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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: COMMUNICATIONS IN HARSH ENVIRONMENTS

Communication systems deployed in harsh environments, such as high-speed trains, subways, deserts, trenches, forests, and underground mines, should be specially constructed to withstand extreme conditions such as high or low temperatures, corrosive humidity, extreme weather, or excessive dust and dirt. Such applications require specially designed wireless communication, fiber-optic communications, satellite communication, or signal processing techniques that can perform under extreme conditions and meet the QoS, security, and reliability requirements. Quite often, communications in harsh environments have an extremely low signal-to-noise ratio (SNR), high Doppler shift, and long latency, and often consume more power and energy. Bandwidth limitation in harsh environments requires spectrum efficient communications. The current state of art technologies such as massive MIMO, advanced modulation and channel coding, artificial intelligence, and signal processing provide different venues to explore this challenging area.

This Special Section aimed to publish the most recent results on communications in harsh environments. The response to the Call for Papers was overwhelming, with 95 articles submitted from around the world. During the review process, each submission was assigned to and reviewed by multiple experts in relevant areas, with a rigorous peer-review process. Thanks to the great support from the Editor-in-Chief of IEEE ACCESS, Prof. Derek Abbott, we were able to accept 45 excellent articles covering various aspects of communications in harsh environments.

The article “Irregular marker codes for insertion/deletion-AWGN channels,” by Liu *et al.*, presents a concatenated coding scheme employing an irregular marker code as the inner code to improve the ability of correcting insertions/deletions. In this scheme, bits associated with each marker symbol are nonuniformly allocated to the symbol of the LDPC code. Since the nonbinary marker symbol at the irregular position provides reliable forward/backward quantities, significant amount of insertions and deletions can be detected and corrected by the presented method.

Pilot contamination (PC) is recognized as a bottleneck for the achievable throughput of multi-cell massive multiple-input–multiple-output (MIMO) systems. In the article “Joint pilot allocation and pilot sequence optimization in massive MIMO systems,” by Nie and Zhao, a joint pilot allocation and pilot sequences optimization (JPA-PSO) scheme is proposed

to mitigate the effects of PC and maximize the system spectral efficiency (SE).

Energy-efficient routing in heterogeneous wireless sensor networks (HWSNs) is useful for prolonging network lifetime and energy conservation. In the article “A novel relay node placement and energy efficient routing method for heterogeneous wireless sensor networks,” by Xie *et al.*, the authors first construct a mathematical model for both relay node placement and energy-efficient routing problems. For the relay node placement problem, it is assumed that HWSN contains unreachable areas where sensor nodes could not be placed. For energy-efficient routing, it is transformed to the path length of wireless communication. As the problem is non-deterministic polynomial (NP) hard, a heuristic method called whale optimizer is used. The article studies the effect of the whale optimizer method with three adaptive schemes.

Person re-identification (Re-ID) in camera networks under complex environments has achieved promising performance using deep feature representations. However, most approaches usually ignore learning features from non-salient parts of pedestrians, which results in an incomplete pedestrian representation. The article “Adversarial erasing attention for person re-identification in camera networks under complex environments,” by Liu *et al.*, proposes a novel person Re-ID method named Adversarial Erasing Attention (AEA) to mine discriminative completed features using an adversarial method. The AEA extracts global and local deep features from original pedestrian images, and learns complementary features using erased pedestrian images. In order to generate effective erased pedestrian images, it presents the adversarial erasing operation to locate salient areas on the attention map and adopts a dynamic strategy to match the dynamic status of AEA.

The article “Investigation of a flexible downstream scheme for sampling rate and bandwidth reduction in short reach communication systems,” by Li *et al.*, demonstrates a cost- and spectrum-effective orthogonal frequency-division multiple access passive optical network downstream scheme based on multi-band and modified sub-Nyquist sampling over transmission reach of 20 km. The sampling rate and bandwidth of ADC are reduced effectively, and double spectrum efficiency (SE) is obtained.

From the perspective of collaborative design of control and scheduling, the article “Dynamic bandwidth scheduling of

software-defined networked collaborative control system,” by Yan *et al.*, presents a software-defined networked collaborative control system (SD-NCCS). Under the framework of the SD-NCCS, a dynamic bandwidth scheduling strategy based on the game theory and network pricing mechanism is proposed, which transforms the network resource allocation problem into the Nash equilibrium solving problem.

In the article “Ambiguity analysis for multitarget estimation using random permuted frequency diverse arrays,” by Li *et al.*, a relation matrix that describes the targets’ relative location is established and analyzed to reveal the principle of ambiguity, that is, the rank deficiency of the relation matrix. Then, a law of relative target locations causing the rank deficiency of the relation matrix and the categories of the relative target locations are developed. Moreover, two cases of the relative target locations causing ambiguity are proposed, which are transformed based on the relative target locations causing rank deficiency. By employing the law of relative target locations causing ambiguity in a frequency increment vector pre-evaluation, more ambiguous frequency increment vectors can be identified compared with the identification using single-target criterion, which improve the unambiguous probability of a multitarget estimation.

The article “Local heterogeneous features for person re-identification in harsh environments,” by Zhang *et al.*, proposes Local Heterogeneous Features (LHF) for person Re-ID in harsh environments. The proposed LHF could learn three kinds of local features from multiple angles. Specifically, it employs the cross-entropy loss to optimize local discriminative features. At the same time, it applies the triplet loss to optimize local relative features and utilizes the center loss to learn local compact features. Finally, it employs local discriminative features to represent pedestrians.

The pilot spoofing attack (PSA) is one kind of active eavesdropping that happens in the channel training phase, in which an intelligent eavesdropper transmits identical pilot sequences synchronously with the legitimate user to spoof the transmitter. To prevent the active PSA “Detection and localization of the eavesdropper in MIMO systems,” by Ning *et al.*, proposes a new effective scheme called the spatial spectrum method (SSM) which can be applied in situations in which the eavesdropper attacks not only the transmitter but also the legitimate user in MIMO communication systems.

In this article “Toward void hole alleviation: Enhanced geographic and opportunistic routing protocols in harsh underwater WSNs,” by Awais *et al.*, two energy-efficient routing protocols are proposed to maximize the PDR by minimizing the ratio of void hole occurrence. Scalability analysis of the proposed routing protocols is also performed. In addition, feasible regions are computed to check the optimality of the proposed protocol in terms of EC. Furthermore, proposed protocols are compared with benchmark routing protocols in counterparts.

Directional modulation (DM) can transmit information to the desired direction or directions with known constellation mappings, but with scrambled ones in other directions.

However, one problem of the design is that when desired receivers and eavesdroppers are in the same transmission direction, their beam responses cannot be distinguished, as steering vectors for these locations are the same. In this article “Metasurface based positional modulation design,” by Zhang *et al.*, positional modulation design with the aid of metasurface as a low-cost flexible reflecting surface has been introduced for the first time, where signals via LOS and reflected paths are combined at the receiver side. Compared with fixed reflection surface, the advantage of using metasurface is the flexible control of reflection direction and phase and intensity of the incident signal. While compared with the high cost of using multiple antenna arrays to achieve positional modulation, metasurface provides a convenient low-cost solution for system construction.

In the article “Thermal stability analysis of filters in substrate integrated technologies under atmospheric pressure and vacuum conditions,” by Nova *et al.*, a complete thermal analysis (under atmospheric pressure and high-vacuum conditions) has been performed for the same five-pole bandpass filter in four different Substrate-Integrated (SI) technologies (SIW, ADLS, ESIW, and ESICL). The filters have been designed, manufactured, and measured at different temperatures according to the ECSS data sheet specifications for thermal testing of devices to be used in real space applications.

Device-to-device (D2D) communications and full-duplex (FD) communications, which can improve the SE of mobile communications, have received much attention. The article “Spectrum-efficient transmission mode selection for full-duplex-enabled two-way D2D communications,” by Han *et al.*, investigates the mode selection problem for FD-enabled two-way D2D communications to improve the SE. Four transmission modes, i.e., FD underlay mode, half-duplex (HD) underlay mode, FD overlay mode, and HD overlay mode, are considered.

The article “Design of intelligent circuit characteristic tester for use in harsh environments,” by Zhao *et al.*, designs and makes an intelligent circuit characteristic tester. It is used to measure the characteristics of a specific amplifier circuit, and then to intelligently determine the reasons for the failure or change of the amplifier due to the change of components.

Human activity recognition has been growing for decades in a variety of technological disciplines. In the article “Temporal-frequency attention-based human activity recognition using commercial WiFi devices,” by Yang *et al.*, a multipath selection algorithm is first proposed to extract the effective multipath information of CSI. It is adaptive in LOS and NLOS environments, especially in environments where there is more multipath information or where the LOS path propagation is blocked. Then, the authors propose a temporal-frequency attention network model based on the attention mechanism to perform feature learning and activity recognition on data and use the attention mechanism to overcome the instability problem of existing data cutting algorithms.

In this article “Deep learning based nonlinear signal detection in millimeter-wave communications,” by Liu *et al.*, a DL-based detection approach is designed, which, as one joint nonlinear equalizer and signal detector, is not only capable of mitigating both power amplifier (PA) nonlinearity and multipath inter-symbol-interference (ISI) at the receiver-end in single-input single-output (SISO) mm-wave communication system, but jointly mitigating PA nonlinearity and decoding STBC code in MIMO communication systems.

Many empirical path loss (PL) models have been developed to assess the performance of new radio networks. The article “An accurate empirical path loss model for heterogeneous fixed wireless networks below 5.8 GHz frequencies,” by El Khaled *et al.*, first studies the state-of-the-art of empirical PL models, along with vegetation effects on radio signal propagation. Next, an accurate empirical PL model is proposed for fixed wireless networks under challenging rural propagation conditions. The proposed model is based on a Canadian dataset from a wireless internet service provider, using the wireless-to-the-home technology in the unlicensed 900 MHz, 2.4 and 5.8 GHz ISM bands, and in the licensed 3.65 GHz band. The proposed model considers several parameters, such as line-of-sight obstructions, frequency bands, and dynamic link distance splitting, in addition to seasonal variations in PL attenuation.

High pilot overhead in channel estimation is a critical problem due to the imaginary interference in multiple input–multiple output (MIMO) employing filter bank multicarrier (FBMC) (MIMO-FBMC) systems. The article “Preamble-based MMSE channel estimation with low pilot overhead in MIMO-FBMC systems,” by Kong *et al.*, proposes a novel preamble design with low overhead, and presents a minimum mean square error (MMSE) algorithm for the channel estimation, which can improve the system performance in harsh environments.

The advantage of device-to-device (D2D) communications may be limited when D2D users are far away from each other or the communication environments are harsh. A promising way to extend the range of D2D communications is to use relaying technique to assist the communications. The article “Power control for two-way AF relay assisted D2D communications underlying cellular networks,” by Han *et al.*, uses a two-way amplify-and-forward (AF) relay to assist the underlay D2D communications and investigate the power control problem.

In the article “A novel detection and recognition method for continuous hand gesture using FMCW Radar,” by Wang *et al.*, a novel method for continuous hand gesture detection and recognition is proposed based on a frequency modulated continuous wave (FMCW) radar.

Magnetic communication is receiving significant interest in RF-challenging environments. In the article “Underwater communication employing high-sensitive magnetic field detectors,” by Hott and Hoehner, a new approach for magnetic underwater communication is presented and evaluated.

In the article “Feature extraction of mine water inrush precursor,” by Zhang *et al.*, coal water inrush acoustic emission (AE) signal is characterized by time-varying, nonstationary, unpredictable, and transient properties. To extract effective features representing coal water inrush information, the AE signal is analyzed by the wavelet characteristic energy spectrum coefficient based on wavelet theory.

The article “Enhanced 6P transaction methods for industrial 6TiSCH wireless networks,” by Ha and Chung, analyzes the performance and problems of 6top protocol (6P) for link scheduling in harsh networks, and proposes parent-initiated 6P transaction and transaction revert methods to overcome such problems.

Early detection and identification of pests can effectively reduce the economic losses caused by pests. In the article “Research on recognition model of crop diseases and insect pests based on deep learning in harsh environments,” by Ai *et al.*, a convolution neural network is used to automatically identify crop diseases.

Due to the climate and sky requirements, high-precision telescopes are generally located in remote areas, suffering from the harsh environments around it. To monitor such systems, predictive tools are needed to identify, hopefully beforehand, the occurrence of failures in all the different subsystems. The article “Slow degradation fault detection in a harsh environment,” by Cho *et al.*, presents a novel fault detection scheme for one of these subsystems, the Intermediate Frequency Processors (IFP).

The design of a robust visible-light communication (VLC) system for underground mining is a challenging task due to the harsh propagation conditions encountered in mining tunnels. The article “A VLC channel model for underground mining environments with scattering and shadowing,” by Játiva *et al.*, provides a novel channel model that incorporates important factors that influence the quality of the VLC link in underground mines.

Positional modulation (PM) has been introduced recently where a given modulation pattern can only be received at certain desired positions. In the article “Sparse antenna array based positional modulation design with a low-complexity metasurface,” by Zhang *et al.*, a sparse antenna array-based positional modulation design is proposed, which exploits multipath effect with the aid of metasurface acting as a low-cost flexible reflecting surface.

Metasurface-based positional modulation design has been introduced recently, where a given modulation pattern can only be received at certain desired positions. In the article “Constant reflection attenuation constraint for incoming signals on metasurface in positional modulation design,” by Liang *et al.*, a constant reflection attenuation constraint for incoming signals is proposed and can be extended to no reflection attenuation.

To improve the accuracy and environmental adaptability of personnel and equipment localization algorithms in the construction and operation of smart water platform, the article “KF-KNN: Low-cost and high-accurate FM-based

indoor localization model via fingerprint technology,” by Du *et al.*, proposes a fingerprint localization algorithm (KF-KNN) based on FM signals.

Spherical antenna array has become highly attractive where hemispherical scan coverage is required as it can provide uniform directivity in all the scan directions. In the article “An intelligent deep learning-based direction-of-arrival estimation scheme using spherical antenna array with unknown mutual coupling,” by Famoriji *et al.*, the authors present a robust DoA estimation and mutual coupling compensation technique based on convolutional neural network (CNN) for spherical array.

The integrity and accuracy of positioning are crucial factors in vehicle safety. The article “A single-frequency real-time lane-level positioning method for vehicle safety,” by Ji *et al.*, proposes an enhanced real-time array calibration (ERAC) technique based on real-time array error calibration with the Beidou navigation satellite system (BDS).

The article “Marker codes using the decoding based on weighted Levenshtein distance in the presence of insertions/deletions,” by Liu *et al.*, presents a novel symbol-level decoding algorithm considering the weighted Levenshtein distance (WLD), and is designed for correcting insertions and deletions, as well as substitutions in the received sequences. In this method, branch quantities in the decoding trellis are calculated by measuring the WLD, which is done using dynamic programming.

The electromagnetic scattering from rough surfaces with different scales of roughness is studied in the article “A study of scattering from rough surface with different scale of roughness based on the efficient numerical strategies,” by Liang and Guo. This type of algorithm contributes to coherent and incoherent scattering parts from the components of different roughness.

A scenario where D2D-assisted cooperative relaying downlink transmission utilizing non-orthogonal multiple access (DC-NOMA) over the same time or frequency resource is described in the article “Power allocation and receiver design for D2D assisted cooperative relaying downlink system using NOMA,” by Cheng *et al.* In order to enhance the reliability in practical mobile communication systems, a NOMA downlink receiver design with acceptable complexity was proposed to reduce the work delay and BLER.

Intrusion detection systems based on machine learning and artificial intelligence significantly improve the terminal side’s abnormal detection capacity. In the article “Abnormal detection of wireless power terminals in untrusted environment based on double hidden Markov model,” by Wu *et al.*, abnormal behavior of wireless power terminals based on a double Hidden Markov Model (HMM) is identified, which solves the computational complexity problem caused by high dimensions in intrusion detection systems using a single HMM.

The article “Multi-link scheduling algorithm of LLC protocol in heterogeneous vehicle networks based on

environment and vehicle-risk-field model,” by Ding *et al.*, derives a new link scheduling algorithm in an LLC layer (LLCA) based on the vehicle risk estimation and event-triggered mechanism to control and schedule the link resources of heterogeneous vehicle networks. This algorithm reduces the transmission delay of WSM data for secure applications and improves the utilization of links on the premise of satisfying most of the QoE network applications.

Ultra-high reliability and ultra-low latency are the key objectives of the Internet of things (IoT) with massive connectivity. In the article “Beamforming optimization and power allocation for user-centric MIMO-NOMA IoT networks,” by Wang and Wu, a resource allocation for the user-centric multi-cell MIMO nonorthogonal multiple access (MIMO-NOMA) based IoT networks is investigated. The effectiveness of the proposed resource allocation scheme for the user-centric MIMO-NOMA IoT networks is demonstrated.

A scheme that can effectively improve the sum throughput of communications in the real world using particular pattern division multiple access (PDMA) with optimized power allocation is presented in the article “Downlink power allocation optimization in pattern division multiple access,” by Zeng *et al.* This type of scheme can outperform the existing schemes and can be effective in harsh environments.

Molecular communication (MC) systems are widespread among cells and organisms at nanoscale in biology, and are widely applied to the fields of environmental monitoring, biological detection, and disease treatment. In the article “Channel capacity analysis of a comprehensive absorbing receiver for molecular communication via diffusion,” by Liu *et al.*, the impacts of various reaction rates on the channel modeling and channel capacity of MC are investigated.

The article “A high-speed well logging telemetry system based on low-power FPGA,” by Zhao *et al.*, presents a field-programmable gate array (FPGA)-based design, implementation, and measurement of a high-speed telemetry system for well-logging. This type of design is less expensive, has better real-time performance, less power consumption and easier implementation.

A post-partum hemorrhage (PPH) predictive diagnosis model by resorting the machine learning techniques is investigated in the article “Ensemble learning based postpartum hemorrhage diagnosis for 5G remote healthcare,” by Zhang *et al.* This type of model based on machine learning allows the successful prediction of the risk of PPH and assesses the critical level of PPH patients.

Cell-free massive MIMO networks are recognized as a possible solution in the future of wireless communication. In the article “Spectral efficiency improvement and power control optimization of massive MIMO networks,” by Zhang *et al.*, spectral efficiency (SE) and power control of cell-free massive MIMO networks uplink and downlink transmission are optimized. The effectiveness of the proposed method for applying in massive MIMO networks with different sensors is derived.

The article “Convolutional neural filtering for intelligent communications signal processing in harsh environments,” by Sun *et al.*, presents a new method based on model-driven deep learning principle by analyzing the theoretical connection between the filter model and the convolutional neural layer named convolutional neural filtering. Based on this method, an embeddable filtering unit fully based on a neural network is provided, which can be easily integrated into a deep learning network targeting.

The cell-free massive multiple-input–multiple-output massive (MIMO) system includes a large number of access points (APs) that simultaneously serve a much smaller number of users, and the APs and users are clustered to provide good service for all users. In the article “Trajectory optimization and power allocation algorithm in MBS-assisted cell-free massive MIMO systems,” by An and Zhao, the authors design a mobile base station (MBS)-assisted cell-free massive MIMO system. The performance of the system designed in this article shows significant improvement compared with the normal cell-free massive MIMO system.

A three-step training (TST) scheme is designed to detect pilot spoofing attack (PSA) in the article “Detect pilot spoofing attack for intelligent reflecting surface assisted systems,” by Liu *et al.* This type of scheme could achieve reliable detection performance by examining the transmitter’s received signal power levels when PSA occurs.

We would like to express our gratitude to the authors for their excellent contributions to this Special Section. We are also thankful for all reviewers who dedicated their efforts in reviewing these articles, and for their valuable comments and suggestions that significantly improved the quality of the articles. We hope that this Special Section will serve as a good reference for researchers, scientists, engineers, and academicians in the field of communications in harsh environments.

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