# 31st IEEE International Conference on Telecommunications

# ICT 2025

## “Towards the era of hyperconnectivity and intelligence in telecommunications”

28-29 April 2025,
Budva, Montenegro

# - Book of Abstracts –

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# BOOK OF ABSTRACTS

31st IEEE International Conference on Telecommunications (ICT 2025)
*"Towards the era of hyperconnectivity and intelligence in telecommunications"*

28-29 April 2025, Budva, Montenegro

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**PUBLISHER:**

University of Montenegro, Faculty of Electrical Engineering,
Džordža Vašingtona bb. 81000 Podgorica
Online publication

**YEAR OF PUBLICATION:**

2025

**PLACE OF PUBLICATION:**

Podgorica, Montenegro

**TECHNICAL ASSISTANTS:**

Djordje Stanković
Andrej Cvijetić

**WEBSITE:** https://ict2025montenegro.ucg.ac.me/

CIP - Каталогизација у публикацији
Национална библиотека Црне Горе, Цетиње

ISBN 978-86-85775-23-9
COBISS.CG-ID 36423940

# About the conference


The 31st International Conference on Telecommunications (ICT), is an event that has a long tradition of highlighting key advancements and pioneering research in the ever-evolving field of telecommunications. Established in 1991, this annual conference has become a renowned gathering place for a diverse community of global researchers, engineers, and stakeholders' representatives. ICT 2025 aims to continue the conference's long successful tradition of facilitating collaborations, discussions and knowledge exchange while revealing the latest trends and innovations in telecommunications. We note the global impact of the recent successful conferences such as ICT 2024 in Amman, Jordan, ICT 2023 in Toba, Indonesia, including ICT 2021 that took place in London, UK. ICT 2025 in Montenegro is expected to continue this journey and provide an existing gathering for further advancing the fields of telecommunications.

The scope of ICT 2025 includes the key areas of telecommunications, including applications of ICT and novel technologies that are driving progress in fields of telecommunications. The conference will attract submissions in core fields such as physical layer, also, higher layers such as MAC and networking including both theoretical and experimental findings. In addition to these fundamental fields, ICT 2025 encourages submissions in all related areas of ICT applications such as business and regulatory aspects, then, the areas of agriculture, smart cities, e-health etc. Submissions including works in new emerging technologies, such as AI, machine learning, advanced signal processing, and their uses in telecommunications, are particularly welcome. ICT 2025 will also include submissions on advancement of telecom systems and services. These are particularly scoped to further developments in 5G and research and visions for 6G, and the Internet of Things, Future Internet etc.

**ICT 2025 papers will be published in IEEE Xplore and indexed in the high-quality Scopus database, ensuring wide accessibility and impact.**

# Speakers and panels

## Dr. Valerio Frascolla

Director of Research and Innovation, Intel Deutschland GmbH, Neubiberg, Munich, Germany

**Keynote Speech:**
*Mixed criticality networks in IoT*

**Panel:**
*Determinism and predictability in multi-domain networks for Industrial IoT and Smart Cities*

## Prof. Izzat Darwazeh

Director of UCL's Institute of Communications and Connected Systems, University College London (UCL), UK

**Keynote Speech:**
*New Techniques for Communications and Sensing in 6G*

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- **Prof. Enis Kočan**, University of Montenegro, Technical Track Chair
- **Assistant Prof. Slavica Tomović**, University of Montenegro, Technical Track Chair

# Contents

# Learn Efficiently Without a Server: RIS-Aided Federated Learning

Anis Elgabli

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**Abstract**—Learning in a fully decentralized environment without the assistance of a parameter server (PS) may not always be feasible, particularly for energy-constrained Internet of Things (IoT) devices facing challenges such as lack of line-of-sight (LOS) links or poor channel conditions between clients. On the other hand, the presence of a PS introduces privacy concerns, especially for sensitive applications. The inversion attack, also known as input recovery from gradient, poses a burgeoning threat to the security and privacy of federated learning (FL). This vulnerability allows a "curious" PS to partially recover clients' private data. To enable energy-efficient learning in a fully decentralized topology, we propose a novel FL approach where clients learn a global model exclusively relying on reconfigurable intelligent surfaces (RISs). The RISs are continuously configured to enable each client to communicate with only one "other" client at each learning iteration, thus, focusing the beam and utilizing energy efficiently. Additionally, we demonstrate that by altering the communication links (i.e., dynamically changing which client communicates with which) while iterating, via adjusting the RIS configuration, we can maintain the same convergence speed of standard tree topology based FL (PS-based FL). Hence, the proposed algorithm significantly reduces energy consumption compared to fully decentralized FL approach which suffers from slow convergence rate due to sparsity of the network connectivity graph while preserving privacy of clients' data from a curious PS.

**Keywords**—Federated learning, Reconfigurable Intelligent Surface (RIS), ADMM, Privacy

# Antenna Arrays for Full-Duplex Systems

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**Abstract**—The 5G technology necessitates the advancement in antenna technology to meet the demands of higher data rates, lower latency and lower power consumption. In wideband mm-wave 5G, these can be partly achieved using wideband antenna arrays. The capacity of the 5G communication can be further enhanced by the use of full-duplex radios. In this paper, a full duplex transceiver antenna array with planar architecture for 28 GHz 5G NR FR2 n258 (27.5-28.35 GHz) band is proposed. In this design, the array gain is about 17 dB at 27.5 GHz/28 GHz and has a significant isolation (over 33 dB) across the band. This is a highly desirable isolation for the overall reduction of the self interference at the RF stage of wideband mm-wave 5G full duplex radios.

**Keywords** — Antenna arrays, Full-duplex radios, 5G NR FR2, Self interference cancellation

# A UAV-Based Mixed RF/FSO System with RIS-Aided Reflection Modulation Multiple Access

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**Abstract**—Reconfigurable Intelligent Surfaces (RISs) have recently gained an increasing attention due to their ability by significantly enhancing the communication quality. In this work, we employ RIS together with Index Modulation (IM) to propose a novel multiple access scheme named as Reflection Modulation Multiple Access (RMMA). The idea of RMMA is to split the RIS into subsurfaces and allow each user to select one subsurface to reflect its uplink signal using the IM concept. The proposed scheme is adopted in a dual-hop Unmanned Aerial Vehicle (UAV)- based system in which the first hop operates via the radio frequency (RF) band, while the second hop operates via the free space optical (FSO). Channel fading of users-RIS, RIS-UAV and UAV-base station links are modeled as Rician, Air-to-Air (A2A) and Gamma-Gamma models, respectively. Results indicate that the proposed scheme can significantly improve the error rate performance as compared to conventional scheme.

**Keywords**—RIS, Index modulation, UAVs, Mixed RF/FSO.

# Optimizing Age of Information for Energy Harvesting Systems Using an Energy-Aware Hybrid Preemptive/Non-Preemptive Discipline

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**Abstract**—The growing integration of Internet of Things technologies, alongside limited energy resources of sensor nodes, has driven extensive research into real-time status update systems powered by energy harvesting (EH) modules. The unpredictability of available energy can adversely affect critical timeliness, as measured by the age of information (AoI) metric. Packet management schemes have been developed to enhance AoI under stochastic energy conditions. However, conventional preemptive (PR) and non-preemptive (NP) service disciplines operate independently of system dynamics, limiting their adaptability to variations in traffic and energy profiles. In this work, we propose a novel energy-aware hybrid PR/NP discipline for a single source status update system. The system is powered by EH technology with a limited-capacity battery and a Poisson energy replenishment process. Service preemptions, which lead to energy depletion, are permitted only when the battery's energy level exceeds a predetermined threshold parameter. We analyze the average AoI using the stochastic hybrid system approach, which leads to deriving a formula for the energy packet loss rate. The numerical study demonstrates that the proposed discipline, by adjusting its threshold parameter, enhances system adaptability and achieves a significant balance between AoI optimization and energy loss reduction.

**Keywords**—Internet of things, real-time status update systems, energy harvesting, age of information, stochastic hybrid system.

# Securing Task Computation Offloading for Mobile Edge Computing in Untrusted Relay Networks

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**Abstract**-This paper aims to secure task offloading and service caching in relay-assisted heterogeneous mobile edge computing networks. The relay nodes might be untrusted in such heterogeneous networks due to their limited computational power. Therefore, a friendly jamming technique is used to confuse the untrusted relay nodes. Hence, an optimization problem is formulated to minimize the system latency and energy consumption under secrecy capacity constraint. As the joint problem of the service caching and task offloading is an NP-hard problem, this work deploys a low-complexity Lyapunov drift- plus-penalty optimization technique based on the Gibbs sampling algorithm. The simulation results show the superiority of the proposed framework over the state-of-the-art in terms of high secrecy capacity and low computational complexity. When the secrecy capacity threshold increases, the secrecy capacity is enhanced by approximately 2.99%, while the system latency and energy consumption increase by 55.85% and 4.76%, respectively, compared to the literature.

**Keywords**-Physical layer security, user association, service caching, untrusted relays, and task offloading.

# Federated Learning with Differential Privacy: Gaussian Mechanism or Laplacian Mechanism?

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**Abstract**—Differential privacy (DP) has been widely used in communication systems, especially those using federated learning or distributed computing. DP comes in the data link layer before line coding and transmission. In this paper, we consider two DP mechanisms; namely, the Gaussian Mechanism (GM) and the Laplacian Mechanism (LM).We start by explaining why we have $\epsilon$-DP if the LM is used, while we must have $(\epsilon, \delta)$-DP if the GM is used. Furthermore, we derive a new lower bound on the perturbation noise required for the GM to guarantee $(\epsilon, \delta)$- DP. Although no closed form is obtained for the new lower bound, a very simple one dimensional search algorithm can be used to achieve the lowest possible noise variance. Since the perturbation noise is known to negatively affect the performance of federated learning such as the convergence and the average loss, the new lower bound on the perturbation noise is expected to improve the performance over the classical GM. Moreover, we analytically derive the border between the region where GM is better to use and the region where LM is better to use.

**Keywords**— Differential Privacy, Gaussian Mechanism, Laplacian Mechanism, federated learning.

# A Lightweight Framework for Network Traffic Scheduling in Cloud-Native Environments

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**Abstract**—With the continuous evolution of network technologies, network functions (NFs) are shifting from dedicated hardware appliances toward virtualized and cloud-native approaches. In a cloud-native environment such as Kubernetes, effectively steering traffic among distributed NF instances becomes a key challenge, especially when dealing with dynamic service chaining and stateful packet processing. This paper proposes a lightweight framework for efficient traffic scheduling in cloud native networks, introducing: (1) an address-based routing mechanism using segment routing, (2) a distributed forwarding plane leveraging XDP/eBPF, and (3) a heuristic scheduling algorithm that achieves 1.9× communication cost compared to optimal while maintaining 95% fairness. Experimental results show our approach reduces end-to-end latency by up to 40% compared to traditional methods while supporting seamless scaling of network functions.

**Keywords**—Cloud-native, Network function, Traffic scheduling, Segment routing, XDP/eBPF

# Digital Twin Architecture for IoT-based Healthcare Systems: A Preliminary Study

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**Abstract**— Digital Twin (DT) represents a synchronized digital replica of a real system, object, or process in a virtual environment, thus reflecting the physical characteristics, dynamics, and behaviors of the real world. It allows for analysis of the system's current state, predicts future behaviors using AI/ML models, and optimizes control through bidirectional communication with the actual system. Utilizing DTs in healthcare enables quantitative analysis of essential life processes, offers personalized care and predictive health analytics, and enhances strategies for disease treatment. However, the application of DTs in healthcare is still in its early stages and faces significant research challenges across various aspects. This paper proposes the architectural framework for implementing DT in IoT-based healthcare networks, as well as model for sensing/actuating and network operation DTs. We have deployed an open-source DT platform to design and test this proposed framework.

**Keywords**— digital twin, network digital twin, healthcare, IoT, open-source platform

# RRCFuzzer: A 3GPP-Guided Fuzzing Method for Radio Resource Control Protocol

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**Abstract**—With the rapid development of telecommunication technology, the number of globally connected user equipment has reached 8.6 billion. Currently, LTE and 5G have become the dominant mobile communication technologies worldwide. The Radio Resource Control (RRC) protocol is a key protocol in LTE and 5G wireless communication systems. Once vulnerabilities exist in the RRC protocol and are exploited by attackers, it can lead to significant security risks with a wide-ranging impact. Due to the large number of RRC protocol messages and their complex structures, current research on fuzzing the RRC protocol mainly relies on manually extracting a limited number of messages, resulting in incomplete message coverage and low code coverage rates. To address this issue, we propose RRCFuzzer, a 3GPPguided fuzzing method for the RRC protocol. RRCFuzzer automatically extracts all message knowledge of the RRC protocol from 3GPP documents to form a set of RRC message templates, guiding the generation of new messages for fuzzing. We design and implement the RRCFuzzer framework, and conduct experimental verification on the open-source project srsLTE/srsRAN. The experimental results indicate that the message coverage increased by 47.28%, the code line coverage increased by 23.93%, and the function coverage increased by 15.24%. RRCFuzzer discovered 18 new vulnerabilities in the open-source project.

**Keywords**—3GPP, LTE, 5G, RRC, Fuzzing

# Experimental 5G Network Testing: A Methodology to study the Impact of Traffic Characteristics on 5G Performance

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**Abstract**—As Fifth Generation (Mobile Network) (5G) networks continue to develop, ensuring high performance and reliability remains a key challenge—particularly within the mobile core, where the transport layer plays a crucial role. Variability in parameters such as jitter, latency, and packet loss can significantly impact both control and user plane functions. This paper presents a framework for conducting controlled performance evaluations of a 5G core network by dynamically adjusting these transport characteristics. Using a containerised Open5GS architecture, each core network function is individually equipped with Traffic Control (TC), allowing fine-grained manipulation of network conditions. The experimental setup includes Software-Defined Radios (SDRs), Commercial Off-The-Shelf (COTS) User Equipments (UEs), and network simulation tools such as PacketRusher to replicate a range of scenarios. This approach provides a structured and repeatable environment for analysing the influence of transport layer variation on core network operations, including user throughput and session establishment. Although preliminary, the results offer valuable insights into the performance of 5G core throughput under different network conditions—most notably the disproportionate impact of jitter on user plane throughput, highlighting the role of this critical link characteristic in the underlying transport network of a 5G network.

**Keywords**—5G Core, Open5GS, Performance Optimisation, 5G

# Leveraging Call Detail Records to Uncover Azimuth Configuration Errors in Cellular Networks

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**Abstract**—Mobile positioning data has proven crucial in addressing many problems related to population distribution, estimating people's daily commuting, and the pandemic's spread. However, the inconsistencies and uncertainties of mobile network characteristics introduce biases and limitations in mobility pattern extraction from Call Details Records (CDR) data. Hence, understanding these factors is crucial to improving accuracy and reducing uncertainty. In this paper, we propose a new approach to detect cellplan inconsistencies, focusing on azimuth errors resulting in apparent cell-swapping. The proposed model allowed us to detect cellplan distortion by analyzing the map-matched trajectories extracted from passive mobile positioning data or CDR. The method uses only Cell Global Identity (CGI) data for positioning, without need for any additional information like Timing Advance or global navigation satellite system data. The experimental results based on actual passive mobile positioning data demonstrated the efficiency of the proposed algorithm.

# A Coverage-Guided Fuzzing Method for Non-Access Stratum Protocol

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**Abstract**—The Non-Access Stratum (NAS) protocol, a critical signaling protocol in the radio access networks of LTE and 5G systems, plays a pivotal role in ensuring the security and stability of communication sessions between user equipment (UE) and the core network. Exploitation of vulnerabilities in the NAS protocol by attackers can lead to severe consequences. However, the lowlatency requirements of the NAS protocol pose challenges for fuzzing, as prolonged message mutation and coverage statistics processing can increase the risk of communication session timeouts and interruptions. To address these challenges, this paper proposes a coverage-guided fuzzing method for the NAS protocol. By leveraging a timing selection algorithm, the method optimizes the timing of code coverage statistics collection, ensuring efficient guidance of the fuzzing process while maintaining uninterrupted communication sessions. This approach not only enhances code coverage but also improves testing efficiency. We design and implement the NASFuzzer framework and evaluate it on an open-source project. Experimental results demonstrate significant improvements, with code line coverage increasing by 24.8% and function coverage by 19.5%. Furthermore, NASFuzzer successfully identifies three previously unknown vulnerabilities in the open-source project.

**Keywords**—LTE, 5G, NAS, Fuzzing, Coverage

# Drone Communication and Monitoring using Cloud Computing

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**Abstract**—Droned cloud is considered as a powerful technology since it can combine various applications of drones to have high impact on several fields in the future like surveillance, disaster management, and logistics. However, one of the challenges which are encountered is to integrate drones to the cloud to provide a consistent and reliable form of communication. Additionally, such system should be scalable and capable of near real time monitoring. In this work, before using actual drones, we have used drone simulator called AirSim and integrated it with cloud for the monitoring. In addition, we have used multiple drones (3 in this case) to gather data from the environment including its own health and send it to a cloud platform. The data is processed and stored on the cloud to facilitate real time visualization of the data. The performance proves that the system enables data flow from the drones to the cloud where the data is manageable and accessible. One of performance metrics (latency) measured to be in the range 0.0008s (Drone-1) to 0.0014s (Drone-3). This work also highlights on the possibility of using drone simulation tools for the creation and evaluation of the drone-cloud integration systems. In addition, they system is expected to be cost efficient, scalable and important for research purposes.

**Keywords**—Cloud Computing, AirSim Simulation, Drone Communication

# NOFS: A Non-Orthogonal Frequency Shaping Waveform to Break the Fast-OFDM Limit

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**Abstract**—We innovate a novel over-the-air signal waveform termed non-orthogonal frequency shaping (NOFS), aiming for artificial intelligence air interface for future 6G communications. By reshaping sub-carriers using irregular Sinc (irSinc) patterns, the proposed NOFS waveform effectively reduces bandwidth and exhibits asymmetric shaping characteristics. The unique irSinc pattern empowers NOFS to utilize two dimensional modulation schemes beyond the Fast-OFDM limit, where previously only one-dimensional modulation formats were applicable. Moreover, NOFS demonstrates robustness in the beyond-Fast-OFDM regime, offering 150% improvement in energy and spectral efficiency. Additionally, the explainable nature of the neural network used in the NOFS waveform design provides insights into the signal patterns, enhancing transparency and trust in the system. Finally, an over-theair
signal transmission is operated in hardware validating the effectiveness of NOFS waveforms in real-world.

**Keywords**—Waveform, non-orthogonal, NOFS, 6G, spectral efficiency, irregular Sinc, irSinc, prototyping.

# SVFF+: Kubernetes FPGA virtualization and reconfiguration for network virtualization

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**Abstract**—Network virtualization concepts are extending their influence to other fields, such as satellite communication. The Waveform Architecture for Virtualized Ecosystems (WAVE) consortium initiative is an example, as they aim to create a new Satellite Communication (SATCOM) ecosystem with interoperable and hardware accelerated virtual functions. This paper presents SVFF+, a software/hardware framework that enables easy FPGA usage in virtualized environments, introducing partial reconfiguration and Kubernetes (K8S) support. SVFF+ was developed withWAVE consortium applications in mind, but it can be extended to any cloud computing or network virtualization use cases, such as NFV. We demonstrate the effectiveness of SVFF+ via benchmarks, showcasing promising resource utilization and flexibility results, i.e., implementing Partial Reconfiguration yielded over 5% savings in FPGA resources with 4VFs while achieving significantly greater flexibility compared to a static design. SVFF+ enhances a previous work (SVFF) with support for Kubernetes and partial reconfiguration.

**Keywords**—FPGA virtualization, network virtualization, cloud computing

# Cost-Efficient Computation Offloading and Service Chain Caching in LEO Satellite Networks

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**Abstract**—The ever-increasing demand for ubiquitous, continuous, and high-quality services poses a great challenge to the traditional terrestrial network. To mitigate this problem, the multiaccess-edge-computing-enhanced low earth orbit (LEO) satellite network, which provides both communication connectivity and on-board processing services, has emerged as an effective method. The main issue in LEO satellites includes finding the optimal locations to host network functions (NFs) and then making offloading decisions. In this paper, we jointly consider the problem of service chain caching and computation offloading to minimize the overall cost, which consists of task latency and energy consumption. In particular, the collaboration among satellites, the network resource limitations, and the specific operation order of NFs in service chains are taken into account. Then, the problem is formulated and linearized as an integer linear programming model. Moreover, we provide a greedy algorithm with cubic time complexity to accelerate the solution. Numerical investigations demonstrate the effectiveness of the proposed scheme, which can achieve the cost gain by around 20% compared to the nominal case where NFs are served in data centers.

**Keywords**—Service Chain Caching, Computation Offloading, Low Earth Orbit Satellite, Integer Linear Programming.

# Enhanced Planning of Truck Platooning for Vehicle Routing in Dynamic Road Networks

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**Abstract**—This work addresses the optimization of truck platooning in the capacitated vehicle routing problem (CVRP) for logistics networks, where trucks carry goods to multiple customers. The problem is crucial because it has an immediate bearing on fuel consumption, operational costs, and the sustainability of freight transport. A simulation modeling, and optimization approach that integrates Google Maps API, OR-Tools, and Knapsack grouping is adopted to develop a scalable solution. This has resulted into 3.9% reduction in operational costs and 4% fuel savings while maintaining a high vehicle utilization efficiency of 96.67%, demonstrating reasonable improvements in route planning and resource allocation. Based on this work, logistics firms will be able to capitalize on optimized truck fleet operations at reduced cost and enhance sustainability.

**Keywords**—Truck Platooning, Logistics Networks, Mixed-Integer Programming, Dynamic Programming Heuristic, Fuel Efficiency Optimization

# Speed-based Handover Decision Algorithm for Integrated Terrestrial and Non-Terrestrial Networks

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**Abstract**—Terrestrial Networks (TNs) have advanced significantly, enabling support for services with diverse Quality of Service (QoS) requirements. However, TNs face inherent coverage limitations, as Mobile Network Operators (MNOs) typically deploy them only in commercially viable areas, leaving many remote regions without service. In addition, TNs are sometimes faced with capacity issues during peak hours. In contrast, Non-Terrestrial Networks (NTNs) offer the advantage of global coverage, support for high mobility, and are resilient to terrestrial disruptions, such as floods and fires, that can impact TNs. Integrating TNs with NTNs presents a promising solution to addressing coverage gaps, mobility constraint, and capacity issues. However, this integration introduces unique challenges, particularly in handover (HO) management due to the fundamental differences between the networks. This paper proposes a speed-based handover decision algorithm for addressing the HO challenge. The proposed algorithm classifies user equipment (UEs) into three groups, namely low-speed UEs, medium-speed UEs, and high-speed UEs. As much as possible, the algorithm admits low-speed UEs, medium-speed UEs, and high-speed UEs into microcells, macro cells, and low earth orbit (LEO) satellites, respectively. By enhancing the HO process, the proposed algorithm reduces HO occurrences by up to 79.58% and prevents HO ping-pong (HOPP) occurrences.

**Keywords**—Terrestrial networks, non-terrestrial networks, UE speed, handover, unnecessary handovers

# Digital Twin as a Service for 6G Radio Access Networks: Functional Model and Key Challenges

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**Abstract**— This paper presents a scalable and flexible functional model for the 6G-Radio Access Network Digital Twin (6G-RANDT), designed through a service-oriented approach to support next-generation radio access network optimization and intelligent management. The proposed model includes an application programming interface for seamless interaction with a 6G-RANDT consumer, 6G-RANDT instances for RAN emulation and simulation, and a 6G-RANDT orchestrator for management and data integration. Several 6G-RANDT typologies and measurement requirements are explored to address diverse use cases. Moreover, key challenges in 6GRANDT development are discussed. To evaluate the impact of modeling accuracy in 6G-RANDTs, we conducted a cellular capacity modeling experiment in which different 6G-RANDT instances were used to train a reinforcement learning (RL)-based capacity-sharing algorithm. Results show that the impact of capacity modeling strategies on the 6G-RANDT instance accuracy and RL agent performance is highly dependent on the cell environment, emphasizing the need for tailored 6G-RANDT services based on specific RAN environment conditions and applications.

**Keywords**— 6G, RAN, Digital Twin, functional model, network optimization, capacity modeling.

# UAV-Assisted Remote Water Quality Monitoring Using Low Power Wide Area Networks

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**Abstract**—River water quality is crucial for the environment, biodiversity, and human health. To improve the decision-making process and enhance river health, platforms for water quality monitoring, prediction, and alarming (often using AI) are used. In this paper, we present the design and implementation of the remote water quality monitoring system based on the smart buoy (with our custom-designed electronics and software) assisted by an unmanned aerial vehicle. Such a system addresses the limitations of traditional in situ methods by improving the spatial and temporal resolution of water quality measurements.

**Keywords**—remote sensing, water quality, smart buoy, drone, LPWAN

# An End-to-End Autoencoder-based Non-Orthogonal Multi-Carrier System for Transmission

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**Abstract**—Multi-carrier techniques remain prime candidates for high-frequency 6G and sub-THz wireless transmission, due their resilience to multi-path effects. Spectrally efficient frequency division multiplexing (SEFDM) conserves bandwidth relative to orthogonal frequency division multiplexing (OFDM) but similarly suffers from high PAPR, which affects the power efficiency of mmWave amplifiers. Moreover, SEFDM suffers from high Intercarrier Interference (ICI) as a result of bandwidth compression, which limits SEFDM's applications and practical deployment. To ameliorate the effects of these two problems, this work proposes an end-to-end autoencoder-based SEFDM system that generates optimized constellation mapping at the transmitter side for reducing PAPR. at the receiver side, a neural network joint SEFDM detection and demodulation is implemented to remove much of the ICI. Simulation based results show that the proposed autoencoder-based SEFDM system achieves BER, which outperforms linear detection techniques. Furthermore, the results show that our optimized constellation improves the PAPR, in specific threshold regions, when compared to conventional QPSK-mapped OFDM and SEFDM signals.

**Keywords**—Autoencoder, OFDM, SEFDM, Deep Learning

# Dynamic Spectrum Management in Multi-Access Systems moving towards 6G

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**Abstract**—This paper provides a survey of key innovations brought in the last ten years in the areas of both dynamic spectrum management and integration of diverse radio access technologies in heterogeneous and multi-access systems, taking into consideration also regulatory and standardization aspects. In particular, recent enhancements proposed by selected EU-funded collaborative research projects are detailed, showing the path towards forthcoming 6G networks.

**Keywords**—Dynamic Spectrum Management, Frequency Bands, 5G, 5G Advanced, 6G, Regulation, Standardization, RAT

# Study on Smart Energy services in 3GPP and evaluation of representative use cases

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**Abstract**—This paper aims at providing study of emerging Smart Energy (SE) services and evolving 3GPP Project 5G-Advanced network infrastructure. Representative use cases and functional requirements are evaluated in selected Smart Grid (SG) application scenarios. According to the study, 5G RedCap terminals improve capacity, low latency, accurate positioning, and high reliability when compared with traditional IoT communication technology in city-wide interconnection.

**Keywords**—5G-Advanced, RedCap, Smart Grid

# Multipath Aggregation Timestamping Method for Precise and Robust Wireless Two-way Time Synchronization

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**Abstract**—To meet the demand for high-precision and stable time synchronization in wireless time-sensitive applications, we propose a Multipath Aggregation Timestamping (MAT) method to address the time-of-arrival (TOA) estimation ”jumping” errors caused by channel symmetry loss in time-varying multipath channels in Time Division Duplex (TDD) systems. We utilize multiple peaks of time-domain channel impulse response (CIR) to achieve more stable and precise TOA estimation. Through variable-length coding, synchronization accuracy and stability are significantly improved at a low cost of communication overhead. Through simulation and SDR validation in WLAN system, nanosecond level synchronization accuracy has been achieved with 99% confidence in WLAN systems.

**Keywords**—Wireless Time synchronization, Time Sensitive Networks, Multipath Channel

# Explainable Decentralized Federated Learning for Energy-Efficient Base Station Sleep Control

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**Abstract**—Given the capacity and performance boosts offered by the 5G cellular networks, energy consumption at the base stations (BSs) has increased tremendously. This paper proposes a decentralized federated learning (DFL)-based intelligent BS switching, integrated with explainable artificial intelligence (XAI) methods, to mitigate the concerns for energy consumption in dense 5G networks. This entails collaboration among distributed but interconnected networks to learn the best policies for BS switching without any central controller, so that knowledge sharing can be ensured while privacy and communication efficiency are maintained. Very importantly, we further researched the XAI techniques to provide better transparency on the decisionmaking of the switching control agent and create some trust in the learned policies. Such explainability allows us to derive the most important factors affecting BS switching decisions and how these contribute in enabling energy savings while maintaining quality of service (QoS). Extensive simulations conducted to validate our proposed framework in presenting valuable XAI analysis have elaborately provided the basis for understanding the learned strategies and key factors driving energy-efficient BS management.

**Keywords**—Base Station Switching, Explainable AI, Decentralized Federated Learning, Deep Reinforcement Learning, Energy Efficient, 5G

# Adaptive compressive sensing for reconstruction and denoising with sparsity-measure-driven sampling

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**Abstract**—This study proposes a compressive sensing-based approach for adaptive reconstruction and denoising of wireless signals. By employing a dynamic sampling strategy, the approach adjusts the sampling rate according to the complexity of the signal region, as determined by the $\ell_1$-norm – more samples are used to reconstruct occupied regions while less samples are used for the less occupied ones. Applied to multiple, overlapping frequency hopping spread spectrum signals corrupted by Gaussian noise, this approach not only recover the signal but also helps in noise reduction, leading to an improvement in the signal-to-noise ratio. Results highlight its potential for interference mitigation and adaptive spectrum management in wireless systems.

**Keywords**— adaptive sampling, compressive sensing, denoising, frequency hopping spread spectrum, sparse signal, recovery, sparsity measure

# Time-Frequency-Inspired Structural Image Analysis

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**Abstract**—This paper presents a time-frequency-inspired technique for image analysis, focusing on the interplay between supercritical intensity and inverse complexity. The method exploits images' structural similarities to time-frequency distributions, allowing noise detection along edges corresponding to the lowest intensities. A nonlinear image transform is applied iteratively to extract edges across varying intensity levels, enabling a comprehensive inspection of image structures. This approach demonstrates a high sensitivity, offering a robust framework for noise detection in images.

**Keywords**—time-frequency distributions, inverse complexity, variance, noisy image

# Analysis of the Image Tiling Influence in its Sparse Reconstruction

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**Abstract**—Compressive sensing (CS) is a powerful framework, allowing reconstruction of under-sampled signals; however, requiring an additional condition of signal sparsity. While the signal sparsity has been well investigated in terms of the lossy multimedia compression algorithms, in the CS terms it is still an interesting research topic. The JPEG and JPEG2000 standards achieve image compression by utilizing, respectively, the discrete cosine and the discrete wavelet transform as a sparsity inducing domain. In this process, the image is divided into individual blocks which are processed separately. While decades of the extensive JPEG application have resulted in the general consensus that the best performance is achieved with 8x8 blocks, and similarly JPEG2000 is often used with 16x16 and 32x32 blocks, the same conclusions cannot be drawn in the context of sparse image reconstruction. In this paper, we have performed detail analysis of the block size influence in the sparse image reconstruction by running extensive simulations on several standard test images for different state-of-the-art sparse reconstruction algorithms, various block sizes, and ratio of vailable pixels, with a goal of finding the optimal one.

**Keywords**—Image reconstruction, Signal sparsity, Compressive sensing, Discrete cosine transform, Discrete wavelet transform.

# Clock and Carrier Synchronization Using Optical Frequency Combs in Radio Access Networks

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**Abstract**—The operation of wireless communication systems, particularly in next-generation networks like 6G, has become increasingly complex, driving a growing demand for precise synchronization, especially with the introduction of technologies such as massive MIMO, ultra-dense cell deployments and Integrated Sensing and Communications (ISAC). This paper proposes a novel method for achieving clock and carrier synchronization using optical frequency combs. By leveraging Wavelength Division Multiplexing (WDM) to combine clock and data signals, and transmitting them over a Single-Mode Fiber (SMF), the system ensures precise synchronization across extensive distances. A 2.5 GHz spaced optical frequency comb is combined with optical data streams, and transmitted through the fiber network. Upon reception, the signals are demultiplexed and converted into electrical form, with the carrier frequencies successfully synchronized at 2.5 GHz, 5 GHz, and 7.5 GHz. The paper presents simulation and experimental results to validate the proposed methodology, demonstrating its feasibility for high precision synchronization in wireless communications. The results highlight the potential of optical frequency combs to enhance the performance of future communication networks, supporting high-speed data transmission with minimal latency and improved reliability.

**Keywords**—Clock and carrier synchronization, Radio Access Network, Optical Frequency Comb, Data transmission

# Hidden Markov Model for Predicting the Sequence of a User's Connections in an Integrated Terrestrial and Non-Terrestrial Network

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**Abstract**—It is envisaged that the 6G network will integrate terrestrial and non-terrestrial networks to provide seamless connectivity to mobile users. In integrated terrestrial and non-terrestrial networks (ITNTNs), WLAN, 5G network, and LEO satellites (LEOS) will be prominent radio access networks (RANs) among others. Thus, we consider the problem of predicting the sequence of RANs a user will connect to over a period of time in an ITNTN consisting of WLAN, 5G network and LEOS. Using the Hidden Markov Model, we develop a predictive scheme which determines the sequence of RANs to which a user will connect based on the user's initial location, mobility indicator, and admission control policy. The predicted sequence of RAN connections for individual users can be used to enhance resource reservation for handoff calls and improve resource utilization in an ITNTN. To the best of our knowledge, this is the first scheme considering the prediction of a user's sequence of RAN connections in an ITNTN. Simulation results are given to show the effectiveness of the proposed scheme.

**Keywords**—Integrated terrestrial and non-terrestrial network, user's model, Hidden Markov Model, RAN, radio resource.

# On optimal forms of the Hermite transform

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**Abstract**— The Hermite transform has been widely studied in the signal processing field due to its desirable properties. It has applicability in various fields starting from digital image processing, biomedical applications to the ultra-wide band communications. This paper explores the Hermite-like signals in the context of the signal estimation and variance reduction. By deriving an optimal estimator and the Cramer-Rao bound, we demonstrate that Hermite functions sampled at the roots of the Hermite polynomial provide an efficient framework for signal representation in the presence of Gaussian noise. The results indicate that the variance of the optimal form is lower than that of the Gauss-Hermite quadrature approximation, highlighting its benefits for signal estimation. Additionally, as expected, the variance increases with both the order of the Hermite function and the number of sampling points. The theory is illustrated with several examples.

**Keywords**— Cramer-Rao bound, Hermite transform, Hermite-like signals, orthogonality, UWB signals, variance

# 5G-Advanced RedCap and Digital Twin Technologies for Emerging IIoT Applications

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**Abstract**— The evolution of 5G Advanced is accelerating future innovations and research efforts toward achieving 6G connectivity. The 5G-Advanced RedCap technology aims to bridge the gaps caused by the limited throughput and latency of LTE-M and NB-IoT while simplifying operations when the full capabilities of a 5G eMBB network are not necessary. 3GPP Release 18 introduces a series of enhancements designed to address the diverse requirements of advanced IoT devices and services. Recently, Network Digital Twin (NDT) technology has been recognized as a key enabler of advanced Smart Manufacturing and Smart City initiatives, creating opportunities for symbiotic operations with RedCap. This paper provides a detailed overview of the latest developments in the 5G-Advanced RedCap specifications. Furthermore, we propose integrating 5G-Advanced RedCap and NDT for planning, construction, operation, maintenance, and optimization of 5G verticals.

**Keywords**—5G-Advanced, RedCap, Digital Twin, Network Digital Twin, Industrial IoT

# Index of Authors

**H**



**I**



**J**



**K**



**L**



**M**



**N**



**O**

**X**



**Y**



**Z**