Guest Editorial Special Issue on "Edge-Based Wireless Communications Technologies to Counter Communicable Infectious Diseases"

Sasitharan Balasubramaniam, Robert Schober, Massimiliano Pierobon, Sudip Misra, and Peter Thomas

THE COVID-19 pandemic has resulted in one of the major challenges for humanity in the 21st century. The impact of these challenges has led to a tremendous loss of life, impact on long-term health, well-being as well as personal psychology, and negative societal changes and not to mention its impact on the global economy. Since this is a health issue, similar to other forms of diseases and pandemics, society has largely relied on the fields of medical, virology, immunology, biotechnology, and pharmaceutical science to develop novel therapeutic solutions for treatments. This has resulted in vaccines that have been rolled out to elevate immunity levels that will hopefully allow the majority of the population to reach herd immunity. However, given the technological advancements that we have reached in the 21st century, questions have also risen as to how other disciplines can play a role in solving and obtaining new knowledge of communicable disease pandemics.

We have witnessed how communication and network technologies have played a role in addressing the challenges of COVID-19. From a practical perspective, we have seen that lockdowns have resulted in increased use of the Internet infrastructure to provide online education and facilitate meetings and interactions. However, other technologies and research areas in the field of communication theory and network engineering have the potential to play important roles in addressing future communicable disease pandemics. This Special Issue presents emerging areas that can potentially be used to investigate new knowledge, insight and information, as well as support and assist in solving future pandemics. Specifically, we dive deep into communication technologies and paradigms that directly interface with people; we sought manuscripts from the research community working in edge wireless technologies, privacy of user data that is used for contact tracing and novel edge-based AI services. One of the major factors contributing to the epidemic spreading of communicable diseases is through propagation of molecules. The mechanism of spread has resulted in new research direction for the field of molecular communications, and in particular for respiratory aerosol expulsion as well as novel biosensor detectors. Based on the importance of this new research area, the Special Issue also incorporated articles from the field of molecular and nano-communications that can connect novel receiver models through the Internet of Bio-Nano Things, as well as propagation behavior of aerosols expelled from people that can result in spreading of infectious diseases.

Our Special Issue brought together researchers in these areas resulting in 26 high-quality submissions. We accepted in total 11 articles that were sub-divided into the following categories: 1) Edge-AI Data Analysis for Communicable Diseases, 2) Privacy and Accuracy of Contact Tracing at the Edge, and 3) Molecular Communications and Internet of Bio-Nano Things.

I. Edge-AI Data Analysis for Communicable Diseases

In [A1], Yang et al. proposed an Edge-AI bot that considers the Age of Information (AoI) for health monitoring as it collects biosensing data from patients. In situations where pandemics are prevalent, and in particular in crowded areas, the timely collection of the most up to date information is required. The article focused on the timely updating of the latest information from AI bots that interact with an edge-wireless system by defining an optimization problem from a mixed-game viewpoint. The proposed algorithm includes cooperative-based bot deployment and stochastic learning-based channel selection, where comparisons were made to baseline solutions and showed that lower AoI measure were achieved with high performance of accuracy.

Increasing number of robotic systems for patient throat-swab sample collections are being deployed during pandemics in order to minimize risks for health care workers. In [A2],

Sasitharan Balasubramaniam and Massimiliano Pierobon are with the School of Computing, University of Nebraska-Lincoln, Lincoln, NE 68588 USA.

Robert Schober is with the Institute for Digital Communications (IDC), University of Erlangen-Nuremberg, 91054 Erlangen, Germany.

Sudip Misra is with the Department of Computer Science and Engineering, Indian Institute of Technology, Kharagpur 721302, India.

Peter Thomas is with the Department of Mathematics, Applied Mathematics, and Statistics, Case Western University, Cleveland, OH 44106 USA.

Color versions of one or more figures in this article are available at https://doi.org/10.1109/JSAC.2022.3210805.

Digital Object Identifier 10.1109/JSAC.2022.3210805

Gao et al. investigated the medical robot audio-video haptic system with cross-modal communications, in order to increase correlations between different modalities that can result in high reliability as well as throughput. The proposed semantic aided cross-modal reconstruction framework is proposed by taking into consideration the user-experience stream scheduling strategy to enhance visual quality through wireless links.

II. Privacy and Accuracy of Contact Tracing at the Edge

While contact tracing can provide useful information to track and determine the pandemic spreading pattern, it has come at a cost of exposing user's privacy. To address this challenge, in [A3], Xie et al. proposed a Confidentiality-Preserving Contact-Tracing (CPCT) system using multiple wireless edge-based nodes. The scheme uses two Physical-Layer Authentication (PLA) schemes for the authentication stage of the CPCT system, a Coordinate-based Location PLA (CLP) scheme based on the estimated coordinates, and a Time-of-Arrival (ToA) based Location PLA (TLP) scheme. The results from simulations have shown that the approach results in higher authentication performance than the prior PLA solutions and the encryption scheme used also results in high confidentiality performance.

In [A4], Cheng et al. proposed the use of Federated Learning (FL) for handling patient COVID-19 data in order to enable protection of data privacy. The "Asynchronous-Adaptive FL" scheme proposed in the paper caters for diverse medical devices performances that have heterogeneous number of local SGD iterations during each communication round or parameter updates. Experiments were conducted on public COVID-19 databases to show that the scheme performs well with high efficiency under system heterogeneity.

Another article in our Special Issue that focuses on privacy of end users while estimating their distances is the work by Li et al. [A5] The authors proposed CoAvoid, which is an edge-based, privacy preserved contact tracing system building on the Google/Apple Exposure Notification (GAEN) API to allow device compatibility and also ensuring operating efficiency. The mechanism used to analyze the location of the user is based on Bluetooth as well as GPS signals. The combination of both can allow accurate detection of close contacts with other people at fine-granularity. In order to hide the end user's privacy information, CoAvoid uses both fuzzification and obfuscation measures. The experimental results compared to state-of-the-art contact tracing applications have shown that CoAvoid can reduce the size of upload data and reduce the verification periods.

One of the major challenges in contact tracing is the accurate estimation of distances between individuals. In [A6], Zhang et al. proposed a distance estimation algorithm that is based on machine learning. Specifically, the algorithm includes Learning Vector Quantization and Regression, and Deep Feed-forward (DFF) Neural Network to process Bluetooth signal information data from mobile phones. The algorithm considers negative effects from the environment (e.g., body shielding), where experimental results showed that the proposed DISTERING algorithm can maintain accuracy of estimated distances between different devices.

In [A7], Wei et al. proposed an anonymous communication model that masks the identity of the sender, by using the physical layer signals through a statistical attribute-based sender detection. The proposed approach can result in increased performance, especially for devices that are equipped with multiple antennas. The scheme is based on a statistical attribute-based sender detection, which lowers the detection error rate for various SNR. The scheme also considers the physical layer anonymity by manipulating the transmitted signaling pattern, which in turn masks the sender's channel characteristics. The simulation results have shown that the proposed approach provides a high level of anonymity over benchmark techniques.

In [A8], Li et al. investigated the prediction of infectious diseases using wireless edge networks. The approach is based on the density of individuals within a wireless edge network and uses a stochastic geometry-based method to determine the infectious probability of individuals within a specified location. The proposed approach can maintain the privacy of users that are connected to a wireless network, without requiring information of their movement trajectory. An analytical model was developed and compared to simulations that analyzed three different mobility models. The authors also go on to propose countermeasures against the spread of COVID-19 by using wireless edge networks.

III. Molecular Communications of Infectious Diseases and Internet of Bio-Nano Things Detection Techniques

In [A9], Chen et al. investigated the impact of aerosol propagation and its impact of inter-symbol interference (ISI) on the detection accuracy. Such ISI can result from a number of different individuals that expel molecular aerosol, resulting in close diffusion clouds of molecules that reduces detection accuracy. The approach taken by the authors is to optimize the detection interval to accurately detect transmitted information symbol. The authors also proposed a modified-signal-to-interference-and-noise amplitude ratio (SINAR) to measure the BER for variable detection interval, where results have shown that the proposed scheme outperforms other optimized detection interval approaches.

In [A10], Sanwan and Jornet proposed a joint nanoscale communication and bio-sensing solution that exploits plasmonic sensing nanoantennas. The approach investigates future implantable devices that can accurately detect specific biomarkers. The authors analyzed the changes in the frequency response of the plasmonic antennas that are functionalized with receptors for the biomarkers and also proposed a chirp-spread spectrum excitation and detection system for nano communication that also facilitates sensing. This approach can result in a new paradigm of in-body nanonetworks as well as the Internet of Bio-Nano Things.

In [A11], Aktas and Akan proposed another receiver model for the Internet of Bio-Nano Things that can detect biomarkers using Flexure field-effect transistor (FET). The receiver is compatible to a new form of modulation scheme for molecular communications, and this is through weight shift keying (WSK). This form of modulation is suitable for viral infections within the body as they replicate and proliferate resulting in weight changes at the receivers. The authors analyzed the performance metrics of the detection accuracy by considering biological interference, and this was validated through simulations.

Acknowledgment

The Guest Editorial team for this multi-disciplinary Special Issue would like to sincerely thank all the authors for their high-quality submissions that will hopefully benefit public health solutions to counter future pandemics. We would also like to thank the reviewers for their dedication and hard work in providing outstanding comments and suggestions to improve the quality of the articles. The Guest Editors would also like to sincerely thank Prof. Raouf Boutaba, Janine Bruttin, and Prof. Petar Popovski for their continued support that has resulted in this successful Special Issue. The Guest Editors would like to thank Prof. Christopher Rose for all his suggestions and guidance in the organization for this Special Issue.

Appendix: Related Articles

[A1] Y. Yang et al., "Mixed game-based AoI optimization for combating COVID-19 with AI bots," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3122–3138, Nov. 2022.

[A2] Y. Gao, S. Ni, D. Wu, and L. Zhou, "Edge-based cross-modal communications for remote healthcare," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3139–3151, Nov. 2022.

[A3] N. Xie, W. Wang, Y. Chen, P. Zhang, and L. Huang, "Confidentiality-preserving edge-based wireless communications for contact tracing systems," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3152–3171, Nov. 2022.

[A4] J. Cheng, N. P. L. Xiong, and J. Wu, "AAFL: Asynchronous-adaptive federated learning in edge-based wireless communication systems for countering communicable infectious diseases," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3172–3190, Nov. 2022.

[A5] T. Li et al., "CoAvoid: Secure, privacy-preserved tracing of contacts for infectious diseases," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3191–3206, Nov. 2022.

[A6] B. Zhang, R. Wang, H. Xu, X. Zhang, and L. Zhang, "DISTERNING: Distance estimation using machine learning approach for COVID-19 contact tracing and beyond," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3207–3223, Nov. 2022.

[A7] Z. Wei, C. Masouros, P. Wang, X. Zhu, J. Wang, and P. A. Petropulu, "Physical layer anonymous precoding design: From the perspective of anonymity entropy," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3224–3238, Nov. 2022.

[A8] X. Li, S. Guo, H.-N. Dai, and D. Li, "Infectious probability analysis on COVID-19 spreading with wireless edge networks," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3239–3254, Nov. 2022.

[A9] X. Chen, M. Wen, F. Ji, Y. Huang, Y. Tang, and W. A. Eckford, "Detection interval of aerosol propagation from the perspective of molecular communication: How long is enough?" *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3255–3270, Nov. 2022.

[A10] A. Sangwan and J. M. Jornet, "Joint communication and bio-sensing with plasmonic nano-systems to prevent the spread of infectious diseases in the Internet of Nano-Bio Things," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3271–3284, Nov. 2022.

[A11] D. Aktas and B. O. Akan, "Weight shift keying (WSK) with practical mechanical receivers for molecular communications in Internet of Everything," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 11, pp. 3285–3294, Nov. 2022.