Guest Editorial Special Issue on Space-Air-Ground Integrated Networks for Intelligent Transportation Systems

NEXT-generation intelligent transportation systems (ITS) are envisioned to greatly improve transportation safety and efficiency by incorporating wireless communications and informatics technologies into transportation systems. As the cornerstone for ITS, vehicular communication networks enable vehicles on the go to exchange information with other vehicles and the external environments, which expect to play a significant role in supporting a variety of services such as road safety, traffic management, and infotainment. However, the existing terrestrial networks including dedicated short-range communications (DSRC)-based networks and cellular networks alone cannot serve the vehicular applications very well in different scenarios, due to the inherent issues of deployment, coverage, and capacity. It is imperative to exploit other communication infrastructures, such as low-earth orbit (LEO) satellites, unmanned aerial vehicles (UAVs), and high-altitude platforms, to support vehicular applications better, resulting in space-air-ground integrated networks (SAGIN). SAGIN can provide more comprehensive and three-dimensional network connectivity for moving vehicles, anywhere and anytime, by exploiting their respective advantages in terms of coverage, flexibility, reliability, and availability.

The objective of this Special Issue is to bring leading researchers and developers from both industry and academia together to present their research to address the fundamental and practical challenges in SAGIN for ITS. A total of 38 submissions were received in response to our open call for papers of this Special Issue. All the papers were rigorously evaluated, considering factors pertaining to factors such as novelty, quality, and technical contribution. After peer review, 14 articles were accepted for publication. In the following, we provide a brief introduction to the accepted articles.

In [A1], Han *et al.* aim to ensure information freshness to enable services in ITS for timely decisions, e.g., autonomous driving and accident prevention. In unmanned aerial vehicle (UAV)-aided intelligent transportation systems, the authors employ the age-of-information (AoI) to measure the freshness of data packets of vehicles so that the usage of vehicular networks and low-latency vehicular services are facilitated. Then, the average AoI is analyzed, and deployment of multiple UAVs is optimized to minimize the average peak AoI according to the traffic intensity of vehicles under the constraints of seamless coverage, finite queue, and coverage probability. The simulation results validate that the proposed system can provide data transmission in a timely manner.

In [A2], Wang *et al.* study the timeliness of the vehicular status updates in SAGIN for ITS. The AoI is used to measure the timeliness of the vehicular status updates in the system. Prediction policy is applied to overcome the end-to-end latency in SAGIN for ITS. The explicit expression of the average AoI is derived, which shows that prediction is more beneficial for short-distance communications. An MDP framework is further presented to improve the AoI performance. The effectiveness of the proposed prediction policy is demonstrated by the theoretical derivation and numerical results.

In [A3], He *et al.* consider the low-orbit multi-beam satellite-terrestrial networks to serve for vehicles in ITS. The authors model a cooperative multi-agent reinforcement learning process, where each beam acts as an agent, where the bandwidth is shared by all the agents. To allocate resources for vehicles with strict delay requirements and minimum bandwidth consumption, a multi-agent actor-critic method with attention mechanism is proposed, taking into account the channel efficiency, the angle of the beams, and the priorities of requests in different regions. They consider both centralized training and distributed execution in the training of the agents. The simulation results are provided to validate the effectiveness of the proposed learning method, where all the agents can achieve efficient resource allocation on-demand for the vehicles with strictly limited bandwidth resources.

In [A4], Yin *et al.* investigate an unmanned aerial vehicle (UAV)-assisted secure communication in multi-beam satellite-enabled vehicular networks. The UAV acts as a relay to improve the secure satellite-to-vehicle link and simultaneously serves as a jammer by deliberately generating artificial noise to degrade the performance of the eavesdropper. Satellite beamforming (BF) and UAV power allocation (PA) are jointly optimized to maximize the secrecy rate of the legitimate user within a target beam while guaranteeing the quality of service (QoS) of vehicular users within other beams. Moreover, an iterative alternating algorithm is proposed to solve such problems. In addition, extensive simulations are provided to evaluate the effectiveness of the proposed approach.

In [A5], Wang *et al.* propose an optimal cell wall paradigm to enhance the throughput in heterogeneous unmanned aircraft systems (UAS) swarm networking. The authors formulate a max-min throughput fair scheduling (MTFS) problem and propose an algorithm to optimize the minimum throughput of the cell wall paradigm. With the optimal max-min throughput, they optimize the schedule with edge-coloring to achieve

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global MTFS. It is demonstrated that the proposed algorithm can globally achieve over 40% improvement in MTFS.

In [A6], Li *et al.* make an effort to address the issues in existing route planning where only one or two fixed metrics are used, without considering the users' preferences. The new algorithm proposed in this work allows multiple metrics to be used and routes could be planned by following a user's preference. Moreover, routes could be planned and adjusted on the move to cope with real-time road conditions. This makes the algorithm more dynamic and scalable to meet personalized needs and improve users' driving experience.

In [A7], Chen *et al.* propose a novel aircraft coordinate prediction hybrid model based on deep learning. The proposed model combines inception modules and long short-term memory (LSTM) modules, where inception modules and LSTM modules are used to extract the spatial and temporal features of the dataset, respectively. In addition, the ADS-B signal strength is used instead of its specific information to obtain aircraft coordinates. This scheme sacrifices a certain precision for reliability. Inception modules and LSTM modules are combined in different ways to perform experiments on the real-world ADS-B datasets from the OpenSky network. The experimental results demonstrate that the proposed 2-Inception-LSTM is the local optimal model.

In [A8], Wang *et al.* study overt spectrum mask-based covert wireless uplink transmission in space-air-ground integrated vehicular networks. To improve the data transmission efficiency, an improper Gaussian signaling (IGS) model is adopted and a joint transmit power and IGS circularity coefficient optimization problem is formulated to minimize the outage probability of the covert communication system. With the approximated outage probability, the optimization problem is solved using the monotonic properties of the objective function and constraints. Extensive numerical results are provided to validate the proposed covert transmission strategy, which demonstrates that the IGS scheme can improve the data transmission efficiency.

In [A9], Zhang *et al.* study multi-domain network resource orchestration in SAGIN. The authors formulate a multi-domain virtual network embedding (VNE) problem and propose a cross-domain VNE algorithm based on deep reinforcement learning (DRL). The authors build a feature matrix based on network attributes extracted from SAGIN and use it as the training environment for the agent in DRL. Through training, the probability of each underlying node being embedded can be derived. In the test phase, they complete the embedding process of virtual nodes and links in turn based on this probability. Finally, the effectiveness of the algorithm from both training and testing is evaluated through simulations.

In [A10], Wang *et al.* explore the airspace structure and safety performance of unmanned aerial vehicle (UAV) systems based on spatial digital twins (DTs). The authors introduce DTs technology and combine the convolutional neural network (CNN) algorithm with the UAV autonomous network. The DTs system of UAV is constructed using wireless communication technology, and its security performance is simulated. The results show that with the increase in the acquisition points, the data amount transmitted only increases slightly, but the packet loss rate does not change significantly. It is found that the UAV DTs system can improve the safety performance of the UAV significantly during airspace flight.

In [A11], Fang *et al.* propose a weighted fractional Fourier transform (WFRFT)-based parallel complex spreading (PCS) approach for enhancing the communication efficiency and the security of SAGIN for ITS. The signal statistical features in baseband signal manipulations are utilized to improve the security. The security analysis demonstrates that the WFRFT-PCS scheme can effectively deal with hostile baseband modulation paradigm recognition, malicious periodicity prediction and illegitimate sequence acquisition. Moreover, the proposed scheme is inherently robust against the large Doppler shift distortions of SAGIN.

In [A12], Tan *et al.* aim to address the two major issues in current vehicle-mounted speech emotion recognition (SER): insufficient service capacity of the vehicle communication network and poor accuracy of SER. The authors propose an SER-enhanced traffic efficiency approach for autonomous vehicles in an SAGIN-based ITSs. The experiments demonstrate that the proposed solution can not only improve the SAGIN's service capabilities in terms of capacity, latency, and reliability but also improve the accuracy of SER as well as the performance, practicality, and user experience in ITSs.

In [A13], Pan *et al.* propose a space-air-sea-ground integrated monitoring network-based forecasting system to support the operational response for ships in distress and oil spills. Specifically, the authors develop a three-layered structure of the framework for monitoring, including a sensing layer, a network layer, and an application layer. The space-borne synthetic aperture radar (SAR) observations for ship and oil spills are verified by air-borne SAR observations and onsite observations. By integrating more observations from the proposed system, the accuracy of the forecasting trajectory can be improved. The forecasting uncertainty is accounted for by an ensemble of the available wind and current forcing, to improve the reliability. Monitoring and forecasting can improve the maritime transportation emergency response.

In [A14], Zhao investigates space-air-ground integrated vehicular crowdsensing (SAGI-VCS) to exploit its great potential to support the services in ITS. In this work, the authors first present a blockchain-enabled service architecture for SAGIN and then propose a tensor computing-based truthful incentive mechanism TensorBC to stimulate vehicles in blockchain-enabled SAGI-VCS to facilitate completing tasks, enhance the security, and maximize social welfare. The proposed TensorBC can eliminate the redundant winner phenomenon, and guarantee truthfulness, individual rationality, and profitability.

In [A15], Liu *et al.* propose an anonymous authentication protocol for space-air-ground integrated vehicular networks. With the proposed protocol, vehicular users can subscribe to network services in a succinct subscription credential and perform anonymous authentication. The security analysis and performance evaluation results respectively demonstrate the security and efficiency of the proposed protocol.

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APPENDIX: RELATED ARTICLES

[A1] R. Han, Y. Wen, L. Bai, J. Liu, and J. Choi, "Age of information aware UAV deployment for intelligent transportation systems," *IEEE Trans. Intell. Transp. Syst.*, early access, Oct. 15, 2021, doi: 10.1109/TITS.2021.3117974.

[A2] Y. Wang, S. Wu, J. Jiao, P. Yang, and Q. Zhang, "On the prediction policy for timely status updates in space-air-ground integrated transportation systems," *IEEE Trans. Intell. Transp. Syst.*, early access, Dec. 1, 2021, doi: 10.1109/TITS.2021.3129837.

[A3] Y. He, Y. Wang, F. R. Yu, Q. Lin, J. Li, and V. C. M. Leung, "Efficient resource allocation for multi-beam satellite-terrestrial vehicular networks: A multi-agent actor-critic method with attention mechanism," *IEEE Trans. Intell. Transp. Syst.*, early access, Dec. 7, 2021, doi: 10.1109/TITS.2021.3128209.

[A4] Z. Yin *et al.*, "UAV-assisted physical layer security in multi-beam satellite-enabled vehicle communications," *IEEE Trans. Intell. Transp. Syst.*, early access, Jun. 23, 2021, doi: 10.1109/TITS.2021.3090017.

[A5] J. Wang, Y. Liu, S. Niu, W. Jing, and H. Song, "Throughput optimization in heterogeneous swarms of unmanned aircraft systems for advanced aerial mobility," *IEEE Trans. Intell. Transp. Syst.*, early access, May 27, 2021, doi: 10.1109/TITS.2021.3082512.

[A6] P. Li, X. Wang, H. Gao, X. Xu, M. Iqbal, and K. Dahal, "A dynamic and scalable user-centric route planning algorithm based on polychromatic sets theory," *IEEE Trans. Intell. Transp. Syst.*, early access, Jun. 7, 2021, doi: 10.1109/TITS.2021.3085026.

[A7] Y. Chen, J. Sun, Y. Lin, G. Gui, and H. Sari, "Hybrid N-inception-LSTM-based aircraft coordinate prediction method for secure air traffic," *IEEE Trans. Intell. Transp. Syst.*, early access, Jul. 21, 2021, doi: 10.1109/TITS.2021.3095129.

[A8] D. Wang, P. Qi, Y. Zhao, C. Li, W. Wu, and Z. Li, "Covert wireless communication with noise uncertainty in space-air-ground integrated vehicular networks," *IEEE Trans. Intell. Transp. Syst.*, early access, Aug. 3, 2021, doi: 10.1109/TITS.2021.3098790.

[A9] P. Zhang, C. Wang, N. Kumar, and L. Liu, "Space-air-ground integrated multi-domain network resource orchestration based on virtual network architecture: A DRL method," *IEEE Trans. Intell. Transp. Syst.*, early access, Aug. 3, 2021, doi: 10.1109/TITS.2021.3099477.

[A10] W. Wang, X. Li, L. Xie, H. Lv, and Z. Lv, "Unmanned aircraft system airspace structure and safety measures based on spatial digital twins," *IEEE Trans. Intell. Transp. Syst.*, early access, Sep. 8, 2021, doi: 10.1109/TITS.2021.3108995.

[A11] X. Fang, Z. Du, X. Yin, L. Liu, X. Sha, and H. Zhang, "Toward physical layer security and efficiency for SAGIN: A WFRFT-based parallel complex-valued spectrum spreading approach," *IEEE Trans. Intell. Transp. Syst.*, early access, Sep. 1, 2021, doi: 10.1109/TITS.2021.3109118.

[A12] L. Tan *et al.*, "Speech emotion recognition enhanced traffic efficiency solution for autonomous vehicles in a 5G-enabled space-air-ground integrated intelligent transportation system," *IEEE Trans. Intell. Transp. Syst.*, early access, Oct. 28, 2021, doi: 10.1109/TITS.2021.3119921.

[A13] Q. Pan *et al.*, "Space-air-sea-ground integrated monitoring network-based maritime transportation emergency forecasting," *IEEE Trans. Intell. Transp. Syst.*, early access, Dec. 24, 2021, doi: 10.1109/TITS.2021.3134838.

[A14] R. Zhao, L. T. Yang, D. Liu, X. Deng, and Y. Mo, "A tensor-based truthful incentive mechanism for blockchain-enabled space-air-ground integrated vehicular crowdsensing."

[A15] D. Liu, H. Wu, J. Ni, and X. Shen, "Efficient and anonymous authentication with succinct multi-subscription credential in SAGVN," *IEEE Trans. Intell. Transp. Syst.*, early access, Feb. 8, 2022, doi: 10.1109/TITS.2022.3147354.

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