⋮ EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: EMERGING TRENDS, ISSUES, AND CHALLENGES IN UNDERWATER ACOUSTIC SENSOR NETWORKS

Saline water covers approximately $360\,000\,000$ km^2, approximately 71% of Earth's surface and 90% of Earth's biosphere. The ocean contains 97% of Earth's water, and oceanographers have stated that less than 5% of the World Ocean has been explored. The total volume is approximately 1.35 billion cubic kilometers with an average depth of nearly 3700 m. Our ocean and coasts provide jobs for millions of people in coastal communities across the world. Ocean industries such as commercial and recreational fisheries, tourism and recreation, and marine transportation generate thousands of billions of dollars every year. We must protect the ocean's long-term health, not only for habitats and marine life that depend on it but also for the humans that have relied on its resources for generations. All of this requires maintaining a healthy ocean ecosystem, even as human demands and stresses to the ocean are increasing. It is more important than ever to understand how the ocean interacts with various offshore applications. To this end, underwater acoustic sensor networks (UASNs) play an important role in the ocean's protection. However, ocean monitoring and research are not an easy task, since the ocean is big and most of the underwater environment is still unknown to us. In addition, due to the high pressures in deep water, it is not suitable for people to work a long time underwater.

This Special Section of IEEE ACCESS aims at providing a chance to share ideas, problems, and solutions for UASNs while pushing forward the development of UASNs in security and reliability.

The article "Positioning systems for Jiaolong deep-sea manned submersible: Sea trial and application," by Zhang *et al.*, analyzes the ultra-short baseline (USBL) sea-trial calibration and the details of long baseline (LBL) sea-trial using the Jiaolong deep-sea manned submersible as a case study. The positioning performance (relative slant range error, relative depth error, and data efficiency) is found to be consistent with calibration results. In addition, a rectangular path with a length of 900 m and breadth of 300 m is designed to verify LBL performance in deep sea. The LBL sea-trial results show that the positioning accuracy of LBL is better than that of USBL, and the USBL positioning performance is affected by the distance from the mothership and its heading.

The article "Research on underwater wireless sensor network and MAC protocol and location algorithm," by Xi *et al.*, studies the medium access control (MAC) protocol and positioning technology of underwater wireless sensor networks (UWSNs) and introduces the typical underwater line sensor network medium access control (MAC) protocol. Aiming at the problem of spatial fairness caused by the propagation characteristics of the underwater acoustic channel and the triple terminal problem caused by the long propagation delay in UWSNs, an underwater multi-channel (SFM-MAC) based on a single transceiver is proposed. Moreover, the Markov chain is used to construct the reservation model of the control channel, and the theoretical analysis of multi-channel throughput is given.

The article "A node self-localization algorithm with a mobile anchor node in underwater acoustic sensor networks," by Lin *et al.*, proposes a mobile node localization algorithm based on compressive sensing for underwater acoustic sensor networks (UASNs). The sparse localization problem based on the cubic module is first transformed into the nodes localization problem by dividing the cubic module of the underwater monitoring area and using the energy between the mobile anchor node and the unknown nodes. Then, the energy localization between nodes is adopted to eliminate the specific path design. Considering the distance problem of the moving path, the mobile node path is based on the random waypoint (RWP) and the LAYERED-SCAN model. The simulation results show that the scheme can reduce network cost and node energy loss while obtaining high localization accuracy.

The article "Localization and detection of targets in underwater wireless sensor using distance and angle based algorithms," by Ullan *et al.*, proposes an improved interpretation for underwater localization. First, a general localization algorithm is presented. Then, the ordinary beacon nodes are deployed to find the error and accuracy of sensor localization. Based on these, the authors present two localization algorithms named distance-based and angle-based algorithms. In particular, a realistic case is considered, where sensor nodes are not time synchronized and the sound speed in water is unknown. The experiment results exhibit that the algorithm can compensate for time synchronization, estimate

the mean errors in localization, and achieve good localization accuracy.

The article "VA: Virtual node assisted localization algorithm for underwater acoustic sensor networks," by Liu *et al.*, proposes a novel underwater acoustic sensor networks localization algorithm based on the virtual node assistance. The algorithm is classified into two parts based on the current marine environment, including virtual node-assisted static (VAS) localization algorithm and virtual node-assisted dynamic (VAD) localization algorithm. The algorithm takes the GPS-equipped ship as a mobile beacon node and auxiliary node to realize the effects of low error localization without complex deployment procedures and time synchronization. The simulation results show that the proposed algorithm can achieve high localization coverage, small localization error, and low communication overhead.

The article "The localization algorithm based on symmetry correction for underwater acoustic networks," by Zhang *et al.*, introduces the significance of the underwater environment and the differences with terrestrial wireless networks (TWNs). The situation is described for the change of sound velocity, which changes nonlinearly with the increasing depth. The symmetry correction based on least square estimation (SC-LSE) is proposed. In the SC-LSE, the initial estimated position is obtained by the traditional LSE algorithm. Then, the correction position is ascertained using the symmetry of the estimated position and the actual target, so that the positioning accuracy is greatly improved. The efficiency of the proposed scheme is proved by the theoretical analysis and simulation experiments.

The article "Adaptive downlink OFDMA system with low-overhead and limited feedback in time-varying underwater acoustic channel," by Qiao *et al.*, focuses on the outdated channel state information (CSI) and proposes an adaptive downlink orthogonal frequency-division multiplexing access (OFDMA) system with low-overhead and limited feedback in time-varying underwater acoustic (UWA) channel. First, a data fitting method is proposed for channel reconstruction. Second, the per-subcarrier channel temporal correlation (PSCTC) and long-term statistical mean value is defined as two indicators of outdated CSI to optimize CSI feedback in UWA channel with large propagation delay. Finally, a CSI selection method based on channel correlation attenuation (CCA) factor is proposed. The sea trial results show that the CSI reconstruction based on data fitting method has lower bit error ratio and less overhead than traditional group quantization method.

The article "Hybrid carrier underwater acoustic communication based on joint time–frequency domain equalization," by Yin *et al.*, proposes hybrid carrier underwater acoustic communication based on the joint time–frequency domain equalization. With the time–domain equalization based on time reversal, multipath spreads of underwater acoustic channels can be greatly suppressed. Thus, the length of the required cycle prefix is shortened, improving the bandwidth efficiency. The residual inter-symbol interference can be removed using frequency-domain equalization based on the minimum mean square error or zero force. The experimental results show that the optimal transform orders to achieve the best communication performance are different in different environments.

The article "Research and application of multi-node communication and energy consumption prediction control in underwater acoustic network," by Qu *et al.*, presents a closed solution for one-hop transmission of any node based on the 3-D stochastic underwater acoustic network under the protocol model. The closed solution takes into account the fact that the vertical transmission efficiency of the underwater acoustic signal is more effective than the horizontal transmission efficiency, and with different network parameters, there is an optimal communication radiation range of nodes to maximize the throughput of the network. In addition, a model predictive control method based on maximum algebra is proposed, which can predict the information generation rate of nodes periodically and estimate the life value of nodes at different routing time points according to the current residual energy of nodes.

The article "Deep learning-based single carrier communications over time-varying underwater acoustic channel," by Zhang *et al.*, proposes a new DL-based receiver for single carrier communication in time-varying underwater acoustic (UWA) channels. Without the off-line training, the proposed receiver alternately works with online training and test modes for accommodating the time variability of UWA channels. Simulation results show a better detection performance achieved by the proposed DL-based receiver and with a considerable reduction in training overhead compared to the traditional channel-estimate (CE)-based decision feedback equalizer (DFE) in simulation scenarios with a measured sound speed profile.

The article "Delay and queue aware adaptive scheduling-based MAC protocol for underwater acoustic sensor networks," by Zhuo *et al.*, proposes a delay and queue aware adaptive scheduling-based medium access control (DQA-MAC) protocol for UASNs. It combines adaptive scheduling transmission, reduction of handshaking packets, and concurrent transmission with the propose of improving the performance of network throughput, shortening end-to-end delay, reducing average energy consumption, and enhancing the fairness of transmission. Data transmission time is scheduled based on the information of propagation delays and the number of data packets waiting in each node queue. Furthermore, the strategy of concurrent transmission is implemented to leverage the long propagation delays. Finally, reducing the number of handshaking packets is achieved with the approach of exchanging information by specially designed packets frames.

The article "Time–frequency domain turbo equalization for single-carrier underwater acoustic communications," by He *et al.*, proposes a time–frequency domain turbo equalization (TFD-TE) scheme for single-carrier modulation. The TFD-TE scheme is to couple a multi-channel

frequency domain equalizer with phase rotation compensation and a low-order single-channel time-domain turbo equalizer. To mitigate the error propagation and further enhance receiver performance, a bidirectional equalizer that combined the soft outputs of a conventional equalizer and a backward equalizer is introduced into the proposed TFD-TE scheme (Bi-TFD-TF). The sparse channel is estimated by the improved proportionate normalized least mean squares (IPNLMS) algorithm block by block. Both the simulated and experimental results show the proposed TFD-TE can effectively improve system performance with acceptable complexity.

The article "Channel estimation based equalizer for underwater acoustic multiple-input-multiple-output communication," by Zhou and Tong, modifies the traditional channel estimation-based decision feedback equalizers (CE-DFE) to adapt to multiple-input-multiple-output (MIMO) communication system. First, the calculation of filter coefficients is modified to accommodate the presence of co-channel interference (CoI). Second, the modified CE-DFE with interference cancellation (IC) is proposed for MIMO underwater acoustic communication by adding IC filters. The filter coefficients for proposed CE-DFE with IC are derived using channel estimates. The simulation results and sea trial results demonstrate the effectiveness of the proposed methods.

The article "Behavior modeling and individual recognition of sonar transmitter for secure communication in UASNs," by Shi *et al.*, studies the individual identification of emitter based on the behavior modeling of the sonar transmitter. Ten approximate sonar transmitters are obtained by memory polynomial modeling. The same signals are input to the sonar transmitter model to collect its output signals, and the output signals are extracted and classified. Moreover, the memory polynomial method is used to model the behavior of the sonar transmitter, and the power spectrum estimation of the output signals is used as the fingerprint feature to identify the transmitters. The experimental results show that this method can effectively identify multiple similar sonar transmitters.

The article "Reinforcement learning-based adaptive modulation and coding for efficient underwater communications," by Su *et al.*, proposes a reinforcement learning-based adaptive modulation and coding scheme for underwater communications in terms of bit error rates (BER), transmission time, and energy consumption of the transmitter. Reinforcement learning is applied to choose the modulation and coding policy in a dynamic underwater communication system. The experiments are performed in both pool and sea environments and prove that the scheme can improve the throughputs and reduce the BER with less energy consumption when it is compared with the benchmark schemes.

The article "Multi-radio multi-channel assignment algorithm in maritime wireless mesh networks," by Xing *et al.*, focuses on the static channel assignment issue and proposes a heuristic algorithm to solve the optimization problem. The problem is addressed by assigning channels to communication links to minimize the interference from the overall network. A modified particle swarm optimization (PSO) algorithm is proposed to optimize the problem, and a new merging solution is adopted to reassign channels for nodes which violate the radio constraints. Multi-radio simulation is performed in NS-3 to validate the effectiveness of the proposed channel assignment algorithm. The results show that the algorithm can find an optimized assignment with fewer iterations than the previous work and improve network performance.

The article "A load-based hybrid MAC protocol for underwater wireless sensor networks," by Zhang *et al.*, proposes a load-based time slot allocation (LBTSA) protocol. The LBTSA selects the slot allocation scheme from a set of possible schemes according to the instantaneous network load. Then, based on the relative priority of the nodes and the optimal number of backoff stages, the host node selects the optimal access control protocol. This not only adapts well to changing network loads but also maximizes network throughput. The proposed protocol is compared with a hybrid MAC protocol (HCR) using channel reservation. The experiment results show that the throughput of the LBTSA is higher than that of the HCR, and the end-to-end delay of the LBTSA is lower than that of the HCR.

The article "Cell search techniques for underwater acoustic cellular systems," by Asim *et al.*, proposes two different types of cell search techniques for the downlink of underwater acoustic cellular (UAC) systems based on orthogonal frequency-division multiplexing (OFDM): a Zadoff–Chu sequence-based cell search technique (ZCS-CST) and a linear frequency modulation-based cell search technique (LFM-CST), all at the physical layer. In the ZCS-CST, parallel ZCS correlators were used in the receiver (UE) to detect the cell ID, which was mapped to the root index of the ZCS. In the LFM-CST, parallel LFM correlators were used in the receiver to detect the cell ID (UBS), which was mapped to the parameters of the LFM waveform. The experiment results show that the ZCS-CST is applicable to UAC systems with a small Doppler shift, while the LFM-CST is suitable for UAC systems with a large Doppler shift.

The article "REMEDY: Receiver-initiated MAC based on energy-efficient duty-cycling in the IoUT," by Khan *et al.*, proposes a REceiver-Initiated medium access control (MAC) protocol based on energy-efficient duty cycling called REMEDY-MAC. In the REMEDY-MAC, sender nodes that wake up before the receiver node (AUV) arrives take turns to listen to the channel based on their residual energy and form a Schedule Table of their next wake up times. When the AUV arrives, it uses this Schedule Table to collect the data packets without any collisions. In addition, a mechanism that caters the sender nodes that are not included in the Schedule Table is provided.

The article "Research and development of a highly reconfigurable OFDM MODEM for shallow water acoustic communication," by Zhou and Tong, provides the design and implementation of a parameter-configurable underwater acoustic OFDM MODEM with the purpose to achieve

flexibility. Specifically, the reconfigurable parameters of the orthogonal frequency division multiplexing (OFDM) MODEM include the number of receivers, the number of null subcarriers, the number of pilot subcarriers, as well as the type of channel estimation algorithms. The number of pilot subcarriers and type of channel estimation methods are determined based on channel characteristics, the number of null subcarriers is determined based on the Doppler shift, and the number of the received channels is based on fading channel.

The article "Real-time observation of range-averaged temperature by high-frequency underwater acoustic thermometry," by Yu *et al.*, proposes a new scheme of high-frequency acoustic thermometry to measure the real-time ranged-averaged underwater temperature. Reciprocal acoustic transmission, cross-correlation analysis, and GPS synchronization are used to derive the propagation times of underwater acoustic signals with the central frequency of 60 kHz and, thus, measure the water temperature. The field experiment performed in the Jiulong River Estuary shows that the range-averaged temperature is correlated with the *in situ* temperature.

The article "An RNN-based delay-guaranteed monitoring framework in underwater wireless sensor networks," by Wei *et al.*, presents a recurrent neural network (RNN)-based underwater monitoring framework to solve the problems of long delay time and high data loss rate. An automatic retransmission mechanism applied in the MAC protocols is proposed to reduce the long end-to-end delay and energy cost. In addition, an RNN learning model is presented to analyze the raw data and predict the missing values. The experiment results show that the model can achieve an accurate estimation with different degrees of missing rates and can provide better performance compared with the non-RNN and RNN baselines.

The article "Centralized fusion based on interacting multiple model and adaptive Kalman filter for target tracking in underwater acoustic sensor networks," by Qiu *et al.*, presents a centralized fusion algorithm based on the interacting multiple models and the adaptive Kalman filter (IMMCFAKF) for target tracking in underwater acoustic sensor networks (UASNs). First, an optimal centralized fusion adaptive Kalman filter (CFAKF) algorithm is obtained by introducing an adaptive forgetting factor. Then, the optimal IMMCFAKF is achieved by combining the optimal CFAKF algorithm and the conventional IMM algorithm.

The article "A multi-layer cluster-based energy efficient routing scheme for UWSNs," by Khan *et al.*, proposes a multi-layer cluster-based Energy Efficient (MLCEE) protocol for Underwater Wireless Sensor Networks (UWSNs) to address the issue of hotspot and energy consumption. First, the whole network is divided into layers, and then nodes at the same layers are clustered. Finally, the cluster head (CH) selects the next hop among the CHs based on greater fitness value, small hotspot, and small layer number. To mitigate the issue of hotspot, the first layer remains unclustered and

any node in the first layer transfers data to the sink directly, while cluster heads (CHs) are selected based on Bayesian Probability and residual energy.

The article "Adaptive energy aware quality of service for reliable data transfer in under water acoustic sensor networks," by Sundarasekar *et al.*, proposes an adaptive energy aware quality of service (AEA-QoS) algorithm for reliable data delivery by formulating discrete times stochastic control process and introducing deep learning techniques. The proposed algorithm has been validated with conventional state-of-the-art methods, and results show that the proposed approach exhibits its effectiveness in terms of less network overhead and propagation delay with high throughput and less energy consumption for every reliable packet transmission.

In the article "Asymmetric satellite-underwater visible light communication system for oceanic monitoring," by Gupta *et al.*, the authors investigate the performance of the proposed oceanic monitoring system. For continuous real-time monitoring and ubiquitous coverage, the communication system is aided with a satellite link. Multiple sensor nodes (SN) are deployed at different water levels that collect sensor data and transmit it to underwater vehicles (UV) using underwater visible light communication (UVLC). The UWC system comprises of horizontal haul (HH) and vertical haul (VH) UVLC links modeled using turbulence-induced fading. The vertical haul links are modeled as the concatenation of successive nonmixing turbulent links to take the change of turbulence with the change of water level into account. The UVs and submarines communicate with the floating vessels (FVs) using vertical haul UVLC link. The UVs collect the data from the low power sensor nodes and offload it to the FVs, which further beam it to the satellite on the RF carriers.

The article "DENPSO: A distance evolution nonlinear PSO algorithm for energy-efficient path planning in 3D UASNs," by Wu *et al.*, proposes an algorithm of distance evolution nonlinear particle swarm optimization (DENPSO), aiming at finding an energy-efficient stable path for autonomous underwater vehicles (AUVs) in 3-D underwater acoustic sensor networks. First, the inertia weighting factor and learning factor are converted from linearity to nonlinearity to ensure the particles fully explore the 3-D underwater environment during the evolution process. Second, to avoid particles falling into local optimum regions, the particles of the poor search regions are randomly perturbed by the distance evolution factor. Third, the penalty function is applied to describe the energy optimization goal under the obstacles and ocean currents. Moreover, each path is divided into several micro-element points to quantify the role of obstacle avoidance in the penalty function.

The article "Cooperative routing for energy efficient underwater wireless sensor networks," by Yahya *et al.*, proposes a novel region-based cooperative routing scheme (RBCMIC) to increase network lifetime in underwater wireless sensor networks (UWSNs). The proposed scheme utilizes mobile courier nodes to effectively handle energy

consumption in the network. To efficiently exploit the mobility of courier nodes, the network is distributed into logical regions. Consequently, an incremental relaying mechanism is used to foster better power consumption in UWSNs. The experiment results show that an overall improvement of 20% is witnessed in energy usage, whereas a notable 89% improvement is achieved in end-to-end delay in comparison to DEADS protocol.

The article "STLFM signal-based adaptive synchronization for underwater acoustic communications," by Yuan *et al.*, proposes an adaptive scheme for underwater acoustic communications (UAC) synchronization. The scheme uses the symmetrical triangular linear frequency modulation (STLFM) signal to design a fractional Fourier transform (FrFT)-based detection algorithm. The frame synchronization is established by detecting the deviation of the two energy peaks, which usually emerge in their optimal FrFT domain in pairs. Instead of detecting the absolute peaks, the proposed method performs an initial synchronization and a precise correction based on the relative positional relationship and amplitude attenuation of the two peaks. The experiment results show that it can peak the time-varying signal amplitude for each frame in UWA channels.

The article "Sarcasm detection using soft attention-based bidirectional long short-term memory model with convolution network," by Son *et al.*, proposes a deep learning model called sAtt-BLSTM convNet that is based on the hybrid of soft attention-based bidirectional long short-term memory (sAtt-BLSTM) and convolution neural network (convNet) applying global vectors for word representation (GLoVe) for building semantic word embedding. In addition to the feature maps generated by the sAtt-BLSTM, punctuation-based auxiliary features are also merged into the convNet. The robustness of the proposed model is investigated using balanced and unbalanced data sets. The experiment results show that the scheme has a superior sarcasm-classification accuracy of 97.87% for the Twitter data set and 93.71% for the random-tweet data set.

The article "S-boxes construction based on the Cayley graph of the symmetric group for UASNs," by Shuai *et al.*, investigates the certain subgraph of the Cayley graph of the symmetric group to get some information about the distribution of the cryptographic properties of S-boxes. Based on the information obtained, an algorithm for designing S-boxes with good cryptographic properties is proposed. The security analysis shows that the preferred S-box constructed by the proposed algorithm has good cryptographic properties.

The article "Fault-tolerant prescribed performance control algorithm for underwater acoustic sensor network nodes with

thruster saturation," by Qin *et al.*, designs a prescribed performance fault-tolerant control strategy for the underwater acoustic sensor network nodes (UASNN) trajectory tracking control in the presence of ocean current disturbances, modeling uncertainties, and thruster faults. Using a general uncertainty observer, the influence of disturbances and uncertainties is estimated. In addition, a novel performance function which determines explicitly the maximum convergence time is utilized. Based on the new performance function and corresponding error transformation, the 6-DOF tracking errors are restricted to prescribed bounds to ensure the desired transient and steady response. Furthermore, when considering thruster saturation, an auxiliary system is introduced to compensate for the saturation.

Finally, we would like to thank the authors who submitted their high-quality manuscripts to this Special Section. We would like to acknowledge the contribution of the reviewers who have participated in the review process, and provided helpful comments and suggestions to the authors to improve their manuscripts. We especially thank Professor Derek Abbott, the Editor-in-Chief of IEEE ACCESS, for his advice and strong support during the process of putting together this Special Section. We also hope that the readers will enjoy reading the articles included in this Special Section.

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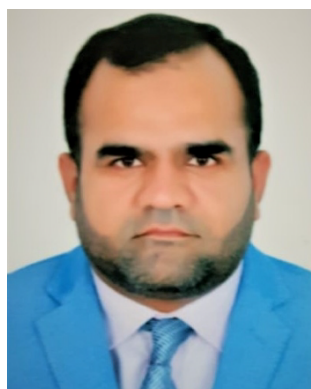
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