Interference in heterogeneous aviation networks

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Abstract

In the very near future, we will witness a rapid increase in both the manned air traffic and the unmanned airborne vehicles. A low-cost, high-reliability, and high-compatibility communication system is desired to meet the upcoming air traffic data, and 5G and beyond 5G technologies are promising candidates to fulfill the requirements. In this paper, based on cellular signals, we study the impact of 5G wireless interference on aviation links. The results show that, comparing with the terrestrial users, the aerial users are more vulnerable to the downlink interference; the transmitting signals of aerial users also "pollute" more base stations.

1 Introduction

In the foreseeable future, the aviation markets will enter a fast-growth period. The FAA (Federal Aviation Administration) in [1] forecasts that in United States, airplane passengers will increase from 840.8 million in 2017 to 1.28 billion in 2038 and that a considerable growth occurs to the number of UAS (Unmanned Aviation System) units from estimated 1.1 million in 2017 to 2.4 million by 2022. [1] also emphasizes that the infrastructure needs to meet future requirement since in the U.S. the total operations (landings and take-offs) at FAA and contract towers is estimated to grow from 51.0 million in 2018 up to 60.5 million in 2038.

The current infrastructure supporting aviation networks is a mixture of ground-based and satellite-based communication. This infrastructure is proved to be reliable but has a high maintenance cost and rather low compatibility with emerging UAVs. Thus new low cost and high compatibility communication systems are necessary to meet the incoming vast airborne vehicles data traffic. The cellular signals turns out to be an excellent candidate to fulfill the rapidly increasing demands in air data traffic [2, 3].

Given the context of cellular signals, the main focus of this paper is on the vulnerability of aerial users to the wireless interference signals when cellular communications are used to complement the Air Traffic Control (ATC) communication links. Both the desired signals and interference signals are largely influenced by the channel characteristics. Taking the terrestrial users as a reference, the downlink/uplink signals propagation undergoes a combination of Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) conditions, whereas the ground-to-air (G2A, i.e., downlink)/air-to-ground (A2G, i.e., uplink) signals for aerial users (during cruise) mostly experience complete LoS conditions. Moreover, the terrestrials users encounter many cluttering situations (cluttering here refers to signals experiencing reflection, refraction, diffraction, scattering and absorption) while the aerial users not; the aerial users may suffer a sudden attenuation caused by the blocking clouds while the terrestrial users are rarely affected by water vapor (e.g., fog)[4, 5]. There are some other different conditions for terrestrial users and aerial users, such as: for an aerial user at a relatively high altitude the distance values between different base stations and itself are nearly the same; however, for a terrestrial user on the ground, the distance values are very distinguishable.

2 Interference Model

For the simplicity of the model, we focus on narrow-band signals and Single-Input Single-Output (SISO) system. Moreover, as shown in Fig. 1, the additional assumptions in this paper are:

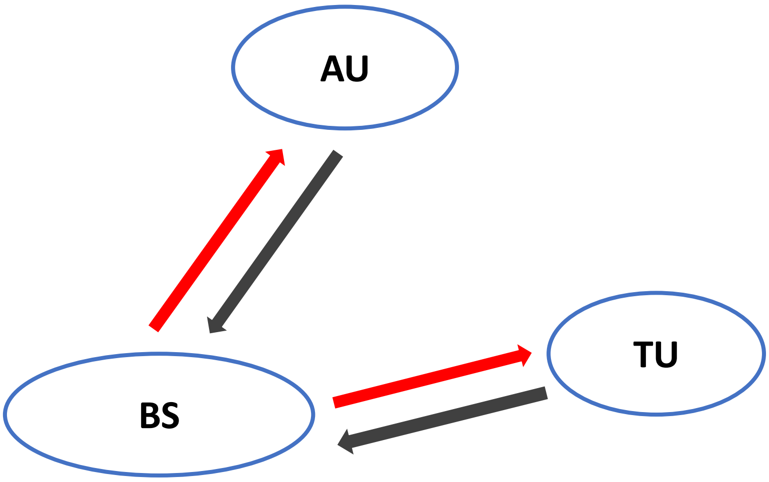

Fig. 1: Interference model. AU denotes the aerial users set, TU denotes the terrestrial users set, BS denotes the base stations set. Red bold arrows indicate the downlink interference, black bold arrows indicate the uplink interference.

1. Only base stations, aerial users and terrestrial users are considered;
2. No interference between aerial users and terrestrial users;
3. No interference and no coordination among all base stations, among all aerial users and among all terrestrial users;
4. Both the loss and gain in transmitters and receivers are 0 dB.

2.1 Downlink

The Signal-to-Interference-Ratio (SIR) $\mathrm{SIR_a}$ for an aerial user is,

$$\mathrm{SIR_a} = \frac{P_{BS}^{(k)} L^{(k)}}{\sum\limits_{i \in \mathscr{K}, i \neq k} P_{BS}^{(i)} L^{(i)}} \tag{1}$$

where $P_{BS}^{(k)}$ is the transmitting power of the kth (desired signal) base station, $L^{(k)}$ is the channel loss that signals propagating from the kth base station, $\mathscr{K}$ denotes the base stations set.

The $\mathrm{SIR_t}$ for a terrestrial user is very much similar with (1).

2.2 Uplink

The $\mathrm{SIR_{bs}^a}$ for a base station from aerial users is,

$$\mathrm{SIR_{bs}^a} = \frac{P_{AU}^{(m)} L^{(m)}}{\sum\limits_{i \in \mathscr{M}, i \neq m} P_{AU}^{(i)} L^{(i)}} \tag{2}$$

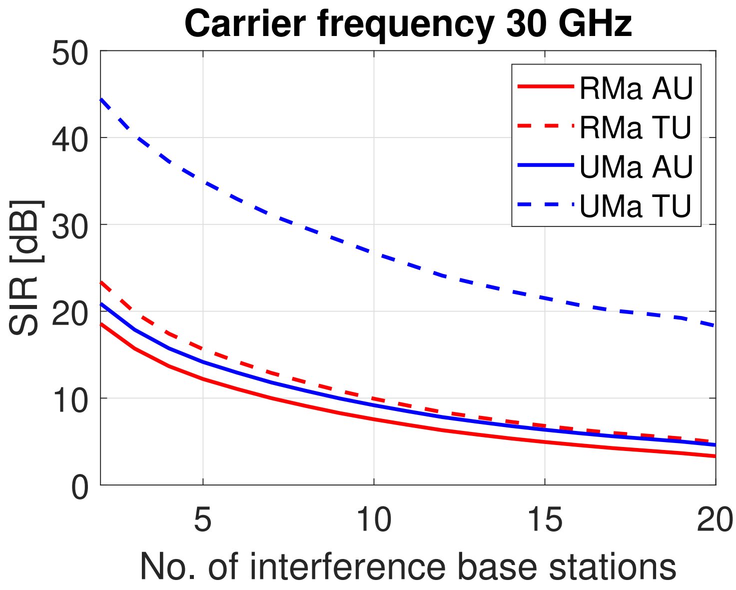

Fig. 2: Comparisons of SIR values. RMa denotes rural Macro cell, UMa denotes urban Macro cell, AU denotes aerial user, TU denotes terrestrial user.

where $P_{AU}^{(m)}$ is the transmitting power of the mth (desired signal) aerial user, $L^{(m)}$ is the channel loss that signals propagating from the mth aerial user, $\mathscr{M}$ denotes the aerial users set.

The $\mathrm{SIR}_{\mathrm{bs}}^{\mathrm{t}}$ from terrestrial users is very much similar with (2).

3 Discussion

From (1) and (2), the factors that dominate the SIR value are transmitting powers and channel loss. If we assume the transmitted power of all base stations/ aerial users/ terrestrial users are the same, the channel loss then becomes the sole element determining the SIR value.

According to 3GPP document [6], in urban area, above 100 m it is purely LoS condition; in rural area, above 40 m it is complete LoS condition. The LoS condition usually implies lower channel loss than the NLoS condition. Regarding to the aerial user, the bright side is that the desired signals going through LoS propagation with large chance; but the interference signals come under LoS conditions as well. For the terrestrial users, both desired and interference signals experience a mixture of LoS and NLoS propagation.

According to ITU recommendation report [4, 5], the attenuation caused by clouds is less than 0.6 dB when all the 2 km propagating path is within clouds, at 1 km altitude, 30 GHz frequency with a typical weather condition, for example, 10°C temperature in clouds, 0.5 $\mathrm{g/m^3}$ liquid water density. The above example is an extreme case, usually the signal path is very unlikely fully within clouds. Therefore, at a relatively low altitude, comparing with path loss, the attenuation caused by clouds is particularly small and could be neglected.

Fig. 2 gives one example on comparison of SIR values under different number of base stations at 30 GHz frequency. Clearly, the aerial users are more vulnerable to interference than terrestrial users.

Due to the fact that the uplink is also mainly determined by the channel loss, the aerial users will bring more interference to base station than terrestrial users.

4 Conclusion

We briefly describe the interference issues in heterogeneous aviation networks, a simple scenario, namely narrow-band signals with SISO system, is investigated. The results show that the aerial users suffer and bring more interference than terrestrial users. The high probability of LoS condition leads to the vulnerability of aerial users to the interference signals.

Acknowledgements

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