Quasi-Synchronous Random Access for Massive MIMO-Based LEO Satellite Constellations

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Abstract:
Low earth orbit (LEO) satellite constellation-enabled communication networks are expected to be an important part of many Internet of Things (IoT) deployments due to their unique advantage of providing seamless global coverage. In this paper, we investigate the random access problem in massive multiple-input multiple-output-based LEO satellite systems, where the multi-satellite cooperative processing mechanism is considered. Specifically, at edge satellite nodes, we conceive a training sequence padded multi-carrier system to overcome the issue of imperfect synchronization, where the training sequence is utilized to detect the devices' activity and estimate their channels. Considering the inherent sparsity of terrestrial-satellite links and the sporadic traffic feature of IoT terminals, we utilize the orthogonal approximate message passing-multiple measurement vector algorithm to estimate the delay coefficients and user terminal activity. To further utilize the structure of the receive array, a two-dimensional estimation of signal parameters via rotational invariance technique is performed for enhancing channel estimation. Finally, at the central server node, we propose a majority voting scheme to enhance activity detection by aggregating backhaul information from multiple satellites. Moreover, multi-satellite cooperative linear data detection and multi-satellite cooperative Bayesian dequantization data detection are proposed to cope with perfect and quantized backhaul, respectively. Simulation results verify the effectiveness of our proposed schemes in terms of channel estimation, activity detection, and data detection for quasi-synchronous random access in satellite systems.

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I. Introduction

As an indispensable component of the space-air-ground integrated network, low earth orbit (LEO) satellites have received extensive attention in the research of beyond fifth generation (B5G) and sixth generation (6G) mobile communication systems [1], [2], [3], [4]. Extensive efforts have been devoted to the construction of satellite constellations over the past few decades, for example, the Iridium system in the 1990s and Starlink LEO constellation projects more recently [5]. With the evolution of space and communication technologies, satellite communication (SatCom) has extended from its original narrowband voice service to broadband multimedia service, which also brings more opportunities to the ubiquitous space-air-ground integrated connectivity.

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