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## EDITORIAL

# IEEE ACCESS SPECIAL SECTION EDITORIAL: CONVERGENCE OF SENSOR NETWORKS, CLOUD COMPUTING, AND BIG DATA IN INDUSTRIAL INTERNET OF THINGS

With growing attention from both academia and industry, Industrial Internet of Things (IIoT), comprised of a multitude of connected devices, is supposed to monitor, collect, exchange, analyze, and instantly act on information to intelligently change the industrial device's behavior or the industrial environment (e.g., autonomous reaction to unexpected changes in production by effectively detecting failures and triggering maintenance processes). Toward this goal, the convergence of sensor networks, cloud computing, and big data in IIoT is recently identified as an essential component. Specifically, to capture various data in IIoT, sensor networks are deployed. Meanwhile, to store and process data powerfully in IIoT, cloud computing platforms are developed. Moreover, to glean valuable findings from the massive data in IIoT, big data analytics tools are utilized. However, to integrate sensor networks, cloud computing, and big data in IIoT in a robust way, there are a lot of tough issues to be solved with respect to various aspects (e.g., framework, greenness, security, quality of service, etc.).

The goal of this Special Section in IEEE ACCESS on “Convergence of Sensor Networks, Cloud Computing, and Big Data in Industrial Internet of Things” is to address the following research issues:

- Novel contributions on the convergence of sensor networks, cloud computing, and big data in IIoT
- Contemporaneous utilization of at least two of the three technologies—sensor networks, cloud computing, and big data in IIoT
- Experimental implementation of the convergence of sensor networks, cloud computing, and big data in IIoT.

This Special Section received an enthusiastic response with a lot of high quality submissions. Per IEEE ACCESS policy, all articles were reviewed by at least two independent referees. The articles were evaluated for their rigor and quality, and also for their relevance to the theme of our Special Section. After a rigorous review process, we accepted 25 articles to form the Special Section.

In the article “An improved ant colony algorithm for path planning in one scenic area with many spots,” by Zhang *et al.*, the authors redefine the path planning of scenic area as a partial node traversal problem in a weakly connected graph

to better reflect the dynamic behavior of individual tourists in IIoT. In the improved ant colony algorithm, the partial nodes traversal problem in the weakly connected graph is resolved through a temporary weight matrix and the shortest path matrix.

In the article titled “Three dimensional comprehensive analytical solutions for locating sources of sensor networks in unknown velocity mining system,” Dong *et al.* discuss a 3-D comprehensive analytical solution (TDCAS) without pre-measured velocity under random sensor networks in IIoT. The engineering practices are combined to verify its effectiveness and accuracy. The proposed method is more efficient than the traditional methods in the aspect of engineering application.

In the article “Collaborative actuation of wireless sensor and actuator networks for the agriculture industry,” by Bai *et al.*, the authors address the collaborative estimation and control problem in the greenhouse environments characterizing the frequent environmental change in IIoT. The sensor nodes conduct a local estimation based on the Kalman filter algorithm and then transmit the data under a dynamic multirate mode to the actuator nodes for data fusion. Moreover, with the estimation of the environmental change in order to combine the fuzzy neural network with the PID control algorithm, the actuators enhance the reliability of their control over the greenhouse environmental changes.

In the article titled “Pulse-based distance accumulation localization algorithm for wireless nanosensor networks,” Zhou *et al.* propose a localization algorithm for wireless nanosensor networks (WNSNs) that can be utilized to estimate the distance between nodes with known positions and nodes with unknown positions. Essentially, WNSNs consist of nanosized communication devices, which are equipped with nanotransceivers, nanoantennas, and other functional modules. A clustering algorithm is first employed to reduce the energy consumption and time delay, then the nanodevice analyzes the value of the received pulse based on the on-off-keying modulation and estimates the distance between nodes. The simulation results show that the proposed scheme can support WNSNs with very high density in ranging and locating.

In the article “Parameterized spatio-textual publish/subscribe in road sensor networks,” by Li *et al.*, the authors take the first step to study parameterized spatial–textual publish/subscribe problem in road sensor networks. To address the problem, basic indexing architecture and enhanced indexing architecture are proposed. To briefly explain, the proposed scheme delivers each incoming message which arrives at a relatively high speed to the relevant subscriptions on its arrival. An extensive simulation study is conducted to evaluate the efficiency of the proposed methods by using a real road sensor network and two data sets.

In the article titled “Big data analytics for program popularity prediction in broadcast TV industries,” Zhu *et al.* analyze massive user behavior data and present the improved method to predict the popularity of broadcast TV programs. The authors apply a dynamic time warping-distance-based K-medoids algorithm to group programs with similar popularity into four evolutionary trends, which has the ability to capture the inherent heterogeneity of program popularity. Then, an extensive experimental evaluation is performed. Essentially, trend-specific prediction models using random forest regression are suggested to obtain better overall predictive performance than a single model trained on the entire data set.

In the article titled “Energy-efficient composition of configurable Internet of Things services,” Sun *et al.* develop a service-oriented mechanism for composing the services of wireless sensor networks (WSNs), which are encapsulated from various functionalities provided by sensor nodes. Extensive evaluations are conducted to evaluate the accuracy and effectiveness of the IoT service composition technique. The experimental evaluation mainly considers the fitness, minimum residual energy of smart things, and the variance of residual energy in smart things.

In the article “Enabling technologies for the Internet of Health Things,” by Rodrigues *et al.*, the authors present a review of techniques based on IoT for healthcare and ambient-assisted living, defined as the Internet of Health Things (IoHT), based on the most recent publications and products available in the market from the industry for this segment. This article identifies the technological advances made so far, analyzing the challenges to be overcome and providing an approach to future trends. As suggested by the authors, there are many services and applications for IoHT, whose solutions can meet the society’s needs, but they are growing isolated. The presented results aim to serve as a source of information for healthcare providers, researchers, technology specialists, and the general population to improve the IoHT.

In the article titled “A grid-based clustering algorithm via load analysis for industrial Internet of Things,” Zhang *et al.* propose a grid-based clustering algorithm via load analysis for industrial IoT. A set of expressions is deduced to indicate network load distribution. It is concluded that the number of delivered packets at each level is related to the grid length at that level. The network is partitioned into unequal grids according to the optimal cluster size, and all the nodes of

a grid are formed into a cluster. The proposed approach is not only limited for the IIoT but also applicable in numerous applications that require sensor nodes to collect data periodically, such as in environmental monitoring. The performance of the proposed scheme is superior to the other baseline algorithms when the node density increases and the size of the monitored area extends.

In the article titled “Chaotic adaptive synchronization control and application in chaotic secure communication for industrial Internet of Things,” Wang *et al.* select the Hindmarsh–Rose neuron discharge chaos model as the object of study for the IIoT, based on the Lyapunov stability theory. Essentially, the controller is applied to chaotic secure communication in IIoT. Extensive simulation results verify the feasibility and effectiveness of the designed controller and the capability of realizing the transmission of confidential information.

In the article “An industrial Internet of Things feature selection method based on potential entropy evaluation criteria,” by Zhao and Dong, the authors present a novel feature selection approach based on potential entropy evaluation criteria (FMPE). In this article the importance of features is measured in the data field. The meaning of each data point is redefined from the field perspective to provide technical support for feature selection. The data are projected to the grid for calculation while converting the data into the data field. Mutual information theory is introduced to calculate the feature correlation between phonological features and selected feature subsets. Only those weakly correlated features are added to the feature subset. The authors presented experiments on open data sets which show that FMPE can effectively eliminate the unimportant or noisy features in high-dimensional data sets and improve the performance of classification algorithms.

In the article “A mobile cloud based scheduling strategy for industrial internet of things,” by Tang *et al.*, the authors proposed a technical solution for task offloading in the context of mobile cloud computing that can serve the industrial Internet of Things for the sake of execution time minimization or energy reduction. In fact, the newly emerging computing paradigms including cloud computing, fog computing, and edge computing can all contribute to the Internet of Things. To realize energy and response delay optimization, they mainly offload tasks to the remote powerful computing center or the edge of the networks. Similarly, the authors in this article proposed a GA-based task offloading strategy which scheduled the tasks among the mobile cloud. They strove to minimize the energy consumption at the device’s side while considering multiple constraints such as cost and deadline. The approach is investigated by extensive simulations and the simulation results have shown the superior performance of the proposed scheduling strategy.

In the article “Efficient dynamic service maintenance for edge services,” by Zhang *et al.*, the authors proposed an efficient dynamic maintenance method for edge services. Given the fast growth of sensor network and mobile edge

infrastructure, a number of sensors have been deployed in edge networks and provide users with edge services. However, edge services can be relocated or changed due to user mobility, and thus an effective mechanism is needed for providing dynamic service maintenance. To this end, the Skyline Graph Model and the directed acyclic graph theory are used to store and update mobile edge services. Specifically, the Skyline Graph algorithm is designed to solve the insertion, deletion, updating, and searching of mobile edge services. The authors presented simulation results to demonstrate the performance and robustness of their proposed solution.

In the article titled “A vulnerability assessment method in industrial Internet of Things based on attack graph and maximum flow,” Wang *et al.* proposed a vulnerability assessment model based on an attack graph for assessing the vulnerability of wireless sensor networks. This work proposed vulnerability quantification method based on the largest loss stream and a search algorithm which uses the augmented path to determine the optimal attack path, avoiding the repeat calculation and obtaining the potential key vulnerability path quickly. A better search solution can be obtained when compared with random augmentations and augmentations based on greedy strategies. The authors evaluated the effectiveness of their method and presented that the method is feasible and can evaluate the vulnerability and risk path objectively.

In the article “Reliable virtual machine placement based on multi-objective optimization with traffic aware algorithm in industrial cloud,” by Luo *et al.*, the authors constructed a single node’s failure tolerance and link loss rate model for the virtualized resource management problem of industrial cloud, and proposed a kind of data center energy consumption and virtualized resource management. A multiobjective particle swarm optimization algorithm for data center energy consumption and virtualized resource management is proposed. Under the premise of ensuring user service reliability and QoS, the physical resource utilization rate and the link loss rate are optimized. In the simulation experiment, the proposed algorithm can effectively restrict the link loss of the data center, which reduces the energy cost in the data center.

In the article “An energy-efficient ring cross-layer optimization algorithm for wireless sensor networks,” by Han *et al.*, the authors established a clustering-based cross-layer optimization model in order to balance energy consumption. In this model, the network layer could get the related information from the physical layer and the datalink layer to effectively route packets. Based on the cross-layer optimization model, an energy-efficient ring cross-layer optimization algorithm is proposed and a new routing algorithm, called Leach-Cross-Layer Optimization (CLO), is also proposed for a ring monitoring domain. This Leach-CLO routing algorithm is based on the typical Leach algorithm. The experiment’s results show that this routing algorithm could effectively and efficiently balance the energy consumption in wireless sensor networks compared with related algorithms.

In the article titled “Low-complexity iterative detection algorithm for massive data communication in IIoT,”

Han *et al.* developed an improved iterative multiuser detection receiver for NOMA in IIoT, and channel information is fully utilized in the receiver. In order to analyze the performance of the proposed multi-user detection receiver, JS-divergence is employed to measure the correlation of the exchanged information between the detector and the decoder. The proposed multiuser detection algorithm can provide performance improvement and brings high reliability to manufacturing processes. Meanwhile, the algorithm also can automatically terminate the iterations among the detector and the decoder in accordance with JS-divergence values of each user and reduce the computational complexity greatly. As a result, the proposed algorithm achieves real-time, multiuser detection with high reliability.

In the article “LSTM-based analysis of industrial IoT equipment,” by Zhang *et al.*, the authors proposed a technical solution for general IIoT equipment, for analyzing time series data and forecasting operation status. This work is focused on using the LSTM model to develop a complete solution for data cleaning, feature engineering, and working status analysis and prediction. The technique of combining correlations of sensors to extract features for inputs to the LSTM model is also designed, which helps to effectively reduce the complexity of data processing while improving the accuracy of the LSTM model. The orthogonal experimental method is used to optimize the hyperparameters of the LSTM model. The evaluations show that the prediction results are stable, which can be applied to analyze IIoT time series data, especially those with sensor correlations.

In the article “An immune genetic algorithm for multi-echelon inventory cost control of IoT-based supply chains,” by Wang *et al.*, the authors consider supply chains consisting of multiple suppliers, a manufacturer, and multiple distributors. The time cost of delayed transportation is integrated into previous studies to construct a new model, which is solved with an immune genetic algorithm. Unlike the genetic algorithm, the memory function and adjustment function of the immune algorithm are included in this algorithm. In contrast to the immune algorithm, genetic operators of the genetic algorithm are included. The immune genetic algorithm effectively overcomes the disadvantages of the genetic algorithm, improving global search ability and search efficiency. The validity and rationality of the optimized model are assessed in comparison with the previous results.

In the article titled “Numerical study on the evolution of mesoscopic properties and permeability in sandstone under hydromechanical coupling conditions involving industrial Internet of Things,” Cai *et al.* study microcracks development, coordination number, volumetric strain, and permeability evolution of sandstone involving industrial Internet of Things. The hydromechanical coupling mesoscopic simulation was carried out using Particle Flow Code 2D software based on experimental results of permeability evolution in the complete stress-strain process obtained via triaxial compression tests. A numerical model conforming to the laboratory experiments was established, and the critical mesoscopic

mechanism was analyzed. The studied results included big data as one of the examples for the application of the industrial Internet of Things.

In the article “An innovative heuristic algorithm for IoT-enabled smart homes for developing countries,” by Hussain *et al.*, the authors proposed an improved algorithm for a DRSREOD-based home energy management systems (HEMS). This heuristic-based algorithm considers DR, photovoltaic availability, the state of charge and charge/discharge rates of the storage battery and the sharing-based parallel operation of more than one power source to supply the required load. The HEMS problem has been solved to minimize the cost of energy (CE) and time-based discomfort (TBD) with conflicting trade-offs. The mixed scheduling of appliances (delayed scheduling for some appliances and advanced scheduling for others) is introduced to improve the CE and TBD performance parameters. An inclining block rate scheme is also incorporated to reduce the peak load. A set of optimized trade-offs between CE and TBD has been computed to address multiobjectivity using a multiobjective genetic algorithm (MOGA) with Pareto optimization (PO) to perform the trade-off analysis and to enable consumers to select the most feasible solution.

In the article “An effective sensor cloud control scheme based on a two-stage game approach,” by Kim, the author proposed an efficient interactive Sensor-Cloud (SC) control scheme to provide on-demand sensing services for multiple applications. By adopting the game theory, a new two-stage game model, which consists of a judicious mixture of selection and incentive algorithms, was developed. In the game model, a user can choose the most adaptable data center to execute its task, and each data center can give appropriate incentives to the participating sensors. The main merit possessed by the two-stage game approach is to shed light on the practical SC control problem while providing excellent adaptability and flexibility to satisfy the different application requirements.

In the article “Energy-aware routing for SWIPT in multi-hop energy-constrained wireless network,” by He *et al.*, the authors concurrently consider SWIPT and routing selection in MECWN. To reduce the energy consumption, first, the information and energy allocation problem of link in a forwarding path was formulated, which is dependent on the next-hop node, and solved by an iterative allocation algorithm. A novel routing metric evaluates the energy consumption of the link transmitted with or without SWIPT. The energy-aware SWIPT routing algorithm allocates the information and energy of the link with the allocation algorithm during the path finding process. The performance studies demonstrate that the proposed algorithms can effectively exploit those node resources whose energy are not enough and significantly decrease energy consumption.

In the article “Bloomfield model based signal process for networks,” by Yao *et al.*, the authors propose a novel speech signal analysis approach based on the Bloomfield (BF) model and provide a formulation of a time-domain BF model for

speech signals with which speech signals can be reconstructed and the relevant characteristic parameters analyzed. The relationship between the parameters of the BF model and those of the linear prediction (LP) model are derived, and the speech feature sets derived via the LP and BF models are compared. A new algorithm is proposed for the recognition of isolated digit speech that utilizes a vector quantization approach and is based on the BF Model. The result is obtained with this BF approach that provides better results than those of the LP model when predicting speech signals.

In the article “A novel heterogeneous wireless sensor node deployment algorithm with parameter-free configuration,” by Kuawattanaphan *et al.*, the authors propose and evaluate a wireless sensor node deployment algorithm, called DeVForce-AP. The proposed algorithm combines the benefits of the two well-known deployment algorithms, the Delaunay triangulation method (D) and the extended virtual force algorithm (eVForce), with the adaptive parameter (AP) tuning mechanism. The DeVForce-AP attempts to improve the sensing coverage and network lifetime of the heterogeneous wireless sensor node. The practical deployment problems, such as the environmental obstacles, the network connectivity, and the sensing coverage area, have also been addressed. The simulation results show that the proposed DeVForce-AP outperforms the random deployment, the traditional Delaunay triangulation deployment, and the traditional virtual force deployment methods.

To conclude, the Guest Editors would like to sincerely thank all the authors for submitting their articles to this Special Section, and the large number of reviewers who kindly volunteered their time and expertise to help them curate a high-quality Special Section on this important and timely topic. The Guest Editors would also like to thank the Editor-in-Chief and other staff members for their support and guidance.

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