# Analysis and Design of Non-Geostationary Satellite Networks for a Fully Connected Globe

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## Abstract

Despite the ubiquitous digital connectivity that we experience all around us, it is a fact that almost half of the population of the world is still "offline" due to the lack of a robust Internet and communications infrastructure in many places on the globe. The main reason is the unaffordable cost of communications infrastructure implementation. In this scenario, a viable solution to cut down on the cost factor is to deploy a sufficient number of satellites in the backbone network to provide connectivity to far-flung or less populated areas [1]. In fact, many big Internet giants have proposed different constellations of satellites to provide global broadband access to the Internet, such as the Starlink supported by SpaceX with 12000 Low Earth Orbit (LEO) satellites. Such a large number of satellites has allowed mass production of components, thereby resulting in a significant reduction in satellite manufacturing costs. It also provides a more cost-effective and reliable alternative to deploying optical fiber and related equipment in such locations of the world.

Although recent works have made considerable contributions to modeling and analyzing various kinds of satellite communication networks [5, 4], most of them did not consider the satellite's rotation. Most literature also ignored the influence of the Earth's rotation, which exists in reality. However, both position variations of the satellite and ground terminals play a crucial role in realistic satellite communication networks, because of unavoidable performance variations and necessary handover actions caused by a considerable communication distance variation. Few works have investigated the time-varying satellite communication system performance while considering the satellite's and the Earth's movement, which motivates us to mitigate this gap.

The evaluation of the performance of the time-varying system is based on the Earth-centered inertial (ECI)-frame and Earth-centered Earth-fixed (ECEF)-frame [3, 2]. The ECI frame is responsible for calculating the satellite's position and velocity, while the ECEF frame is similar to the ECI frame but rotates along with the Earth, hence, it is fixed to the Earth. Based on the mentioned ECEF and ECI frames, the instantaneous communication distance between two devices at any time slot in satellite communication systems can be exactly obtained, which yields a more practical system model, where a satellite could only serve users within the satellite visibility window (the time that uses located in the coverage area of the satellite).

Therefore, based on the proposed practical satellite communication system, the instantaneous performance, as well as the ergodic performance during a satellite visibility window for a point-to-point non-stationary satellite communication system, can be analyzed, while taking the Earth's and satellite's rotations and the movement of the ground user into account. Whether the ground user is fixed or moving, and no matter whether it is in the air or on the ground or underwater, the system performance can always be analyzed. By comparing the results with the one that

does not take the Earth's rotation into account, the impact of the Earth's rotation can be further investigated and provide insights for practical implementation.

Based on the system model and derived analytical results, several meaningful works can be further conducted. Firstly, the analytical results facilitate resource allocation. For example, the minimum transmitting power satisfying the quality of service (QoS) can be obtained directly from the analytical closed-form expressions of different performance indices. Moreover, the signal combination and interference cancellation problem resulting from multi-satellite communication systems can also be analyzed easily based on our system model, where the ground device is located in the intersection area of multiple satellites with various altitudes and rotation speeds. Another interesting problem that can be solved is satellite handover. Based on the proposed satellite coordinate, the rotation routing and the serving time of satellites can be predicted in advance. The most suitable next satellite to serve the target ground user can be found and reserves enough resources to perform a more fluent satellite handover. More importantly, the proposed non-stationary system contributes to finding the most efficient transmission path satisfying the performance requirement with the shortest transmission delay between two very remote devices (ground terminals/satellites) without the direct communication link because of huge path loss, the power limit, and limited coverage area, where the transmitted information forwarded by several satellites subsequently, which results in the multi-hops satellite relaying system.

# References


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