INTEGRATED TERRESTRIAL-SATELLITE NETWORKS: PART ONE


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The rapid growing data traffic brings more and more pressure to the wireless networks, which is predicted to increase by over 10,000 times in the next 20 years. However, currently, there is still large number of population without coverage of mobile service. In addition to the issue of coverage, future wireless networks also need to guarantee the service continuity for emerging services such as Machine-to-Machine and Internet of Things. Many emerging scenarios, such as Unmanned Aerial Vehicle (UAV) control, pipeline monitoring, or global container tracking, require the aid of wireless networks. However, existing networks are severely hindering these services from achieving their true potentials. Considering the deficiency in existing wireless networks nowadays, ubiquitous on-demand coverage is the key to ensure service continuity in future communication paradigm.

On the other hand, the cost of providing ubiquitous converge has also to be taken into account for mobile networks operators. The concept of a "Long tail" distribution is embodied in many innovative Internet business models. It indicates that the revenues may be made from infrequent usage if one can effectively cater to various individual demands. It is applicable to wireless networks operation as well, where the usages far from urban centers can also lead to considerable revenue. However, the cost of pure terrestrial coverage quickly becomes unbearable with the increasing network requirements for those rural, remote and other areas.

Satellite network is an ideal solution to address such a dilemma. While the terrestrial networks can achieve high-speed data service at low cost, satellites may cover an area with a radius of thousands of kilometers, providing coverage to otherwise inaccessible locations. Therefore, the satellite and terrestrial networks should be deeply integrated to realize the full benefits of each of them. The coexistence and cooperation between terrestrial and satellite networks are of great potential in future communication networks. As a matter of fact, the satellite radio access network has already been considered in the fifth-generation (5G) networks to be supported for Phase 2. Thus, investigations of innovative technologies in terrestrial-satellite networks are in great need to bring out its true potential.

Notable research groups are focusing on satellite applications in 5G, such as the 5G CHAMPION program (8 European and 13 Korean partners), mainly investigating integrated 5G radio-access, core-network and satellites. Meanwhile, FCC, ITU will discuss the Ka-band spectrum sharing between satellites and 5G in WRC 2019. Furthermore, China launched the Space Integrated Ground Network Program in 2016, as a national major project. On the other hand, in the satellite mobile communication field, integration, miniaturization and multifunction are the developing trends. In the past, the satellite stations are usually large scale with very low mobility, and the satellite can only realize the point to point communication. Recently, the Sat-Fi was developed by Globalstar, in which the mobile antenna and modem are integrated into a hotspot box that can establish a bridge between the satellite and smart phones. Meanwhile, the users' terminals are also becoming increasingly miniaturized, compared with the past heavy and big satellite terminals with less functionality. As technology continues to develop, the Thuraya XT-Pro was produced by Thuraya, on which the satellite modem was designed as a phone companion, providing quite convenient experience to users.

A new vision of next generation networks (NGN) has been proposed by International telecommunication union

(ITU), in which the integrated and/or hybrid satellite and terrestrial network is supposed to play important roles. Against this background, this special issue calls for papers on the topic of "Integrated Terrestrial-Satellite Networks" to explore the key technologies and possible applications in future terrestrial-satellite networks. In the first issue, we have accepted four papers as follows.

The first paper, "Efficient Recovery of Structured Sparse Signals via Approximate Message Passing with Structured Spike and Slab Prior", investigated the Micro-satellite signal processing issue. Due to limited volume, weight and power consumption, Micro-satellite has to reduce data transmission and storage capacity by image compression when performs earth observation missions. However, the quality of images may be unsatisfied. It considers the problem of recovering sparse signals by exploiting their unknown sparsity pattern. To model structured sparsity, the prior correlation of the support is encoded by imposing a transformed Gaussian process on the spike and slab probabilities. Then, an efficient approximate message-passing algorithm with structured spike and slab prior is derived for posterior inference, which, combined with a fast direct method, reduces the computational complexity significantly. Further, a unified scheme is developed to learn the hyperparameters using expectation maximization (EM) and Bethe free energy optimization. Simulation results on both synthetic and real data demonstrate the superiority of the proposed algorithm.

In recent years, a number of Non Geostationary Orbits (NGEO) communication systems working in the Ku and Ka-band were proposed, creating a new era of commercial communication applications. These NGEO constellations which contain hundreds or even thousands of small satellites can provide high-capacity and low-latency multimedia services but may generate harmful interference to other satellite systems, especially geostationary (GEO) satellite networks. This potential has attracted a great deal of research interest and various interference mitigation methodologies have proposed. However, previous mitigation methods usually focused on optimizing constellation parameters or transmit power to facilitate the sharing of spectrum resources among multiple satellite networks. We then introduce the second paper, "Spectral Coexistence between LEO and GEO Satellites by Optimizing Direction Normal of Phased Array Antennas", to address this problem. This paper discusses the spectral coexistence between LEO constellation and GEO belt for global distributed earth stations. A specific method is introduced to mitigate the in-line interference by tilting the direction normal of phased array antennas of LEO satellites, and the optimal direction is found by solving a non-linear programming problem. The simulation results prove that the proposed approach leads to greater link availability while guaranteeing the desired received signal level especially for low-latitude earth stations.

The third paper, "Hybrid-Traffic-Detour Based Load Balancing for Onboard Routing in LEO Satellite Networks", deals with the dynamic and imbalanced traffic requirements in Low Earth Orbit satellite networks. Several distributed load balancing routing schemes have been proposed for this problem in the past. However, because of the lack of global view, these schemes may lead to cascading congestion in regions with high volume of traffic. To solve this problem, a Hybrid-Traffic-Detour based Load Balancing Routing (HLBR) scheme is proposed, where a Long-Distance Traffic Detour (LTD) method is devised and coordinates with distributed traffic detour method to perform self-adaptive load balancing. The forwarding path of LTD is acquired by the Circuitous Multipath Calculation (CMC) based on prior geographical information, and activated by the LTD-Shift-Trigger (LST) through real-time congestion perception. Simulation results show that the HLBR can mitigate cascading congestion and achieve efficient traffic distribution.

Finally, the fourth paper "Topology Discovery Sub-Layer for Integrated Terrestrial-Satellite Networks Routing Schemes" is accepted for the contribution on routing protocols in integrated terrestrial-satellite networks. With the booming development of terrestrial network, scaling terrestrial network over satellite network to build Integrated Terrestrial-Satellite Networks (ITSNs) and meanwhile to provide the global Internet access, has become ever more attractive. The widely and successfully used terrestrial routing protocols are the promising protocols to integrate the terrestrial and satellite networks naturally. However, the terrestrial routing protocols, which rely on propagating routing messages to discover the new network topology (NNT) in the terrestrial network with rare topology changes, will suffer from overly numerous routing messages in the satellite network whose topology frequently changes as the satellite moves. The authors firstly propose a Topology Discovery Sub-layer for ITSN routing schemes (TDS-IRS) to avoid the propagation of numerous routing messages by taking advantage of the satellite movement predictability and the requirements of routing schemes to discover the NNT in advance of the topology change. Secondly, a Weighted Perfect Matching based Topology Discovery (WPM-TD) model is designed to conduct the NNT discovery on the ground. Thirdly, this paper builds a testbed with real network devices and meanwhile interconnect that testbed with the real Internet, to validate that RS-TDS can discover the NNT immediately with the less on-board overhead compared with the optimized routing schemes. Finally, different network scenarios are applied to validate the WPM-TD, i.e., the core module of TDS-IRS. Extensive experiments show WPM-TD can work efficiently, avoiding the invalid NNT discovery and decreasing 20% ~ 57% of the potential topology changes, which can also improve up to 47% ~ 105% of the network throughput.

The editors would like to thank all the authors for their excellent research activity and also for having chosen this Special Issue for disseminating the outcomes of their work. We also appreciate the valuable time and carefully review work of the reviewers. Their expert knowledge in the field has helped to improve the quality significantly. We hope this special issue can give an overview of the key issues of future terrestrial-satellite networks, and more works are expected to further explore this area.

Biographies

Linling Kuang, [IEEE S'01-M'06] received the B.S. and M.S. degrees from the National University of Defense Technology, Changsha, China, in 1995 and 1998, respectively, and the Ph.D. degree in electronic engineering from Tsinghua University, Beijing, China, in 2004. Since 2007, she has been with the Tsinghua Space Center, Tsinghua University. Her research interests include wireless broadband communications, signal processing, and satellite communication, in which she has published two monographs, more than 50 technical papers, and more than 40 patents. She is a member of the IEEE Communications Society.

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Giovanni Giambene, [IEEE S'94-M'03-SM'09] received the Dr. Ing. degree in Electronics in 1993 and the Ph.D. degree in Telecommunications and Informatics in 1997, both from the University of Florence, Italy. He was Technical External Secretary of the European Community COST 227 Action ("Integrated Space/Terrestrial Mobile Networks"). From 1997 to 1998, he was with OTE (Marconi Group) in Florence, Italy, working on a GSM development program. In 1999, he joined the Department of Information Engineering and Mathematical Sciences of the University of Siena, Italy, where, he is associate professor on Networking. He was vice-Chair of the COST 290 Action (2004-2008), entitled "Traffic and QoS Management in Wireless Multimedia Networks" (Wi-QoST). He participated to: (i) the SatNEx I & II network of excellence (EU FP6, 2004-2009) and SatNEx III (ESA 2010-2013); (ii) the EU FP7 Coordination Action "Road mapping technology for enhancing security to protect medical & genetic data" (RADICAL); (iii) the COST Action IC0906 (2010-2014) "Wireless Networking for Moving Objects" (WiNeMO) as national representative; (iv) the EU FP7 Coordination Action RESPONSIBILITY coordination action (2013-2016). At present, he is involved in the ESA SatNEX IV project. Giambene is IEEE senior member. Since January 2015, he is IEEE Transactions on Vehicular Technology editor. His research interests deal with wireless and satellite networking, cross-layer air interface design, and network coding applications.