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Forward link outage performance of aeronautical broadband satellite communications

Key words: Aeronautical broadband satellite network; Free-space optical transmission; High throughput mmWave communication; Outage probability; Phase error

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Motivation

- In aeronautical broadband satellite communications, millimeter-wave (mmWave) user links have potential to meet the broadband demands of aeronautical communications. Meanwhile, free-space optical (FSO) feeder links can satisfy the increasing demand for higher data rates compared to radio frequency (RF) links.
- There is an urgent need for a novel beamforming scheme that can provide superior performance for aeronautical broadband satellite communications where the perfect CSI is unavailable.
- Due to hardware impairment in practical aeronautical communication, it is necessary to consider the effect of the phase error on system performance in phased array antennas.

Main idea

- We present an analytical framework for the forward link of an aeronautical communication system, where HTS is used to improve the system capacity. Here, the feeder link from the gateway to the HTS exploits FSO transmission, while the user link from the HTS to the aircraft operates at the mmWave band.
- We propose a location-based BF scheme to maximize the expected output SNR of the forward link with the amplify-and-forward (AF) protocol, which turns out to be the phased array and can avoid the complex procedure of estimating CSI. Moreover, we consider the phase errors of the phased array antenna at the aircraft in a practical aeronautical communication system.

Main idea (Cont'd)

- By assuming that the FSO feeder link is subjected to Gamma-Gamma fading and that the mmWave user link is characterized by shadowed Rician (SR) fading, we derive a closed-form outage probability (OP) expression of the forward link for the considered system with the AF protocol. The asymptotic OP expression at high SNR is also presented to reveal the achievable diversity order and coding gain of the system. These OP expressions can largely facilitate the study of the effects of phase errors on the forward link.

System model

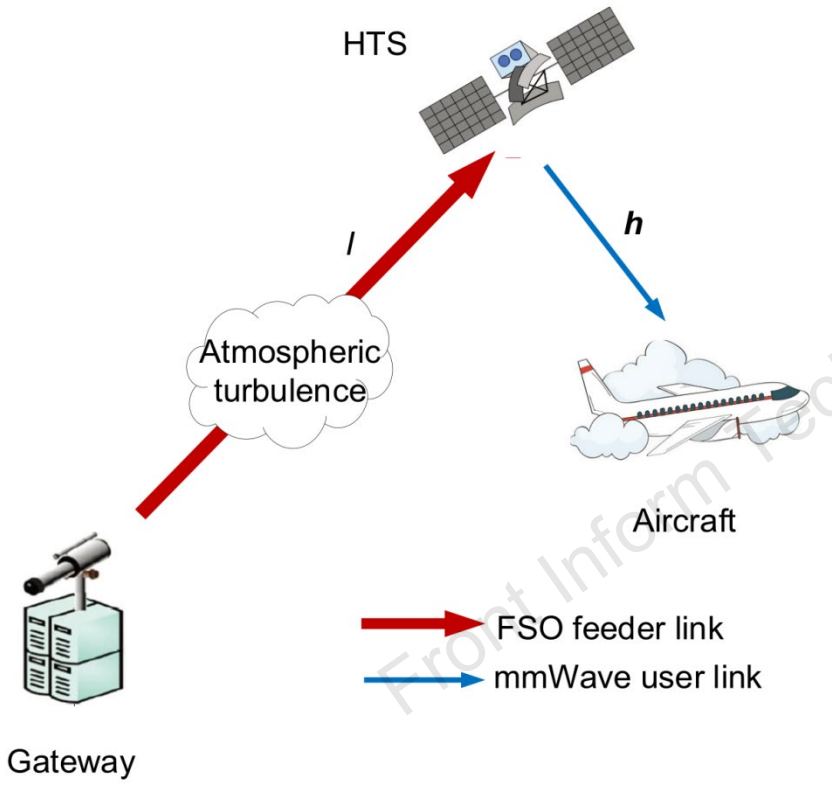

Fig. 1 System model

We consider the forward link of an aeronautical broadband satellite communication system, where the feeder link employs FSO while the mmWave band is exploited for the user link to meet the broad bandwidth demands of aeronautical communications.

Method

The BF weight vector is given by

$$\boldsymbol{w}^* = \frac{\boldsymbol{a}(\theta_0)}{\sqrt{N}}.$$

With the help of Fig. 2, θ_0 can be calculated as

$$\theta_0 = \arctan\left[\frac{\cos\theta_{\mathrm{a}}\cos\varphi_{\mathrm{a}} - 0.151}{\sqrt{1-(\cos\theta_{\mathrm{a}}\cos\varphi_{\mathrm{a}})^2}}\right]$$

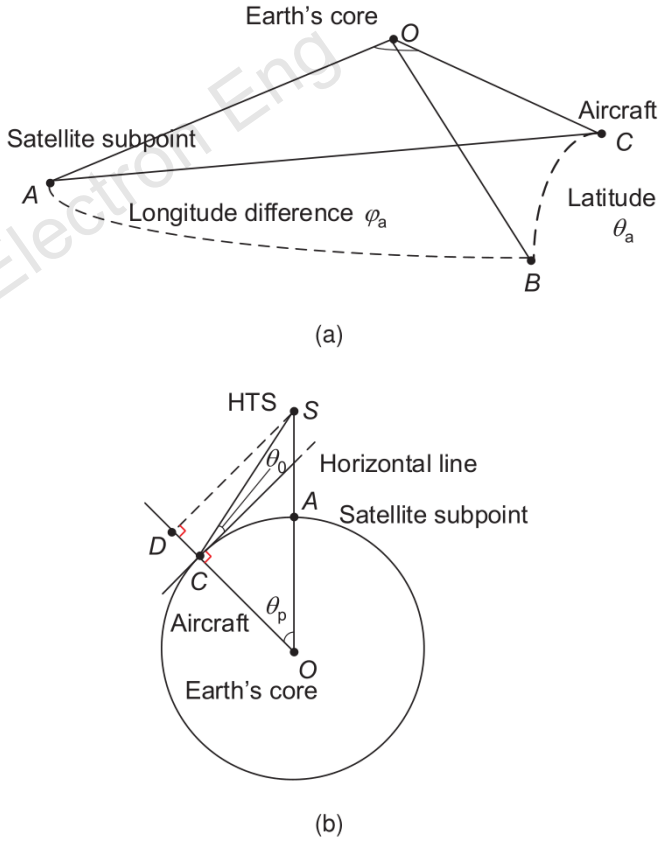

Fig. 2 Geometrical relation between the HTS and the aircraft

Method (Cont'd)

In the phased array antenna, the actual phase shift of the n^{th} antenna element can be denoted as

$$\boldsymbol{v} = \mathrm{e}^{\mathrm{j}\boldsymbol{\Lambda}}\boldsymbol{w}^*$$

$$\boldsymbol{\Lambda} = \mathrm{diag}\left(\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_N\right)$$

ε_n is the random phase error.

Major results

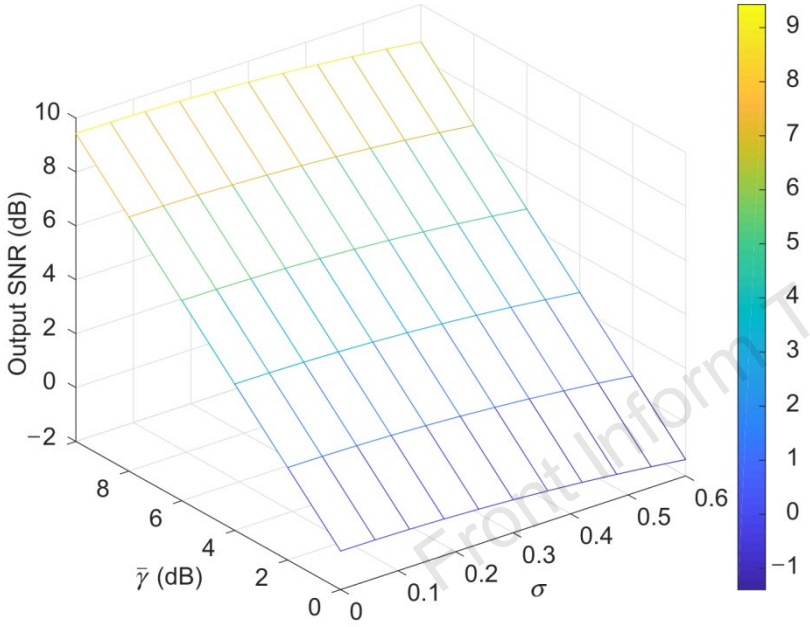

Fig. 3 Output SNR of the system with different phase errors

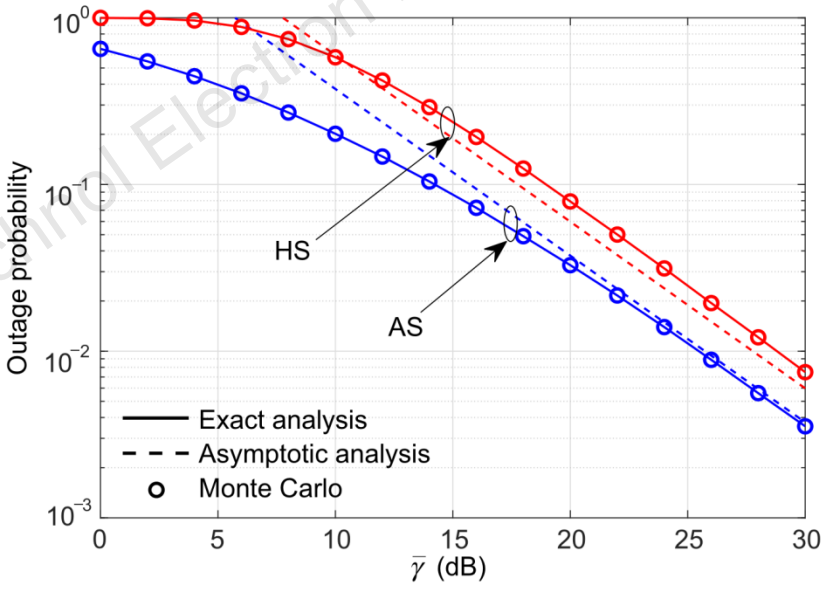

Fig. 4 Outage probability with different SR fading for the user link

Major results (Cont'd)

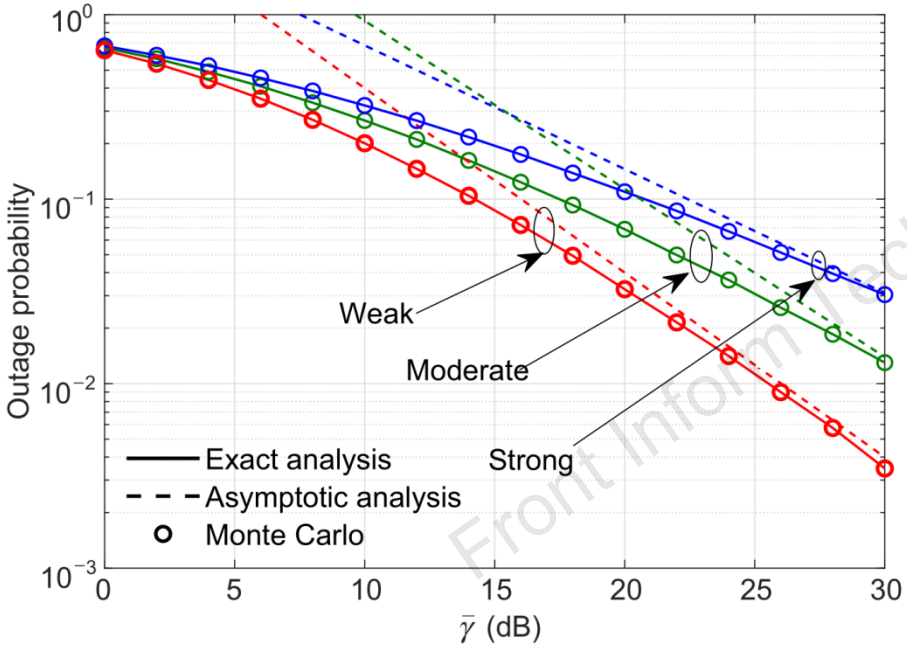

Fig. 5 Outage probability with different Gamma-Gamma fading for the feeder link

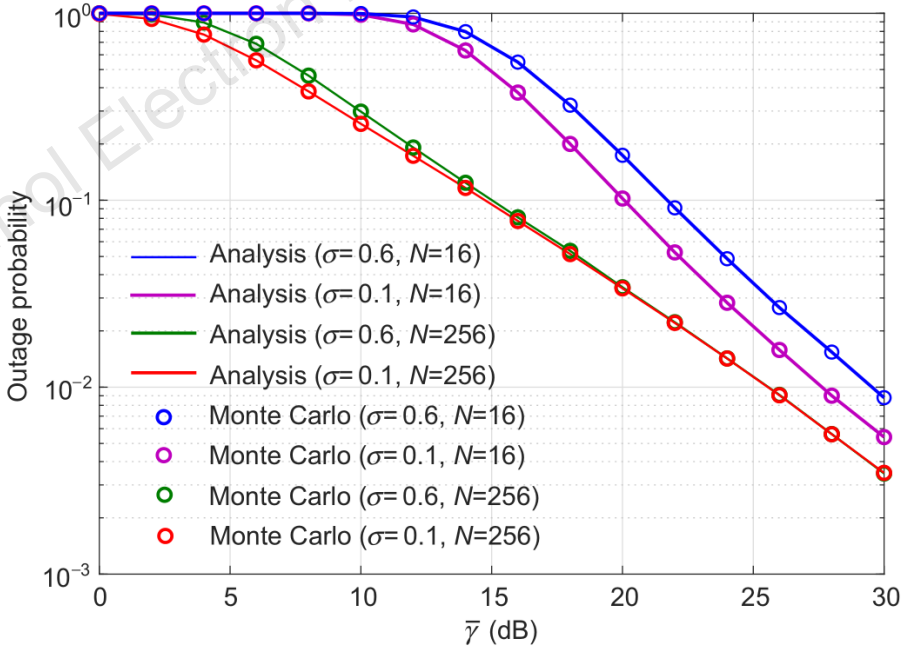

Fig. 6 Outage probability with different antenna numbers and phase errors

Conclusions

- With the help of the location-based BF weight vector, we have derived the exact and asymptotic expressions for the OP of the forward link of the considered system, in which the phase error has been taken into account in the user link.
- Simulation results have shown notable effects of phase errors on the overall system performance.
- Our findings provide valuable insight into the aeronautical broadband satellite communications.