Performance Evaluation of
Low Earth Orbit Communication Satellites

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Abstract

Recently, there is a growing trend toward deploying low Earth orbit communication satellites due to lower latency and easier launching compared with geostationary satellites. In this paper, we study the effect of altitude and inclination angle on the coverage probability and data rate of a user located in Tampere. The simulations show that the minimum inclination angle that results in sufficient coverage and data rate decreases as altitude increases. On the other hand, for inclination angles which are larger than the minimum required inclination, the better performance is obtained for lower altitudes. This study provides a guideline for LEO constellation design based on coverage and data rate needs.

1 Introduction

Low Earth orbit (LEO) communication satellites can provide the infrastructure for tremendous data rates and connectivity. Nowadays, many LEO constellations, i.e., LeoSat, OneWeb, SpaceX and Telesat, have secured investors and/or launched their prototype satellites. Therefore, performance analysis of these networks is of high importance to ensure that they meet technical and commercial requirements.

In [1], an insight into the interrelationship between various downlink parameters of the LEO constellation was studied by presenting upper and lower bounds on the downlink throughput. LEO satellite network supporting the Internet of Things has also attracted significant attention. In [2], issues and solutions of satellite networks for IoT were studied. Authors in [3] provided an overview of the appropriate structure of satellite constellations for IoT applications. A solution for modeling the uneven coverage for quantitatively analyzing the relationship between parameters and performance of LEO-IoT was proposed in [4]. A comprehensive overview on key issues for LEO systems was presented in [5] including system architectures, constellations, coverage models, interference coordination schemes, and resource management methods. Authors in [6] applied a genetic multi-objective solution to minimize the total number of satellites constrained on the user and design requirements. General expressions for the single LEO satellite visibility time were provided in [7, 8].

In this paper, we will evaluate the effect of two critical constellation design parameters, i.e., altitude and inclination angle, on the performance of a LEO constellation in terms of coverage probability and data rate.

2 System Model

We consider a LEO satellite constellation where N satellites are distributed evenly in P orbital planes and inclined at I degrees with reference to the Equator. Two LEO constellations for $I = 90°$ and $I = 60°$ are depicted in Fig. 1. Satellites' orbits are assumed to be circular with radius $R_e + H$, where R_e is Earth radius and H is the satellite's altitude. The user is assumed to be located in Tampere and associated to the nearest satellite. We also assume that only the satellites which are above the user's horizon are visible to the user. The propagation model takes into account the free-space path loss without fading. The assumption is based on the fact that in air-to-ground satellite

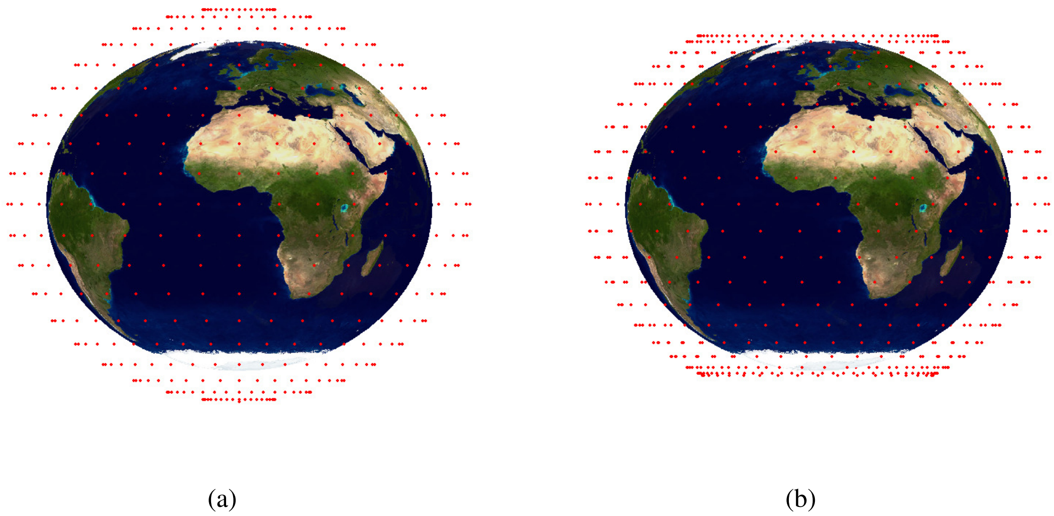


Fig. 1: (a) A polar LEO constellation and (b) a 60° inclined LEO constellation.

communication the line-of-sight (LoS) component is stronger [9]. All satellites transmit with the same power p_t, so, the received power at a node with the distance r from a satellite is $p_t r^{-2}$. It is assumed that the serving and interfering channels have the same propagation model.

The signal-to-interference-plus-noise ratio (SINR) at the receiver is

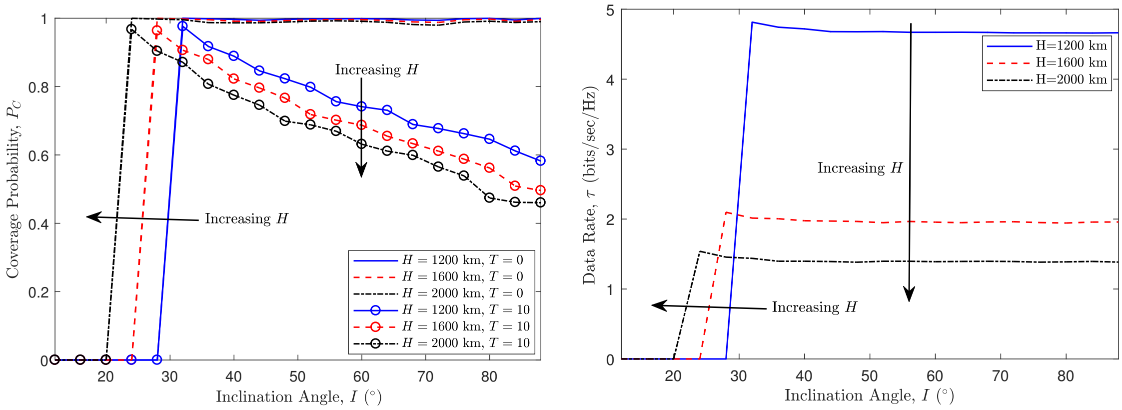
$$\mathrm{SINR} = \frac{p_t r_0^{-2}}{p_t \sum_{i=1}^{N_v-1} r_i^{-2} + \sigma^2} \tag{1}$$

where r_0 and r_i are the distances from the user to the serving and ith visible interferer, respectively. N_v is the number of visible satellites to the user (above the user's horizon). We also assume an additive noise with constant power of σ^2. The coverage probability and mean data rate can be obtained as $P_\mathrm{C} \triangleq \mathbb{P}[\mathrm{SINR} > T]$ and $\tau \triangleq \log_2(1 + \mathrm{SINR})$, respectively, where T is the SINR threshold.

3 Numerical Results

In this section, the numerical results for coverage probability and data rate are provided through Monte Carlo simulations. We assume 128 satellites are distributed evenly on eight orbits. In order to make the coverage probability sufficient for a commercial communication system, we apply frequency reuse to mitigate the effect of interference. Fig. 2(a) depicts the effect of inclination angle on coverage probability and data rate. According to Fig. 2(a), the minimum inclination that results in sufficient coverage decreases with increasing the altitude. This happens due to the fact that the visibility of satellite to the user is directly connected to the altitude. Moreover, by increasing the threshold value, the coverage probability decreases dramatically after its maximum point. After the peak value, the number of interferes increases while the chance of making connection with a better serving satellite remains at the same level, therefore, the lower the latitude, we will reach higher coverage probability. Fig. 2(b), depicts the average data rate versus inclination angle for different altitudes. The minimum inclination which results in a positive data rate is inversely related to the altitude. After the peak value, the lower the altitude, the higher data rate can be reached.

Fig. 3 shows coverage probability and average data rate for different altitudes while setting the inclination angle to 30°, 60°, and 90°. From Fig. 3(a) can be observed that the peak value



(a) (b)

Fig. 2: The effect of inclination angle on (a) coverage probability and (b) data rate. There is a trade off to select the suitable value for H as it has adversary effect on the minimum required inclination and network performance.

of coverage probability moves to lower altitudes as inclination angle increases. However, the maximum value for 60° and 90° inclination is not within the practical range of LEO constellation. As altitude increases, better coverage probability can be achieved by lower inclination. The same as coverage probability, the maximum value of data rate occurs in lower altitudes as inclination increases as shown by Fig. 3(b). Generally, both plots in Fig. 3 present the same behavior since both are originated from SINR function.

4 Conclusion

In this paper, we presented the effect of two important design parameters for LEO constellations, i.e., inclination angle and altitude. We modeled a LEO network in a non-fading propagation environment and studied the effect of the aforementioned parameters on coverage probability and average data rate of a user located in Tampere region. Simulation results show a maximum point in some specific inclination angles which is dependent to altitude. Although, the higher altitudes result the better performance for lower inclination, they show poorer performance as inclination increases. The behavior of data rate is almost the same as coverage in terms of inclination angle. Moreover, the effect of altitude on both performance metrics has been studied. The results show that lower inclination provides the possibility to have better performance within LEO licensed range. The study can be used as a useful guideline for satellite constellation design.

Acknowledgements

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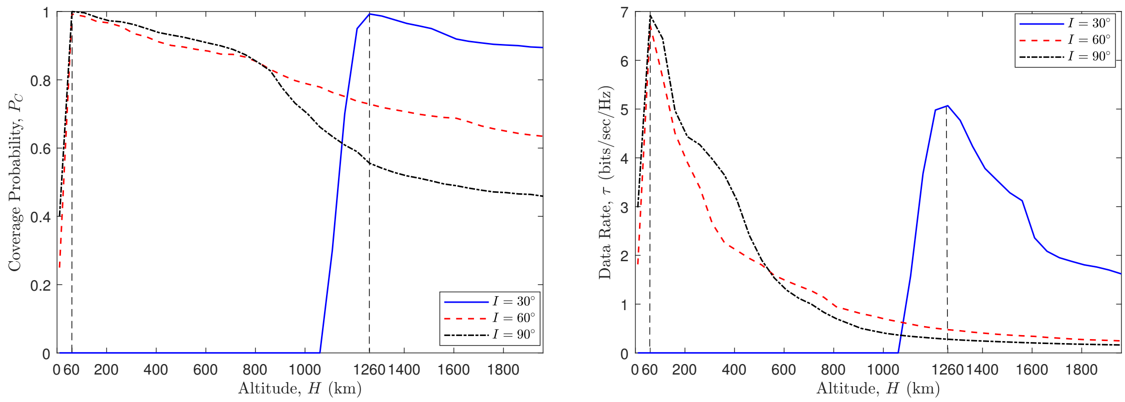
References

[1] A. Mokhtar and M. Azizoglu, "On the downlink throughput of a broadband LEO satellite network with hopping beams," *IEEE Communications Letters*, vol. 4, no. 12, pp. 390–393, Dec. 2000.

[2] M. De Sanctis, E. Cianca, G. Araniti, I. Bisio, and R. Prasad, "Satellite communications supporting Internet of Remote Things," *IEEE Internet of Things Journal*, vol. 3, no. 1, pp. 113–123, Feb. 2016.



(a) (b)

Fig. 3: (a) The effect of altitude on coverage probability and (b) data rate.

[3] Z. Qu, G. Zhang, H. Cao, and J. Xie, "LEO satellite constellation for Internet of Things," *IEEE Access*, vol. 5, pp. 18 391–18 401, Aug. 2017.

[4] H. Zhou, L. Liu, and H. Ma, "Coverage and capacity analysis of LEO satellite network supporting Internet of Things," in *Proc. IEEE International Conference on Communications (ICC)*, May. 2019.

[5] Y. Su, Y. Liu, Y. Zhou, J. Yuan, H. Cao, and J. Shi, "Broadband LEO satellite communications: Architectures and key technologies," *IEEE Wireless Communications*, vol. 26, no. 2, pp. 55–61, Apr. 2019.

[6] J. Jiang, S. Yan, and M. Peng, "Regional LEO satellite constellation design based on user requirements," in *Proc. IEEE International Conference on Communications in China (ICCC)*, Aug. 2018.

[7] J. Wenjuan and Z. Peng, "An improved connection-oriented routing in LEO satellite networks," in *Proc. WASE International Conference on Information Engineering*, Aug. 2010.

[8] I. Ali, N. Al-Dhahir, and J. E. Hershey, "Predicting the visibility of LEO satellites," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 35, no. 4, pp. 1183–1190, Oct. 1999.

[9] "Propagation data and prediction methods required for the design of Earth-space telecommunication systems," *Recommendation ITU-R*, pp. 618–12, 2015.