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Advance Higher Throughput Communications and Networks for GEO and LEO satellites (3)

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OPTIMIZATION OF MULTI-BEAM SATELLITE CONSTELLATIONS FOR BEYOND 5G TERAHERTZ COMMUNICATIONS IN LEO ENVIRONMENTS

Abstract

This research considers multi-beam satellite constellations designed for future 5G terahertz (THz) communications in low Earth orbit (LEO) environments. With rapid development in communications technology, in addition to increased requirements for high-data-rate transmissions, low latency, and increased spectral efficiency, an investigation of THz frequencies for future spatial networks is initiated. Nevertheless, utilizing THz frequencies in LEO environments comes with significant challenges, such as atmospheric absorption, restrictions in terms of distance between links, and a need for efficient beamforming and handing over in order to maintain continuous connectivity. We introduce a full-fledged system combining state-of-the-art orbital dynamics with state-of-the-art communications methodologies for both constellation topology and optimized resource planning. In specific, mixed-integer linear programming (MILP) is utilized for deciding the ideal number of satellites, their altitudes, and distribution in three dimensions in order to have continuous worldwide coverage with minimum interference and maximized throughput. In addition, a new and efficient algorithm for increased adaptability in terms of beamforming is proposed, allowing real-time variation in terms of beamwidth and directionality according to density, motion, and channel behavior of the users. The performance of the proposed system is confirmed through simulation, with a throughput of 1 Tbps per satellite and a one-millisecond latency, outpacing current Ku/Ka-band alternatives. In addition, the platform ensures efficient handing over between satellites and beams, even at high speeds, and therefore continuous connectivity. Sensitivity analysis confirms a significant contribution of atmospheric loss in terms of budget and underlines the utmost importance of selecting proper operational bands in the THz range in a wise manner. The study underscores the potential of THz communications for enabling ultra-high-capacity broadband services in LEO constellations, paving the way for transformative applications such as real-time Earth observation, high-definition video streaming,

and inter-satellite links. Future work will focus on extending the framework to incorporate hybrid RF/THz architectures and exploring strategies for mitigating rain fade and other weather-induced impairments in THz links. This research contributes to the foundation of beyond 5G space-based communication systems, addressing key technological gaps and advancing the frontiers of satellite telecommunications.