

# ITU Journal

*Future and evolving  
technologies*

FREE | FAST | FOR ALL

Volume 3, Issue 2, September 2022



ISSN: 2616-8375



The ITU Journal on Future and Evolving Technologies (ITU J-FET) is an international journal providing complete coverage of all communications and networking paradigms, free of charge for both readers and authors.

The ITU Journal considers yet-to-be-published papers addressing fundamental and applied research. It shares new techniques and concepts, analyses and tutorials, and learnings from experiments and physical and simulated testbeds. It also discusses the implications of the latest research results for policy and regulation, legal frameworks, and the economy and society. This publication builds bridges between disciplines, connects theory with application, and stimulates international dialogue. Its interdisciplinary approach reflects ITU's comprehensive field of interest and explores the convergence of ICT with other disciplines.

The ITU Journal welcomes submissions at any time, on any topic within its scope.

### **Publication rights**

© International Telecommunication Union, 2022

Some rights reserved. This work is available under the CC BY-NC-ND 3.0 IGO license:

<https://creativecommons.org/licenses/by-nc-nd/3.0/igo/>.

### **SUGGESTED CITATION:**

ITU Journal on Future and Evolving Technologies, Volume 3, Issue 2, September 2022.

### **COMMERCIAL USE:**

Requests for commercial use and licensing should be addressed to ITU Sales at: [sales@itu.int](mailto:sales@itu.int).

**THIRD PARTY MATERIALS:** If the user wishes to reuse material from the published articles that is attributed to a third party, such as tables, figures or images, it is the user's responsibility to determine whether permission is needed for that reuse and to obtain permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

**GENERAL DISCLAIMERS:** The designations employed and the presentation of the material in the published articles do not imply the expression of any opinion whatsoever on the part of ITU concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by ITU in preference to others of a similar nature that are not mentioned.

### **ADDITIONAL INFORMATION**

Please visit the ITU J-FET website at:

<https://www.itu.int/en/journal/j-fet/Pages/default.aspx>

Inquiries should be addressed to Alessia Magliarditi at: [journal@itu.int](mailto:journal@itu.int)

## EDITORIAL BOARD

---

### Editor-in-Chief

Ian F. Akyildiz, *Truva Inc., USA*

***Special issue on “AI and machine learning solutions in 5G and future networks”***

### Leading Guest Editor

Aldebaro Klautau, *The Federal University of Pará (UFPA), Brazil*

### Guest Editors

Michaela Blott, *Xilinx, USA/Ireland*

Nada Golmie, *National Institute of Standards and Technology (NIST), USA*

Sevgi Gurbuz, *University of Alabama, USA*

José Suárez-Varela, *Universitat Politècnica de Catalunya, Spain*

### Reviewers

Thomas Basikolo, *International Telecommunication Union, Switzerland*

Samuel Bayliss, *AMD, USA*

Guillermo Bernárdez, *Universitat Politècnica de Catalunya, Spain*

Steve Blandino, *National Institute of Standards and Technology, USA*

Mahdi Boloursaz Mashhadi, *University of Surrey, UK*

João Paulo Borges, *Universidade Federal do Pará, Brazil*

Gaojie Chen, *University of Surrey, UK*

Ilan Correa, *Universidade Federal do Pará, Brazil*

Kristof Denolf, *AMD, USA*

Miquel Ferriol-Galmés, *Universitat Politècnica de Catalunya, Spain*

Nicholas Fraser, *AMD, USA*

Norihiro Fukumoto, *The University of Tokyo, Japan*

Luan Gonçalves, *Universidade Federal do Pará, Brazil*

Felix Jentzsch, *Paderborn University, Germany*

Hamid Latif Martínez, *Universitat Politècnica de Catalunya, Spain*

Francisco Müller, *Universidade Federal do Pará, Brazil*

Cleverson Nahum, *Universidade Federal do Pará, Brazil*

Ingrid Nascimento, *Universidade Federal do Pará, Brazil*

Jordi Paillissé Vilanova, *Universitat Politècnica de Catalunya, Spain*

Alessandro Pappalardo, *AMD, USA*

Vishnu Ram OV, *Independent Expert, India*

Leonardo Ramalho, *Universidade Federal do Pará, Brazil*

Thiago Sarmento, *Universidade Federal do Pará, Brazil*

Ana Siravenha, *Universidade Federal do Pará, Brazil*

Andreas Springer, *Johannes Kepler University Linz, Austria*

Yaman Umuroglu, *AMD, USA*

Francesc Wilhelmi, *Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain*

### **Regular papers**

### **Editors**

Mónica Aguilar Igartua, *Universitat Politècnica de Catalunya, Spain*

Pelin Angin, *Middle East Technical University, Turkey*

Flávia C. Delicato, *Fluminense Federal University, Rio de Janeiro, Brazil*

Wolfgang Gerstacker, *University of Erlangen-Nuernberg, Germany*

Richie Leo, *ZTE Corporation, China*

Albert Levi, *Sabanci University, Turkey*

Martin Reisslein, *Arizona State University, USA*

Giuseppe Ruggeri, *University of Reggio Calabria, Italy*

Zhi Sun, *Tsinghua University, China*

Cedric Westphal, *Huawei Innovation Center, USA*

The full list of the ITU J-FET Editors is available at <https://www.itu.int/en/journal/j-fet/Pages/editorial-board.aspx>.

## Reviewers

Sedat Akleylek, *Samsun Ondokuz Mayıs University, Turkey*

Yaqoob Al-Zuhairi, *Universitat Politècnica de Catalunya, Spain*

Xueli An, *Huawei Technologies, Germany*

Ahmet Aris, *Florida International University, USA*

Emmanuel Bertin, *Orange Labs, France*

Claudia Campolo, *University Mediterranea of Reggio Calabria, Italy*

Martin Cave, *London School of Economics, UK*

Gianluca Cernigliaro, *VRTogether, Spain*

Hesham ElBakoury, *Futurewei Technologies Inc., USA*

Xiaoming Fu, *University of Goettingen, Germany*

Hongzhi Guo, *Norfolk State University, USA*

Zixuan Huang, *National University of Singapore, Singapore*

Deepak Jose, *Christ University, Bangalore, India*

Ahan Kak, *Nokia Bell Labs, USA*

Piotr Krawiec, *National Institute of Telecommunications and Warsaw University of Technology, Poland*

Guangyi Liu, *Research Institute of China Mobile, China*

Ganapathy Mani, *Qualcomm Inc., USA*

Faik Kerem Örs, *Sabanci University, Turkey*

Ibrahim Ozcelik, *Sakarya University, Turkey*

Andrea Renda, *CEPS, Belgium*

**Special issue on “Emerging trends and applications in future communication networks”**

## Leading Guest Editor

Merouane Debbah, *CentraleSupélec and TII, France and UAE*

## Guest Editors

Petar Djuric, *Stony Brook University, USA*

Octavia Dobre, *Memorial University, Canada*

Zoran Hadzi-Velkov, *Ss Cyril and Methodius University, North Macedonia*

Konstantinos Oikonomou, *Ionian University, Greece*

## Reviewers

Pelin Angin, *Middle East Technical University, Turkey*

Aymen Fakhreddine, *Technology Innovation Institute, United Arab Emirates*

Wolfgang Gerstacker, *University of Erlangen-Nuernberg, Germany*

Konstantinos Giannakis, *University of Bergen, Norway*

Tolga Girici, *TOBB University of Economics and Technology, Turkey*

Maurizio Magarini, *Politecnico di Milano, Italy*

Milica Pejanovic-Djurisic, *University of Montenegro, Montenegro*

Slavche Pejovski, *Ss. Cyril and Methodius University in Skopje, North Macedonia*

Nassim Sehad, *Aalto University, Finland*

Mohit Sharma, *Technology Innovation Institute, United Arab Emirates*

Georgios Tsoumanis, *University of Ioannina, Greece*

Yiqin Wang, *Shanghai Jiao Tong University, China*

Qiyang Zhao, *Technology Innovation Institute, United Arab Emirates*

### **ITU Journal Team**

Alessia Magliarditi, ITU Journal Manager

Erica Campilongo, Publishing Editor

## TABLE OF CONTENTS

	Page
<b>Papers of the special issue on "AI and machine learning solutions in 5G and future networks"</b>	
Research on network cloud equipment anomaly and root cause analysis <i>Dandan Zou, Jianbing Ding, Xidong Wang, Xiaozhou Ye, Ye Ouyang</i> .....	89
Utilizing machine learning algorithms for localization using RSSI values of wireless LAN <i>Chirantan Ganguly, Sagnik Nayak, S. Irene, Anil Kumar Gupta, Suresh V., Pradeep Kumar CH</i> .....	98
4G/5G Cell-level multi-indicator forecasting based on dense-MLP <i>Jiacheng Yin, Wenwen Li, Xidong Wang, Xiaozhou Ye, Ye Ouyang</i> .....	108
Federated spatial reuse optimization in next-generation decentralized IEEE 802.11 WLANS <i>Francesc Wilhelmi, Jernej Hribar, Selim F. Yilmaz, Emre Ozfatura, Kerem Ozfatura, Ozlem Yildiz, Deniz Gündüz, Hao Chen, Xiaoying Ye, Lizhao You, Yulin Shao, Paolo Dini, Boris Bellalta</i> .....	117
QT-Routenet: Improved GNN generalization to larger 5G networks by fine-tuning predictions from queueing theory <i>Bruno Klaus de Aquino Afonso, Lilian Berton</i> .....	134
Decision tree-based radio link failure prediction for 5G communication reliability <i>Nethraa Sivakumar, Pooja Srinivasan, Nikhil Viswanath, Venkateswaran N</i> .....	142
Neural network compression with feedback magnitude pruning for automatic modulation classification <i>Jakob Krzyston, Rajib Bhattacharjea, Andrew Stark</i> .....	157
AI powered solution for radio link failure prediction based on link features and weather forecast <i>Priyanshu M, Venkatesh Subramanya Iyer Giri, Shachi P, Geetishree Mishra, Suma M N</i> .....	165
Network resource allocation for emergency management based on closed-loop analysis <i>Guda Blessed, Ibrahim Aliyu, James Agajo, Thiago Lima Sarmiento, Cleverson Veloso Nahum, Lucas Novoa, Rebecca Aben-Athar, Mariano Moura, Lucas Matni, Aldebaro Klautau, Deena Mukundan, Divyani R Achari, Mehmet Karaca, Doruk Tayli, Özge Simay Demirci, V. Udaya Sankar, Sai Jnaneswar Juvvisetty, V.M.V.S. Aditya, Abhishek Dandekar, Shabnam Sultana, Jinsul Kim, Vishnu Ram OV</i> .....	175
Simultaneous beam selection and users scheduling evaluation in a virtual world with reinforcement learning <i>Ilan Correa, Ailton Oliveira, Bojian Du, Cleverson Nahum, Daisuke Kobuchi, Felipe Bastos, Hirofumi Ohzeki, João, Borges, Mohit Mehta, Pedro Batista, Ryoma Kondo, Sundesh Gupta, Vimal Bhatia, Aldebaro Klautau</i> .....	202
Low-precision deep-learning-based automatic modulation recognition system <i>Satish Kumar, Aakash Agarwal, Neeraj Varshney, Rajarshi Mahapatra</i> .....	214

Addressing RouteNet scalability through input and output design <i>Junior Momo Ziazet, Charles Boudreau, Brigitte Jaumard, Huy Duong</i> .....	224
Network anomaly detection based on keyword embedding log <i>Yong Song, Zhiwei Yan, Yukun Qin, Yuchen Xie, Xiaozhou Ye, Ye Ouyang</i> .....	235
AI-based indoor localization using mmWave MIMO channel at 60 GHz <i>Shubham Khunteta, Ashok Kumar Reddy Chavva (Senior Member, IEEE), Avani Agrawal</i> .....	243
BacalhauNet: A tiny CNN for lightning-fast modulation classification <i>José Rosa, Daniel Granhão, Guilherme Carvalho, Tiago Gonçalves, Mónica Figueiredo, Luís Conde Bento, Nuno Paulino, Luís M. Pessoa</i> .....	252
RFNet: Fast and efficient neural network for modulation classification of radio frequency signals <i>Mohammad Chegini, Pouya Shiri, Amirali Baniasadi</i> .....	261
<b>Regular papers</b>	
Wireless communication research challenges for Extended Reality (XR) <i>Ian F. Akyildiz, Hongzhi Guo</i> .....	273
Collaborative digital regulation: A much-needed approach to achieving growth of the digital economy <i>Raul Katz, Juan Jung</i> .....	288
A robust high capacity Gray code-based double layer security scheme for secure data embedding in 3D objects <i>Ghadir Mostafa, Wassim Alexan</i> .....	310
Dynamic infrastructure-as-a-service: A key paradigm for 6G networks and application to maritime communications <i>Sokratis Barmounakis, Nancy Alonistioti, George C. Alexandropoulos, Alexandros Kaloxylos</i> .....	326
Sensing fusion in vehicular network digital twins for 6G smart city <i>Chen Cheng, Haibin Lv, Zhihan Lv</i> .....	342
System intelligence for UAV-based mission critical services with challenging 5G/B5G connectivity <i>Cristiano Bonato Both, João Borges, Luan Gonçalves, Cleverson Nahum, Ciro Macedo, Aldebaro Klautau, Kleber Cardoso</i> .....	359
Non-coherent modulation with random phase configurations in RIS-empowered cellular MIMO systems <i>Kun Chen-Hu, G. C. Alexandropoulos, Ana Garcia Armada</i> .....	374
Using manufacturer usage descriptions for IoT network security: An experimental investigation of smart home network devices <i>Milad Kazemi Darazam, Pelin Angin, Cengiz Acartürk</i> .....	388
Intrusion detection systems for IoT: Opportunities and challenges offered by edge computing <i>Pietro Spadaccino, Francesca Cuomo</i> .....	408

Holographic-type communication: A new challenge for the next decade <i>Ian F. Akyildiz, Hongzhi Guo</i> .....	421
<b>Papers of the special issue on "Emerging trends and applications in future communication networks"</b>	
A measurement data-based investigation of fading modeling for indoor THz wireless systems <i>Evangelos N. Papatirou, Alexandros-Apostolos A. Boulogeorgos, Angeliki Alexiou</i> .....	443
Optimal beamforming and deployment of millimeter-wave drone base stations <i>Tolga Girici, Fatih Yürekli</i> .....	459
Experimental evaluation of multi-PHY 6TiSCH networks <i>Milica Lekić, Gordana Gardašević, Milan Mladen</i> .....	470
A probabilistic refined policy for topology-independent medium access control in ad hoc network environments <i>Vasileios Dragonas, Georgios Tsoumanis, Konstantinos Oikonomou</i> .....	483
Binary vs partial offloading in wireless powered mobile edge computing systems with fairness guarantees <i>Marija Poposka, Zoran Hadzi-Velkov</i> .....	498
Optimal wireless rate and power control in the presence of jammers using reinforcement learning <i>Fadlullah Raji, Lei Miao</i> .....	508
Analysis of spatial scheduling in downlink vehicular communications: Sub-6 GHz vs mmWave <i>Mehdi Haghshenas, Francesco Linsalata, Luca Barbieri, Mattia Brambilla, Monica Nicoli, Maurizio Magarini</i> .....	523
Dispersed passive RF-sensing for 3D structural health monitoring <i>Abeer Ahmad, Xiao Sha, Akshay Athalye, Samir R. Das, Kelly Caylor, Branko Glišić, Milutin Stanačević, Petar M. Djurić</i> .....	535