Communication Link Characteristic Analysis of Aircraft-Ground Station

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***Abstract* - In air satellite mobile communication, aeronautical channel characterization usually includes parking scenario, en-route scenario, taxi scenario, arrival/take-off scenario, etc. This paper mainly analyzes the fading types, power spectrum density and delay characterization of communication channel, and provides typical parameter of air-ground station communication model.**

I. Introduction

In wireless communication, it is generally known that the problem of multi-path transmit between the receiver and the transmitter can cause multi-path effects [1]. The aeronautical channel is usually considered to consist of direct line-of-sight (LOS) path and multi-path propagation, which is called Rice fading channel. And the multi-path propagation part is generated by the reflecting and scattering of microwave in the transmitting environment. Besides the channel characterization that general satellite mobile communication has, air satellite mobile communication has other special characterizations: on one hand, the airframe reflecting, the ground/sea reflecting and the LOS part cannot be blocked; on the other hand, since during one arrival/take-off process, the aircraft needs to experience taxi scenario, take-off scenario, flying over ground station scenario, en-route scenario and arrival scenario with different communication conditions. In the aircraft-ground station communication, different scenarios of aircraft can generate different fading types [2-4]. Generally, in the parking scenario, because of the influence of the parking apron and hangar, LOS does not exist, which can lead to Rayleigh fading—the worst fading type. And in other scenarios, the received signal usually includes LOS and scattering part, which can lead to Rician fading. So it is necessary to model and research each scenario [5]. This paper mainly analyzes aircraft-ground station communication link characterization different scenarios.

II. AIRCRAFT-GROUND STATION COMMUNICATION CHANNEL CHARACTERIZATION

In the aircraft-ground station communication, different status of aircraft can lead to different characterizations which are determined by fading types, Doppler spectrum and the delay characterization, etc. And the multi-path characterization of scattering is determined by Doppler power spectrum and delay power spectrum, but it is necessary to consider the LOS part and the scattering part separately. To construct exact channel model, aeronautical channel is generally considered to consist of parking scenario, en-route scenario, taxi scenario, arrival/take-off scenario [5, 6]. When aircraft is on the parking apron, in the hangar or moves at quite low speed, it is usually regarded as the parking scenario. Because of the influence from buildings around, no LOS signal exists between aircraft and ground station. At this time, the channel is fully made up of the scattering part, which corresponds to the typical COST-207 urban fading environment. When aircraft is in the taxi scenario, the environment around is comparatively broad, and therefore the channel is considered to consist of the LOS part and the scattering part, which corresponds to the typical COST-207 rural fading environment. When aircraft is in the en-route(after aircraft is off ground), the communication can possibly happen between aircraft and ground station, in which the channel consists of LOS part and scattering part, and the LOS part is dominant. The arrival/take-off scenario describes the process in which aircraft leaves the altitude and speed of the en-route scenario and is going to land, or aircraft leaves the speed of the taxi scenario and is going to take off. This scenario is usually influenced by the shadow by the building around the airport, but the influence extent is between that of the en-route scenario and the taxi scenario [7].

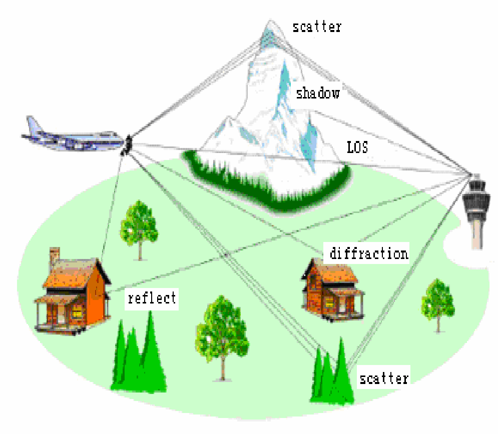

Fig. 1 Different scenarios of aeronautical channel.

These different scenarios can be defined by the fading type, Doppler power spectrum and delay power spectrum. The ratio of the LOS power and the scattering power is called Rice factor: $K_{Rician} = a^2 / c^2$, a^2 is the LOS power, c^2 is the multi-path average power. If K_{Rician} tends to be 0, it will be

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Rayleigh fading. On the other hand, if it tends to be infinite, it will be Additive White Gaussian Noise [8, 9].

En-route scenario

The en-route scenario is the process in which aircraft is in the air and meanwhile communicates with ground station or with other aircrafts. When aircraft is in the air, channel is supposed as a two-ray model, in which one ray is the LOS signal and the other ray is the Rayleigh fading scattering signal. Moreover, the relative speed between the receiver and the transmitted is quite high. Meanwhile, the scattering part distributes non-uniformly, which means that the beam width is less than 360°, and 3.5° is generally supposed to be the beam width for calculating.

(1) Fading type: approximately the direction of aircraft is on the same line with the transmitting direction of the radio wave, which means that the LOS signal is at the direction of the tail or nose of aircraft. And K_{Rician} is equal to 2～20dB, and the typical value is 15dB. The scattering signal is Rayleigh process.

(2) Doppler power spectrum: the en-route is the process with rapid decline. Since the multi-path signal is not all-directional, which leads to the result that the Doppler power spectrum does not satisfy the Jakes spectrum. It is considered that the direction of multi-path signal is reverse to that of the LOS signal. And the beam width of multi-path signal is 3.5° and distributes uniformly, which means that the Doppler spectrum is not 0 within 3.5° , and satisfies Jakes spectrum.

$$p_{f_D}(f_D) = \frac{1}{\pi f_{D_{\max}} \sqrt{1 - \left(f_D / f_{D_{\max}}\right)^2}} \quad |f_D| < f_{D_{\max}} \tag{1}$$

When $0 \le \varphi_{\alpha_L} < \varphi_{\alpha_H} \le \pi$, （$\varphi_{\alpha_L}, \varphi_{\alpha_H}$ are the minimum arrival angle and the maximum angle）,

$$p_{f_D}(f_D) = \frac{1}{\left(\varphi_{\alpha_H} - \varphi_{\alpha_L}\right) f_{D_{\max}} \sqrt{1 - \left(f_D / f_{D_{\max}}\right)^2}} \quad f_{D_{\max}} \cos\varphi_{\alpha_H} < f_D < f_{D_{\max}} \varphi_{\alpha_L} \tag{2}$$

When $\pi \le \varphi_{\alpha_L} < \varphi_{\alpha_H} \le 2\pi$,

$$p_{f_D}(f_D) = \frac{1}{\left(\varphi_{\alpha_H} - \varphi_{\alpha_L}\right) f_{D_{\max}} \sqrt{1 - \left(f_D / f_{D_{\max}}\right)^2}} \quad f_{D_{\max}} \cos\varphi_{\alpha_L} < f_D < f_{D_{\max}} \varphi_{\alpha_H} \tag{3}$$

(3) Multi-path delay power spectrum: suppose typical altitude of aircraft is 10km,and the max delay of air-ground communication is $\tau_{\max} = 33us$, and the delay of air-air communication is $\tau_{\max} = 66us$.

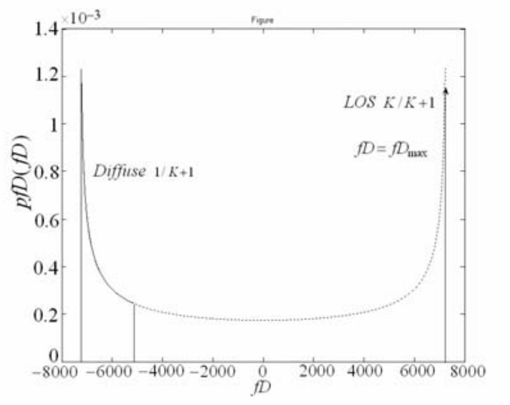

Fig. 2 Doppler power spectrum of en-route scenario

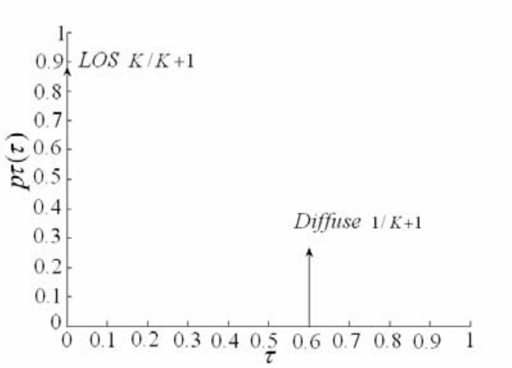

Fig. 3 Multi-path delay power spectrum of en-route scenario

Arrival/Take-off scenario

The arrival/take-off describes the process in which aircraft leaves the speed and altitude of the en-route scenario and is going to land, or leaves the axis scenario and is going to take off. This stage is between the en-route scenario and the taxi scenario. The arrival scenario is similar with the take-off scenario, so just the arrival scenario is analyzed in this paper.

(1) Fading type: the LOS signal is stronger and the typical value of K_{Rician} is 15dB. The scattering signal mainly comes from buildings around airport, and is Rayleigh process. The channel model can also be equivalent to Rician channel. The channel fading characterization is shown in the figure below.

(2) Doppler power spectrum: since no strong multi-path signal exists, thereby the angle of the multi-path signal distributes between 0 degree and 180 degrees and the Doppler power spectrum is the standard Jakes spectrum.

$$P_\tau(\tau) = \begin{cases} \dfrac{1}{\tau_{slope}(1 - e^{-\tau_{\max}/\tau_{slope}})} e^{-\tau/\tau_{sople}} & 0 < \tau \le \tau_{\max} \\ 0 & other \end{cases} \tag{4}$$

(3) Delay power spectrum: approximately meets the exponential distribution.

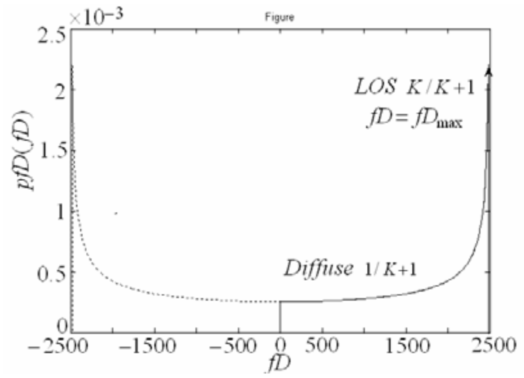

Fig. 4 Doppler power spectrum of arrival/take-off scenario

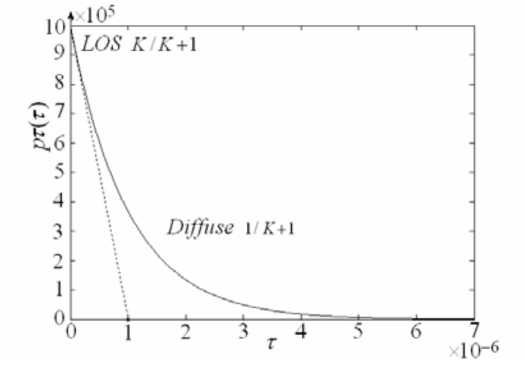

Fig. 5 Delay power spectrum of arrival/take-off

Taxi scenario

Taxi scenario describes the process in which aircraft moves towards or leaves the termination. ◦ In taxi scenario, the speed of aircraft is generally less than 15 m/s , and the highest speed is no more than 50 m/s. In this scenario, the angles of all reflecting signals distribute uniformly around aircraft. And the scattering signal is considered to distribute uniformly within 360°. Meanwhile, the LOS signal arrives from the front of aircraft with certain angle, which can lead to the carrier frequency of the LOS signal is close to : $f_{D_{LOS}} = 0.7 f_{D_{max}}$. The Doppler power spectrum, the delay power spectrum and the Rician factor is based on the model of no mountains.

(1) Fading type: the channel characterization of taxi scenario can be described by Rician distribution. The typical value of K_{Rician} is 6.9dB.

(2) Doppler power spectrum: the taxi scenario is the process of slow fading, and the multi-path signal distributes uniformly between 0°and 360°. The LOS signal arrives from the front of aircraft with certain angle, which can lead to the carrier frequency of the LOS signal is close to: $f_{DLOS} = 0.7 \cdot f_{D\max}$.

(3) Delay power spectrum: the delay power spectrum meets the exponential distribution, which can refer to rural environment parameters of COST-207 model. And the maximum multi-path time delay is $\tau_{\max} = 0.7us$, and the path distance is $\Delta d = 2100$ m. Meanwhile, the multi-path time delay decreases according to the time slope $\tau_{slope} = 1/9.2us$.

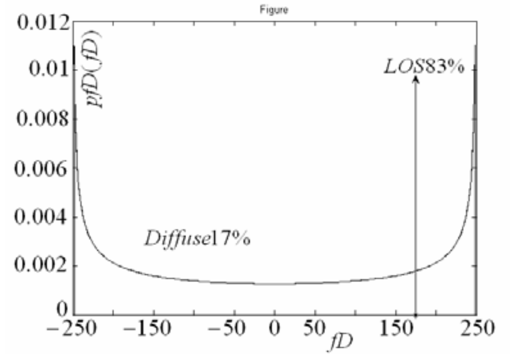

Fig. 6 Doppler power spectrum of taxi scenario

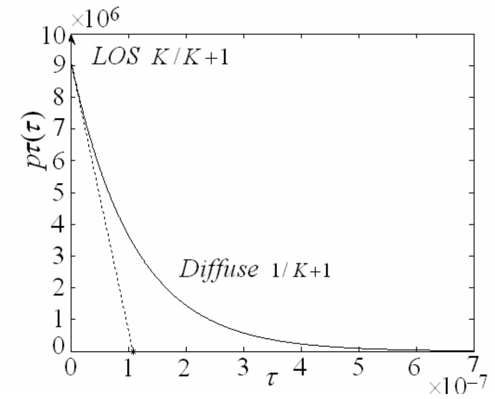

Fig. 7 Delay power spectrum of taxi scenario

Parking scenario

The parking scenario describes the process in which aircraft moves at quite low speed towards or away from the termination. And the LOS signal does not exist so that Rayleigh fading exists, which is the worst supposition. In this scenario, aircraft stops or moves at the speed of less than 5.5 m/s, so the carrier Doppler frequency is quite small.

(1) Fading type: the LOS signal is blocked, so the type is Rayleigh fading. Because the density of aircrafts in the airport is quite high, therefore it is not always possible for ground station to see the aircraft, which is also the worst condition. And the fading is selective frequency fading.

(2) Delay power spectrum: it meets the Jakes spectrum. Since the Doppler frequency is quite low, the shape of power spectrum is nearly not influenced, and the multi-path angle distributes uniformly between 0 degree and 360 degrees.

(3) Delay power spectrum: the delay power spectrum meets the exponential distribution, which can refer to urban environment parameters of COST-207 model. And the

maximum multi-path time delay is $\tau_{max} = 0.7us$, and the path distance is $\Delta d = 2100$ m. Meanwhile, the multi-path time delay decreases according to the time slope $\tau_{slope} = 1/9.2us$. The typical simulation parameter for aircraft-ground station communication channel model is shown in table I [5].

TABLE I
THE TYPICAL SIMULATION PARAMETER FOR AIRCRAFT-GROUND STATION COMMUNICATION CHANNEL MODEL

	Parking scenario	*Taxi scenario*	*Take-off scenario*	*Enroute scenario*
Aircraft speed v [m/s]	0---5.5 Typical value: 5.5	0-----15 Typical value:15	25--150 Typical value:85	17--440 Typical value:250
Maximum time delay [us]	7.0	0.7	7.0	6---200 Typical value:33
Number of path N	20	20	20	20
Rician factor [dB]	--	6.9	9----20 Typical value:15	2-----20 Typical value:15
$f_{D_{LOS}} / f_{D_{max}}$ factor	--	0.7	1.0	1.0
Start angle of beam [°]	0.0	0.0	-90.0	178.25
End angle of beam φ_{α_H} [°]	360.0	360.0	+90.0	181.75
Delay function of multi-path	exp	exp	exp	exp
Change rate of Time delay [us]	1.0	1/9.2	1.0	--

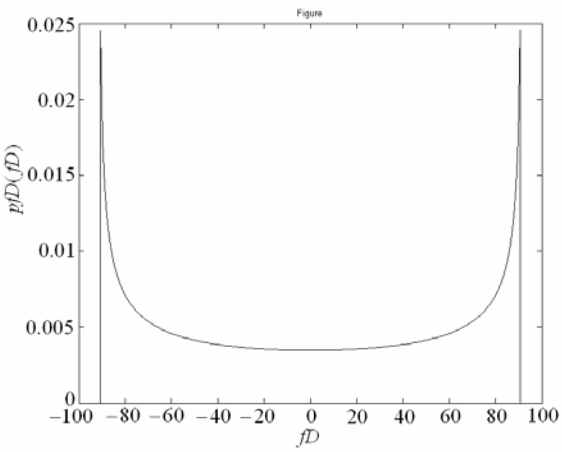

Fig. 8 Doppler power spectrum of parking scenario

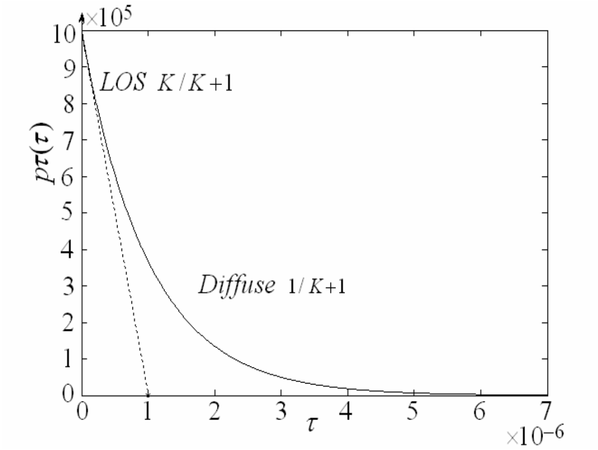

Fig. 9 Delay power spectrum of parking scenario

III. CONCLUSION

In the aircraft-ground station communication, different scenarios of aircraft can lead to different channel characterizations, different fading types, Doppler spectrum and delay extend characterizations, etc[10]. Meanwhile, the characterization of the scattering multi-path is determined by Doppler characterization and delay extend characterization. To construct exact channel model, aeronautical channel model is usually divided into parking scenario, en-route scenario, taxi scenario, arrival/take-off scenario, etc. This paper mainly analyze fading type, power spectrum and delay extend characterization of the communication link channel characterization in four typical scenarios of aircraft, and at the end this paper provides typical aircraft-ground station channel model parameter.

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