the papers in this Special Issue present some of the **latest and finest results** in the evolution of communication networks research. They cover a broad range of topics—from TeraHertz radio interfaces and machine learning for decoding, to edge computing, network automation with AI, joint communication-sensing, advanced congestion control, vertical industry integration, and deterministic networking. Each contribution pushes the state of the art in its domain, but, more importantly, they collectively move us closer to a 6G ecosystem that is both ultra-capable and aligned with real-world needs for a green and digital future. We thank all authors and reviewers for their efforts in making this Special Issue possible. It is our hope that these works will inspire further research and innovation toward making the 6G vision a reality—one that delivers enhanced connectivity and services **without compromising sustainability**.

Author contribution
All authors have equally contributed to this Editorial

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