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

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Introduction

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". 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.

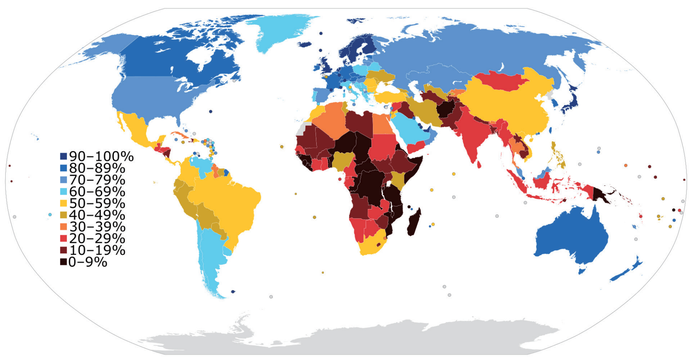

Fig. 1. Digital connectivity probability over the world.

Motivation and Contribution

Although recent works have made considerable contributions to modeling and analyzing various satellite communication networks, most of them did not consider the satellite's rotation and 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.

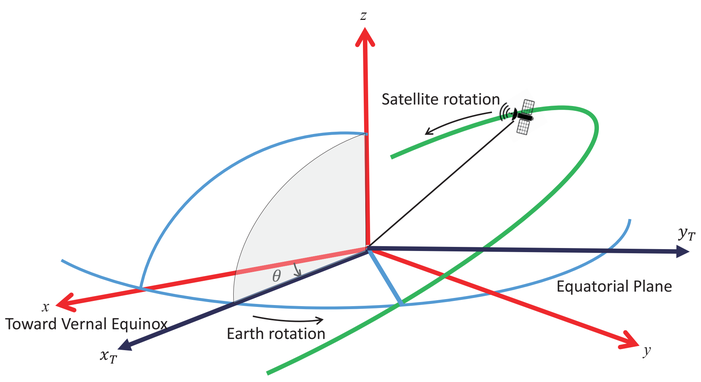

Fig. 2. Spherical coordinates.

The evaluation of the performance of the time-varying system is based on the Earth-centered inertial-frame (x-y-z) and Earth-centered Earth-fixed-frame (x_T-y_T-z) shown in the above figure. Accordingly, 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. 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.

Numerical Results

By denoting the case considering the Earth's rotation as ER, while the one ignoring the Earth's rotation as WER, some selected results regarding the system outage probability (OP) and throughput are shown in Fig. 3-Fig. 4, respectively. Observing from the numerical results, some remarks can be achieved as follows:

1) There is an apparent difference in the communication distance for WER and ER, which leads to performance gaps and cannot be ignored in practical implementations. Also, the distance difference between ER and WER is a periodic function.

2) Considering a mobile user moving randomly within a limited area, named WER-RU and ER-RU. The users' mobility can lead to better throughput or much worse throughput, depending on practical movements.

3) A large radius of satellite orbit brings an improved throughput. However, it can be eliminated by high path loss. The throughput of WER could be treated as an upper bound for the throughput of ER.

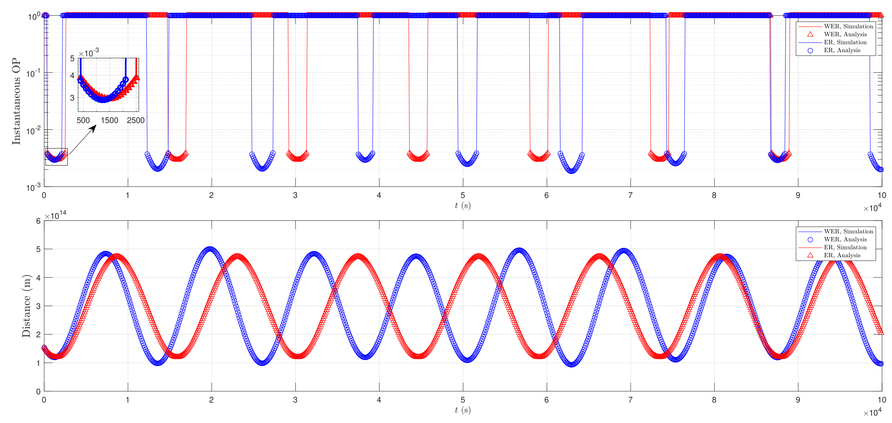

Fig. 3. ER instantaneous OP vs WER instantaneous OP and ER instantaneous distance vs WER instantaneous distance.

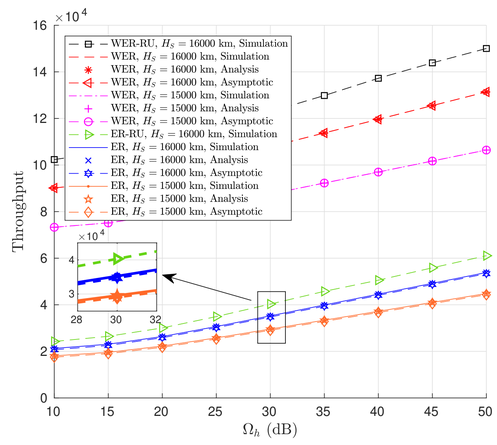

Fig. 4. ER throughput vs WER throughput for various H_S.

Applications

The proposed system model and derived analytical results serve as a solid foundation and powerful tool for future research of advanced satellite communication systems and practical implementation. Firstly, it can provide an easier way to allocate resources, such as, the transmit power. Moreover, the signal combination and interference cancellation problem resulting from multi-satellite communication systems shown in Fig. 5 can also be analyzed easily based on the proposed system model.

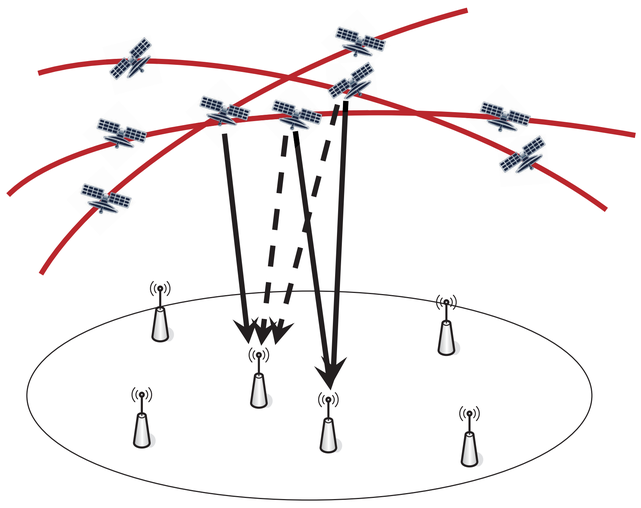

Fig. 5. Multiple satellite communication system.

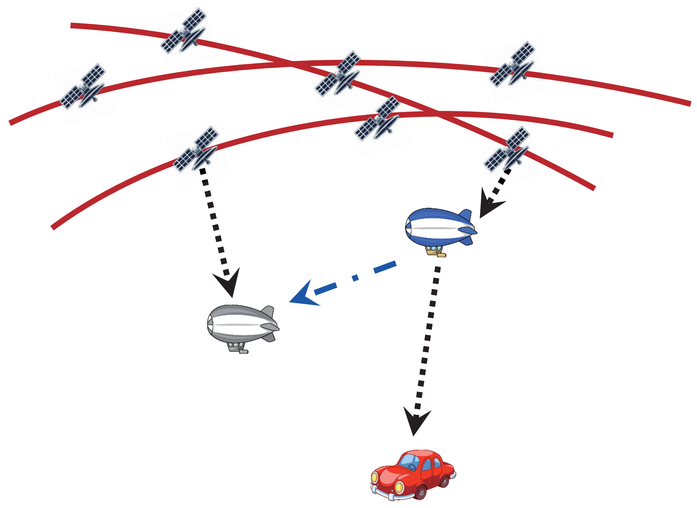

Fig. 6. Space-air-ground integrated network and handover

Additionally, the aerial platforms can also be integrated into the system to compose a space-air-ground system, which is shown in Fig. 6. The moving devices also arise another interesting problem, that is, the 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. As can be seen from Fig. 7, the handover prediction based on the proposed method can greatly decrease the latency compared to the one without prediction.

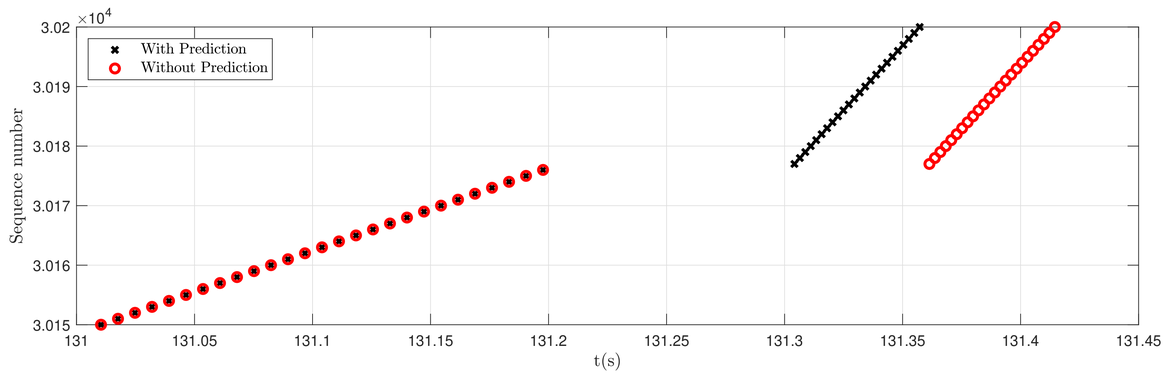

Fig. 7. Transmission latency with handover prediction vs transmission latency without handover prediction.