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A Research on the Applicability of ADS-B Data Links in Near Space Environment

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***Abstract*—To test the applicability of ADS-B data links in near space environment, the channel propagation models of 1090ES and UAT (two kinds of ADS-B data links) in near space and in ground environment are proposed. Simulations of channel transmission performance of links between airplane and near space platform are conducted and an analysis of simulation results is made in aspects of path loss, signal to noise ratio and bit error rate. The results show that, within certain near space platform coverage, ADS-B data links can meet all conditions of aeronautical communication in near space communication environment.**

Keywords-ADS-B data links; near space; applicability; channel propagation model

I. INTRODUCTION

Automatic Dependence Surveillance-Broadcast (ADS-B) is an important broadcasting and regulatory service, and is classified as the "Critical service" of Air Traffic Control (ATC) by Federal Aviation Administration (FAA). Through the use of ADS-B, information acquisition of air-air aircrafts and information monitoring of air-ground aircrafts can be achieved, realizing a comprehensive and detailed understanding of the traffic conditions of the surrounding airspace. Currently among all the aeronautical data links that supporting ADS-B, the mainly used ones are Universal Access Transceiver (UAT) and 1090 MHz Mode S Extended Squitter (1090ES). The 1090ES data link is mainly for air transport and commercial aviation transport, while the UAT data link is mainly for general aviation [1].

With the growing needs of communication, near space communication is gaining more and more attention in the world. Air traffic management is an important task in near space communication field. To achieve this task, High-Altitude Platform System (HAPS) needs to support ADS-B service [2] and be equipped with ADS-B data link devices.

However, ADS-B data links are originally intended for communications between aircraft and aircraft, or between aircraft and ground stations. ADS-B data links do not necessarily apply to communications between HAPS and aircraft, for the reason that HAPS is in near space, which is quite different from ground environment, and environmental factor is critical to the performance of data link. Therefore analysis and verification of the applicability of ADS-B data links in near space environment is an important research problem in the field of aeronautical communications.

To test the applicability of ADS-B data links in near space environment, this paper proposes the channel propagation models of the 1090ES and UAT data links in near space and in ground environment respectively, and conducts a simulation of the channel transmission performance of links between airplane and HAPS in aspects of path loss, signal to noise ratio and bit error rate. It finally gives out the result and analysis.

II. HAPS-BASED ADS-B COMMUNICATION SYSTEM

The HAPS-based ADS-B communication system consists of a HAPS and multiple 1090ES airborne stations and UAT airborne stations. HAPS is usually located at the altitude of 20km to 25km, and the location is relatively fixed. HAPS equipped with both 1090ES and UAT data link devices, can communicate with the two kinds of aircrafts at the same time, realizing ADS-B service and aviation regulation. The HAPS-based ADS-B communication system is illustrated in Fig. 1.

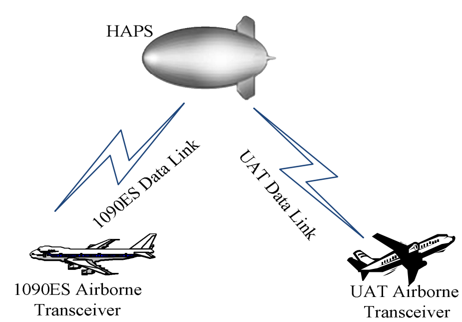

Figure 1. HAPS-based ADS-B system overview

III. PROPAGATION MODEL

To test the applicability of ADS-B data links in near space environment, it needs a comparative analysis of the difference between channel transmission performances of links in near space environment and in terrestrial environment. To do it, the channel propagation models of 1090ES and UAT data links in near space and in ground environment need to be made. Based on the model, it can examine whether the performance of 1090ES and UAT data links under near space can meet

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communication equipment's performance requirements in [3] and [4].

Channels in near space environment and terrestrial environment are both affected by free space propagation. In addition, each one is subject to other additional factors.

Because HAPS is in the stratosphere and aircraft in the troposphere, the link between aircraft and ground stations and link between aircraft and HAPS, are both influenced by near-Earth atmosphere, including atmospheric absorption and rain attenuation.

Due to the complexity of ground environment, ground station can receive multipath signal reflected by the ground. Therefore, signal propagation between aircraft and ground stations suffers from not only free-space propagation, but also multipath fading.

Compared to ground stations, HAPS locates in high altitude. If aircraft is located in medium or high altitude, the signal propagation between HAPS and aircraft can be viewed as line-of-sight propagation, affected only by free space loss. When the aircraft is located at low altitude (1km~3km), uplink between HAPS and aircraft is still a free-space propagation channel, while downlink additionally suffers from ground reflection, which cannot be ignored.

A. Atmospheric absorption and rain attenuation

In sunny weather, the atmosphere (mainly oxygen and water molecules) will bring additional absorption loss to radio wave propagation. For radio signal with frequency below 10GHz (the frequencies of 1090ES and UAT are both about 1GHz), the atmosphere absorption loss decay rate is less than 0.01dB/km. Considering that the distance between aircraft and HAPS or ground station is about 10km, absorption loss is less than 0.1dB. Compared with free space propagation loss, it can be ignored.

Rain attenuation is generated by the absorption and scattering of radio waves by rain and fog. For 1GHz signal, when rainfall is 150mm/h, rain attenuation rate is less than 0.01dB/km [5]. Similar with atmosphere absorption, rain attenuation in the propagation path between aircraft and HAPS or ground station is much less than the free space propagation loss. Therefore rain attenuation can be ignored.

B. Aircraft - ground station (air-ground) link's multipath fading

In air-ground communication, due to the complexity of terrestrial environment, ground station can receive multipath signals generated by ground reflection. Therefore, the air-ground communication channel is essentially a multi-path channel. However, because ground station is generally located in relatively open areas (e.g. suburbs), the received signal has a direct component. The direct component of the signal may also be obscured by barriers such as trees, power lines or high obstacles. Mathematical analysis shows that, the strength of received signal obeys Rician distribution under log Gaussian condition, and the phase obeys $[0, 2\pi]$ uniform distribution.

Test results of real satellite mobile communication links show that the strength of received signal is relevant to the elevation α of the receiver to the sender. However, due to the rapid movement of the aircraft relative to the ground, the elevation is constantly changing during the communication. Therefore, from the perspective of system design, it's desired that ground environment where ground station is located in can solely determine the average of the fading margin (average in different elevations). Assuming the ground station in the suburbs or non-open rural areas, according to a large number of foreign test data, it's estimated that when the validity of the received signal is 95%, the average fading margin is 8dB [6].

C. Aircraft – HAPS (air-air) link's ground reflection fading

When HAPS sends signals to aircraft flying at low altitude, radio signals received by the aircraft will be affected by ground reflected signal.

Different terrains have different affection on radio wave propagation, among which are mainly reflection, diffraction, and ground scattering. During the communication between HAPS and aircraft, ground scattering has little effect on the main beam, and diffraction is difficult to occur, so both can be neglected. Therefore here only the influence of ground reflection is considered. For simplicity, the ground covered in this article doesn't take into account the impact of earth's bump height. The scenario of ground reflection is shown in Fig. 2.

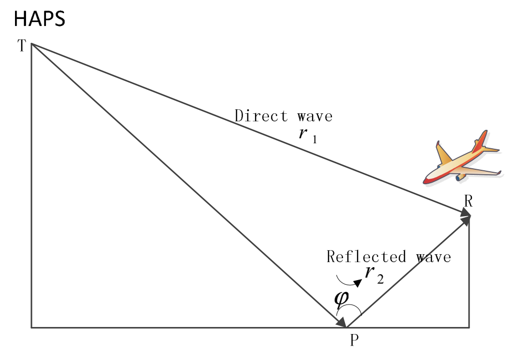

Figure 2. Ground reflection

At the signal receiving point R, the ratio of synthetic field intensity to free-space field intensity, is referred to as ground-reflection fading factor V. It can be expressed as follows:

$$V = \frac{E}{E_0} = \sqrt{1 + \phi^2 + 2\phi\cos\left[\varphi + \frac{2\pi}{\lambda}(\Delta r)\right]} \tag{1}$$

$$V_{dB} = 20\log V \tag{2}$$

Among the above equations, ϕ is the modulo of the reflection coefficient, φ is the phase angle of the reflection coefficient, $r_2 - r_1 = \Delta r$ represents the progressive inequality of the reflected wave and direct wave, and λ is the wavelength. If the reflection topography is city, mountain or forest areas, the reflection coefficient ϕ is about 0.3 [7].

IV. SIMULATION RESULTS

In the simulation, it's assumed that the environment is in the city, mountain or forest areas. According to the ITU-RF 1500 Recommendation, HAPS can stay in the stratosphere of 21km height and the elevation can reach 5 degree. Aircraft flies in a straight line and at a fixed height. The simulation scenario is shown in Fig. 3. There are two cases in the height of aircraft, which are 2km and 10km, corresponding to the aircraft in low and high altitude.

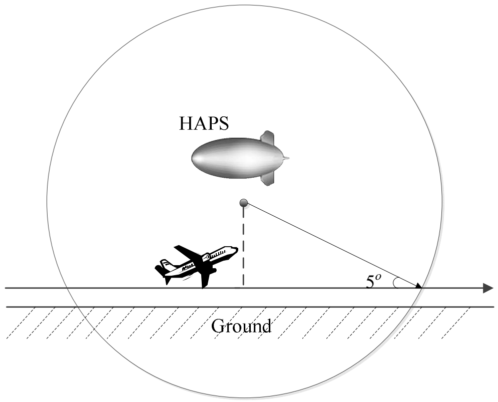

Figure 3. Simulation scenario

The transmit power and antenna gain of aircraft and HAPS are set up according to the performance parameters of 1090ES and UAT communication equipment of type A1 [3, 4]. The parameters used in the simulation are shown in Table 1.

TABLE I. SIMULATION PARAMETERS

Simulation parameters	Values
UAT Transmit Power	12dB
1090ES Transmit Power	21dB
Transmit / receive antenna gain	0dB
UAT Radio frequency	978MHz
1090ES Radio frequency	1090MHz
Receiving antenna elevation	Uniform
Receiver noise	-130.7dB [3]
Ground-reflection coefficient	0.3

A. *Ground reflection fading*

Fig. 4 and Fig. 5 respectively show ground reflection fading of 1090ES data link and UAT data link changing with receiver elevation. It can be seen from the figures, as the receiving antenna elevation changes, the distance between aircraft and HAPS changes, resulting in the dramatic change of ground reflection fading. The ground reflection fading has both positive and negative value, which conforms to the Fresnel zone theory. For 1090ES data link and UAT data link, ground reflection fading looks almost the same. The maximum positive fading values of two kinds of data link are both approximately 2.3dB, and the maximum negative fading values are both -3.1dB.

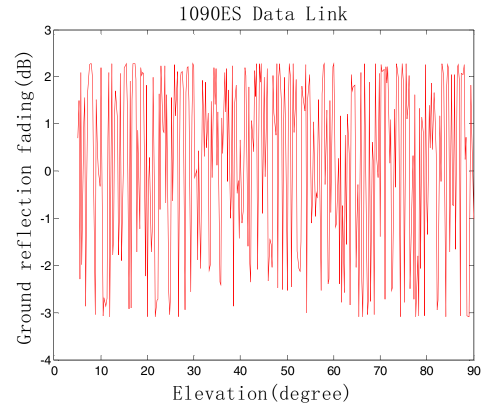

Figure 4. Ground reflection fading of 1090ES data link

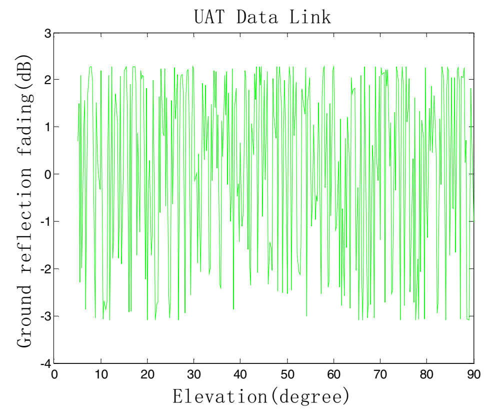

Figure 5. Ground reflection fading of UAT data link

B. *Path loss*

Fig. 6 and Fig. 7 respectively show path loss of 1090ES data link and UAT data link changing with receiver elevation. It can be seen from the figures, as the receiving antenna elevation increases, the distance between aircraft and HAPS decreases, leading to the path loss decreases. When aircraft flies in high altitude, the path loss is less than in low altitude. This is because the propagation distance of the former one is shorter, leading to less free space loss. When aircraft flies in low altitude, the signal attenuation of HAPS-aircraft downlink suffers severe jitter because of the affection of ground reflection fading.

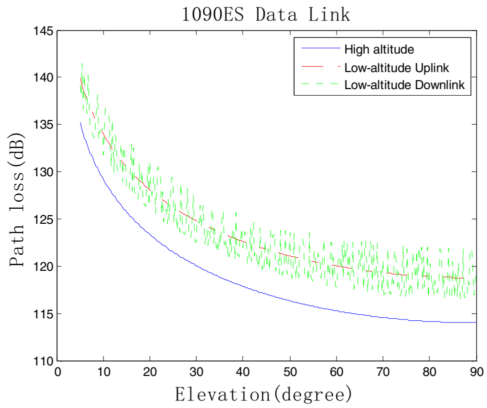

Figure 6. Path loss of 1090ES data link

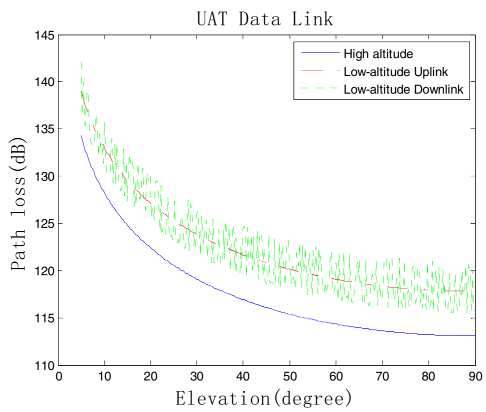

Figure 7. Path loss of UAT data link

C. *Signal to noise ratio*

According to the signal to noise ratio (SNR) calculation formula, we can obtain the SNR of 1090ES data link and UAT data link changing with receiver elevation, as shown in Fig. 8 and Fig. 9. It can be seen from the figures, because the noise is definite, the signal to noise ratio of receiving signal increases with the elevation increases.

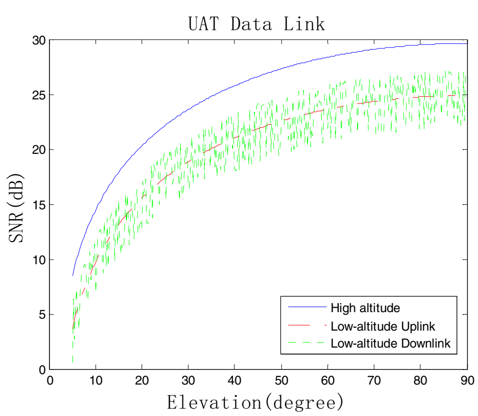

Figure 8. SNR of UAT data link

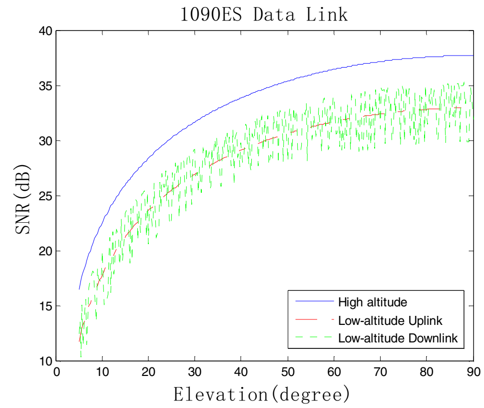

Figure 9. SNR of 1090ES data link

D. *Bit error rate*

The modulation used for UAT data link is GFSK and PPM for 1090ES. The bit error rate formulas of GFSK and PPM [8, 9] are as follows:

$$P_{GFSK} = a \cdot \exp(-(\frac{SNR}{b})^{c}) \tag{3}$$

$$P_{PPM} = \frac{1}{\sqrt{\pi} \times SNR} \cdot \exp(-\frac{1}{4} \times SNR^{2}) \tag{4}$$

In (3), the values of a, b and c are respectively 0.5724、1.5268、0.9377 [8]。*SNR* represents signal to noise ratio.

According to the formula, we can obtain the bit error rate of 1090ES data link and UAT data link changing with receiver elevation in near space environment, as shown in Fig. 10 and Fig. 11.

It can be seen from the figures, as the receiving antenna elevation increases, the bit error rate of two data links decreases. However, the maximum bit error rate of 1090ES data link is much less than that of UAT data link, and the speed of decrease is very fast. After the elevation reaches to 10^{o}, the bit error rate of 1090ES data link has become infinitesimal.

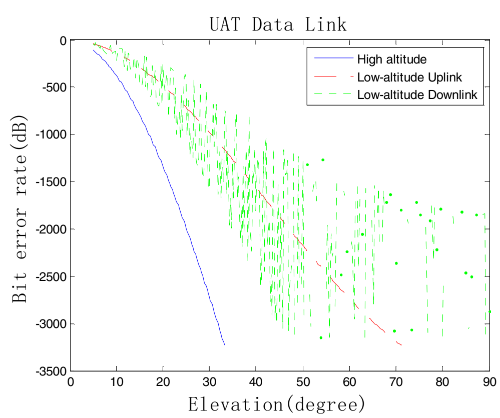

Figure 10. Bit error rate of UAT data link

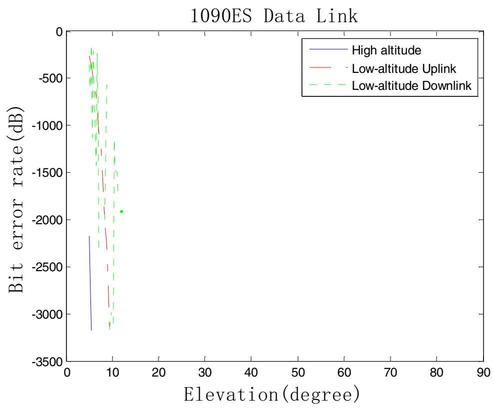

Figure 11. Bit error rate of 1090ES data link

V. SIMULATION ANALYSIS

According to the simulation results, a comparative analysis of the difference between channel transmission performances of aircraft-HAPS link (air-air link) and aircraft to ground stations links (air-ground link) can be made.

When aircraft flies at a high altitude of 10km, with the same receiver elevation, the propagation distances of the two links are equal, so are free space losses. However, the multipath fading of air-ground link is 8dB more than that of air-air link, so with aircraft at high altitude, the transmission performance of air-air links is better than the air-ground links.

When aircraft flies at a low altitude of 2km, with the same receiver elevation, because the propagation distances of the two links are quite different, the path loss of air-air uplink is 11dB more than that of air-ground link, while the path loss of air-air downlink may be 14dB more than that of air-ground link duo to ground reflection fading. Therefore with aircraft at low altitude, the transmission performance of air-air link is worse than the air-ground link.

Transmit power of 1090ES A1 device is 21dB and receiver threshold is -109dB; Transmit power of UAT A1 device is 12dB and receiver threshold is -123dB. Therefore path loss can be 130dB at most for 1090ES data link, and 135dB for UAT data link. It can be seen from the simulation results of path loss, when aircraft flies at a high altitude of 10km, for 1090ES data link receiver elevation can reach 9^o at most, while for UAT data link it can reach HAPS's minimum elevation angle (5^o). When aircraft flies at a low altitude of 2km, for 1090ES uplink receiver elevation can reach 16^o at most, and it can reach 22^o at most for 1090ES downlink. Meanwhile for UAT uplink receiver elevation can reach 8^o at most, and 10^o for UAT downlink.

In addition, according to the digital communications requirements, if the bit error rate is less than 10^{-6}, it's basically feasible to recover the source signals in the end. It can be seen from the simulation results of bit error rate, the maximum bit error rate for 1090ES data link is -136dB, which can meet the requirements. However, when aircraft flies at a low altitude of 2km, the maximum bit error rate for UAT data link cannot meet the requirements. To meet the requirements, receiver elevation for UAT low-altitude downlink mustn't be less than 6.5^o , and 9^o for low-altitude uplink, which path loss's limits on the receiver elevation have already meet under the same conditions.

In summary, when aircraft flies at a high altitude, the performance of data link in near space is better than that in ground environment. However, the scope of application of 1090ES data link cannot achieve the maximum coverage of HAPS. When aircraft flies at a low altitude, the performance of data link in near space is worse than that in ground environment, and the scope of application of 1090ES data link or UAT data link can neither achieve the maximum coverage of HAPS. Nevertheless, in certain HAPS coverage, regardless of aircraft in a high-altitude or low-altitude, both 1090ES and UAT data links are applicable.

VI. CONCLUSION

This paper focuses on the applicability of ADS-B data links in near space environment, proposes the channel propagation models of 1090ES and UAT data links in near space and in ground environment, simulates the channel transmission performance of links between airplane and HAPS, and makes an analysis of simulation results in aspects of path loss, signal to noise ratio and bit error rate. The results show that, within certain HAPS coverage, regardless of aircraft in a high-altitude or low-altitude, both 1090ES and UAT data links are applicable, and with aircraft in a high-altitude, the performance of data link in near space is better than that in ground environment.

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