Proceedings of APCC2008 copyright © 2008 IEICE 08 SB 0083

Research on the Cancellation of Doppler Offset by Information Aid for Aviation Mobile Broadband Communication

Wu Xian[1], Zhang Jun[2], Liu Zhongkan[3]

[1 2]School of Electronic Information Engineering, Beijing University of Aeronautics and Astronautics, Beijing, China

[3] School of Science, Beijing University of Aeronautics and Astronautics, Beijing, China

[1]wuxian@ee.buaa.edu.cn [2]buaazhangjun@vip.sina.com [3] zkliu4129@buaa.edu.cn

***Abstract-* A new method, IAADO (Information-Aided Anti-Doppler-Offset), aiming at eliminating ICI (Inter-Channel-Interference) caused by DFO (Doppler Frequency Offset) and improving the performance of AMBC (Aviation Mobile Broadband Communicaiotn), is presented with a view to the characteristics of the high DFO of aviation channel and the aircraft as a platform of AMBC. The strong ICI caused by large DFO, degrades the performance of AMBC badly. And the DFO can be computed by the aid information, the position and the velocity vector of its own and the positions and the velocity vectors of the aircrafts or ground stations around, which is derived from equipments onboard, such as navigatioin equipments and surveillance equipments, in real time or near real time. According to that the compensation can be done at the receiver, although it is of uncertainty. In this paper, the performance of information-aided cancellation of ICI caused by DFO is analyzed, and the effect of the uncertainty of aid information is investigated also. The simulation results show that the combined method which combines the estimation and IAADO based on aid information with uncertainty, resolves the ICI caused by DFO effectively, and makes AMBC get better performance in high-speed movement, i.e. En_route phase and Arrival phase.**

Keywords: Aviation Mobile Communication, OFDM, Doppler Effect, Information Aid, ICI

I. INTRODUCTION

The future of aviation mobile communication is being developed to broadband, and OFDM(Orthogonal Frequency Division Multiplexing) will be the key technique of realizing AMBC, for it has been used widely in the ground communication system, because of its high frequency efficiency, high transmision speed and the capability of suppressing multipath interference. Now, B-VHF (Broadband VHF) is on the way[1].

But, the characteristics of the aviation channel with high DFO and large delay expand challenge the application of OFDM in AMBC.

In general, the ISI(Inter Symbol Interference) caused by multipath delay expansion can be totally suppressed by the properly designed symbol duration and cyclic repetition. But the movement speed of an aircraft is very high, so the high DFO caused by it destroys the orthogonality among the subcarriers, leading to severe ICI, which degrades the performance of AMBC.

In order to decrease the ICI caused by DFO, three kinds of main methods have been presented. The first method is based on channel estimation [2][3], the second one is doppler frequency diversity [4][5], and the third is ICI self-cancellation [6][7].

The method based on channel estimation, usually uses pilot signal or training sequence, and the estimation only takes effect within some range of channel variety. If the variation of channel is beyond the designed parameters, the performance of estimation and restoration becomes bad, or even takes no effect. The only way to improve the capability is to increase the density of pilot signals at a cost of decrease the effective bandwidth. For example, under the condition of the time-varying channel rooted in high DFO, it takes more pilots on the time dimension to reach workable performance, hence the utilization of channel becomes less. And in some excessive case, it is of no use on the increase- ment of pilot to gain the improved capability.

With regard to the method based on doppler frequency diversity, the performance of the method in[4] varies greatly with DFO, and the method in [5] is stable but it requires veracious DFO and the calculation is large.

ICI self-cancellation takes several subcarriers to transmit one symbol so as to make frequency efficiency low.

So, in this paper, IAADO, which uses aid information to eliminate the DFO in order to improve the performance of AMBC, is presented.

As the platform of AMBC, an aircraft owns many equipments, such as Navigation equipments and Surveillance equipments, on, which can offer the information of its own postioin and velocity, and the information of postioin, velocity and movement intention of surrounding aircrafts and ground stations in real time or near real time. The information of position and velocity is called aid information, by which DFO of received signal can be computed, which compensates the received signal through the aviation channel to eliminate ICI and improve the performance of AMBC.

The organization of this paper is as follows. In Section II, the system model is introduced. In the Section III, the compensation method of DFO is presented. In Section IV, simulation results are presented and analyzed. Sectioin V concludes the paper.

This work was supported by the National Nature Science Foundation of China under Grant No. 60532030 and 60625102.

II. SYSTEM MODEL

A. System Structure

Fig.1 shows the system model, which includes transmission modules, receive modules and channel modules. On the left of the vertical dashed line, the common OFDM system model is presented. On the right of the dashed line, a new cross-system module is introduced, which collects the aid information from other equipments, such as navigation equipments and surveillance equipments. Other equipments are defined as equipments which can provide the information of position, velocity and acceleration of its own and surrounding aircrafts and ground stations. This module collects the aid information, computes DFO and compensates the received signal.

Since there is uncertainty in the aid information, because of the uncertainty of the data from those equipments, the effect of the uncertainty is investigated in the next sectioin and the performance is analyzed by simulation in Section IV.

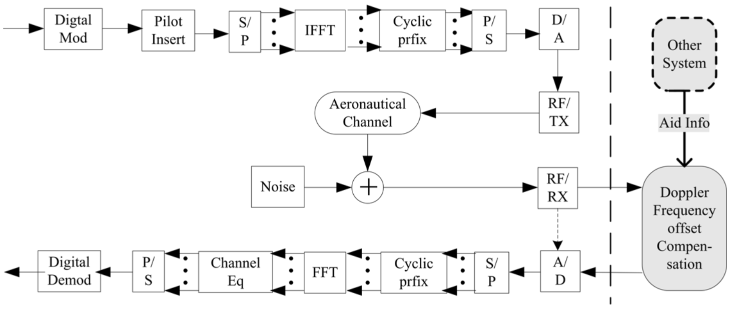


Fig. 1 System Model

B. Aviation Channel

Aviation channel is a time-varying and multipath channel, described in Eq.(1).

$$h(\tau,t)=\sum_{p=0}^{P-1} r_p e^{j(2\pi t f_{d_p}+\varphi_p)}\delta(\tau-\tau_p) \qquad (1)$$

There are P paths between the transmitter and the receiver, r_p is the gain of each path, f_{dp} is the DFO of each path, φ_p is the initial phase of each path, and τ_p is the delay of each path. Without loss of generalirity, φ_p can be set to 0.

In [8], the aviation channel can be modeled as four typical scenarios, i.e. Enr (En_route), Arrival, Taxi and Parking. In these four typical scenarios, Enr and Arrival are the scenarios, in which an aircraft moves in a high speed, and large DFO occurs.So, the Enr and Arrival scernarios are the scenarios that our research is focused on. The similarity of these two scenarios is that the paths can be devided into two kinds, one LOS (Line-Of-Sight), the other NLOS (Non-Line-Of-Sight), and the LOS is the direct path containing main transmission power.

Without loss of generality, the path of p=0 is assumed as LOS path, and τ_0=0. And K_{RICE} is defined in Eq.(2).

$$K_{RICE}=10\log_{10}\left(\frac{r_0^2}{\sum_{p=1}^{P-1} r_p^2}\right)dB\,,\quad K_{RICE}\in[2,20] \qquad (2)$$

C. Compute DFO by Information Aid

According to the theory of electromagnetic wave, the DFO is computed by Eq.(3), as shown in Fig.2, by the aid information of transmitter's position (POS_S) , velocity (v_1) and receiver's position (POS_R) , velocity(v_2), if they are veracious and timely.

$$f_d=\frac{f_c}{c}(v_1\cos\theta_1-v_2\cos\theta_2) \qquad (3)$$

θ_1 -- angle between $\overrightarrow{v_1}$ and $\overrightarrow{SR}$

θ_2 -- angle between $\overrightarrow{SR}$ and $\overrightarrow{v_2}$

$\overrightarrow{SR}=POS_R-POS_S$

Nevertheless, POS_R and v_2 from navigation equipments onboard, POS_S and v_1 from surveillance equipments onboard, are all of uncertainty, and $E_{pos\text{-}R}$, Δv_2, $E_{pos\text{-}S}$ and Δv_1 are their maximal errors respectively.

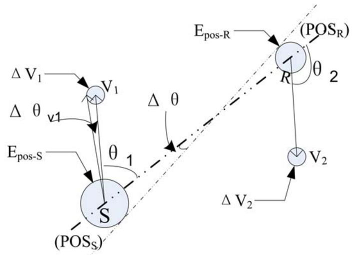


Fig. 2 Computing Relative Velocity by Information Aid

So, DFO of main path, with uncertainty, $\tilde{f}_d$, is computed in Eq.(4). The max error and relative error of DFOs, $\boldsymbol{\Delta f_d}$ and $\boldsymbol{\delta f_d}$, is computed in Eq.(5) and Eq.(6) respectively. The value range of $\boldsymbol{\Delta\theta}$, $\boldsymbol{\Delta\theta_{v1}}$ and $\boldsymbol{\Delta\theta_{v2}}$ are shown below. The error of velocity ($\boldsymbol{\Delta v_1}$, $\boldsymbol{\Delta v_2}$) outputed from navigation equipments after mergence is little, that is less than 0.6m/s(not more than 0.4% comparatively) usually, and the error of position data from navigation equipments after mergence is no more than 25m (in the case of WAAS(Wide Area Augmentation System)), that approaches to 10% comparatively (the distance between two high-sppeed aircatfs is more than 500m generally). So the relative error mainly due to $\boldsymbol{\Delta\theta}$. Fig.3 shows the distribution change of relative error of DFO in typical velocities.

$$\tilde{f}_d=f_c(\tilde{v}_1\cos\tilde{\theta}_1-\tilde{v}_2\cos\tilde{\theta}_2)/c \qquad (4)$$

$$\begin{aligned}\Delta f_d&=\left|\frac{\partial f_d}{\partial v_1}\right|\Delta v_1+\left|\frac{\partial f_d}{\partial\theta_1}\right|(\Delta\theta+\Delta\theta_{v1})\\&\quad+\left|\frac{\partial f_d}{\partial v_2}\right|\Delta v_2+\left|\frac{\partial f_d}{\partial\theta_2}\right|(\Delta\theta+\Delta\theta_{v2})\\&=(\left|\cos\theta_1\right|\Delta v_1+\left|v_1\sin\theta_1\right|(\Delta\theta+\Delta\theta_{v1})\\&\quad+\left|\cos\theta_2\right|\Delta v_2+\left|v_2\sin\theta_2\right|(\Delta\theta+\Delta\theta_{v2}))\end{aligned} \qquad (5)$$

$$\begin{aligned}\delta f_d&=\frac{\Delta f_d}{f_d}=\frac{1}{\left|(v_1\cos\theta_1-v_2\cos\theta_2)\right|}\\&\quad(\left|\cos\theta_1\right|\Delta v_1+\left|v_1\sin\theta_1\right|(\Delta\theta+\Delta\theta_{v1})\\&\quad+\left|\cos\theta_2\right|\Delta v_2+\left|v_2\sin\theta_2\right|(\Delta\theta+\Delta\theta_{v2}))\end{aligned} \qquad (6)$$

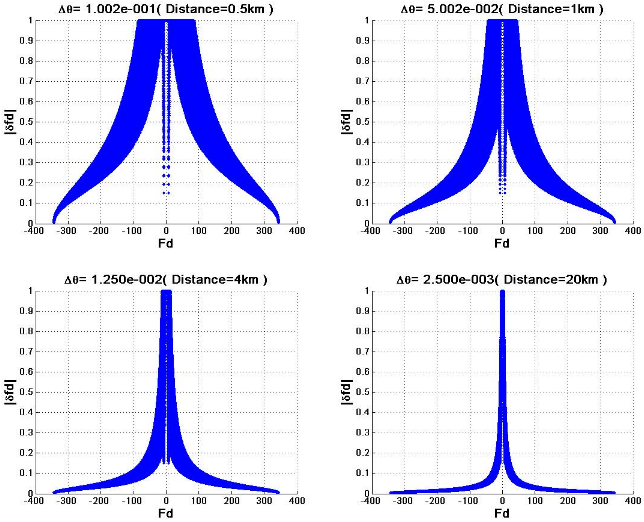
$$\Delta\theta_{\max} = \left| \arcsin\left(\frac{E_{pos-R} + E_{pos-S}}{\left|POS_R - POS_S\right|}\right) \right| \leq 0.1$$

$$\Delta\theta_{v1-\max} = \left| \arcsin\left(\frac{\Delta v_1}{v_1}\right) \right| \leq 0.004$$

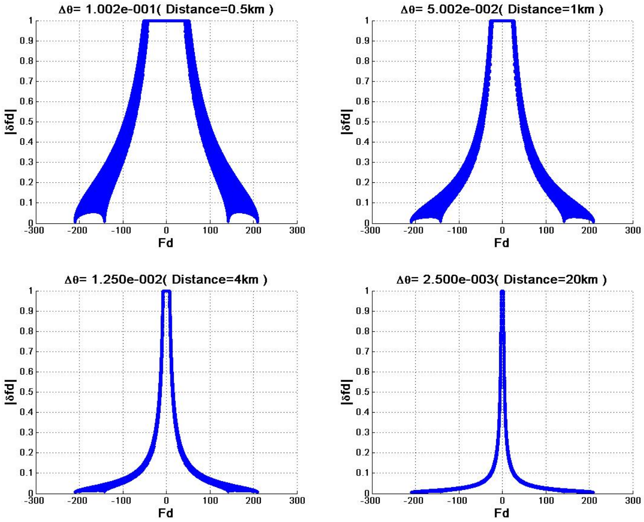
$$\Delta\theta_{v2-\max} = \left| \arcsin\left(\frac{\Delta v_2}{v_2}\right) \right| \leq 0.004$$

$$\theta_1, \theta_2 \in [0, 2\pi)$$

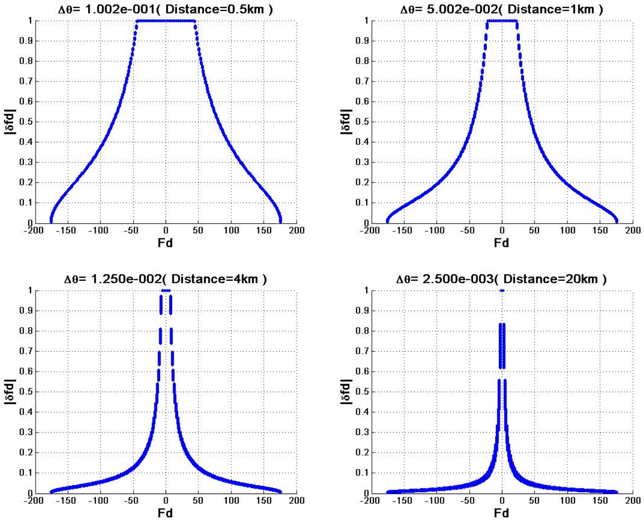
The four charts in each Fig.3 (a), (b),(c) and (d), show the same trend of distribution change of relative error of DFO with ***Δθ***, that is the bound of F_d within which the large bias occurs, becomes close to zero with decrease of ***Δθ*** because of the increase of distance between transmitter and receiver, no matter what the velocities of the transmitter and receiver are high or low. In summary, the less the value of ***Δθ*** is, the less effect on $|\delta f_d|$ the variation of F_d takes. And a receiver will not suffer from large $|\delta f_d|$ when the transmitter is at a normal distance and with a comparatively large enough $|F_d|$, which makes high ICI.



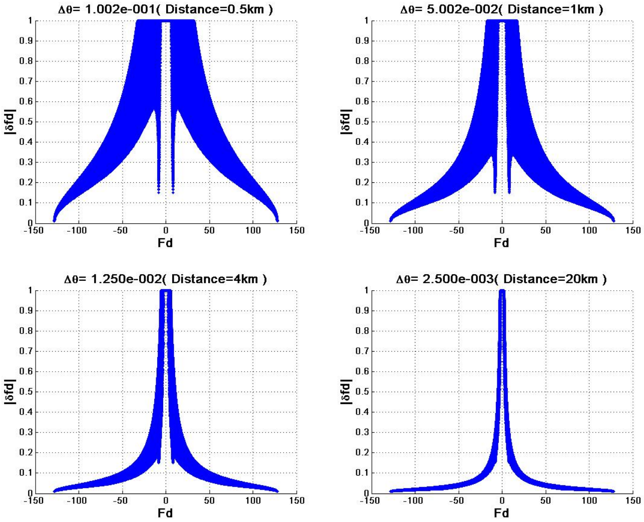
(a) V₁= 440m/s V₂ = 420m/s



(b) V₁= 440m/s V₂ = 85m/s



(c) V₁=440m/s V₂ = 0m/s



(d) V₁= 150m/s V₂ = 170m/s

Fig. 3 Distribution of relative error of DFO

III. COMPENSATION OF DFO

Based on DFO of main path computed by aid information, the method of IAADO (Information-Aided Anti-Doppler- Offset) at receiver to compensate DFO is presented.

The typical equivalent expression of baseband OFDM transmitted signal is described in Eq.(7),

$$x_C(t) = \frac{1}{\sqrt{T_S}} \sum_{k=0}^{N-1} S_k e^{j2\pi tk/T_S} u(t) \qquad (7)$$

where S_k is digital modulated symbol on the kth subcarrier, and *Ts* is the OFDM symbol length. The received signal through the time-varying channel is described in Eq.(8).

$$\begin{aligned} y(t) &= h(t,\tau) * x_C(t) + w(t) \\ &= \sum_{p=0}^{P-1} r_p e^{j2\pi t f_{d_p}} x_C(t-\tau_p) + w(t) \end{aligned} \qquad (8)$$

It is assumed that $\tau_p \leq T_g$, so there is no ISI. The received symbol y_m on the m*th* subcarrierr is computed in Eq.(9) and Eq.(10).

$$y_m = \frac{1}{\sqrt{T_S}} \int_0^{T_S} y(t) e^{-j2\pi mt/T_S} dt \qquad (9)$$

$$
\begin{aligned}
y_m = \frac{1}{T_S}(r_0 S_m \int_0^{T_S} e^{j2\pi t f_{d_0}} dt \\
+ \sum_{k=0,k\neq m}^{N-1} r_0 S_k \int_0^{T_S} e^{j2\pi t(f_{d_0}+(k-m)/T_S)} dt \\
+\sum_{p=1}^{P-1} r_p S_m e^{-j2\pi m\tau_p/T_S} \int_0^{T_S} e^{j2\pi t f_{d_p}} dt \\
+\sum_{p=1}^{P-1}\sum_{\substack{k=0\\k\neq m}}^{N-1} r_p S_k e^{-j2\pi k\tau_p/T_S} \int_0^{T_S} e^{j2\pi t(f_{d_p}+(k-m)/T_S)} dt) \\
+w(m)
\end{aligned}
\tag{10}
$$

From (10), the interference in the received signal contains white noise, multipath doppler interference from other subcarriers, multipath interference of the same symbol, and ICI.

If the received signal is processed by IAADO, it is described in Eq.(11),

$$
y'(t) = (h(t,\tau) * x(t) + w(t)) \times d(t) \tag{11}
$$

where *d(t)* is the filter of eliminating DFO, described in Eq(12).

$$
d(t) = e^{-j2\pi t f_{d_0}} \tag{12}
$$

The DFO of main path, is computed in Eq.(4). Then, the symbol on the m*th* subcarrier after the elimination of DFO is described in Eq.(13).

$$
\begin{aligned}
y'_m = r_0 S_m \\
+\frac{(\sum_{p=1}^{P} r_p S_m e^{-j2\pi(m\tau_p/T_S)} \int_0^{T_S} e^{j2\pi t(\tilde{f}_{d_p}-f_{d_0})} dt)}{T_S} \\
+\frac{(\sum_{p=1}^{P}\sum_{\substack{k=0\\k\neq m}}^{N-1} r_p S_k e^{-j2\pi(\frac{k\tau_p}{T_S})} \int_0^{T_S} e^{j2\pi t(f_{d_p}-\tilde{f}_{d_0}+\frac{(k-m)}{T_S})} dt)}{T_S} \\
+w_d(m)
\end{aligned}
\tag{13}
$$

From Eq.(13), it shows that ICI caused by DFO of main path is eliminated totally, which degrades the performance mainly.

The signal power on the m*th* subcarrier after the elimination of DFO is computed in Eq.(14).

The interference power on the signal power on the m*th* subcarrier after the elimination of DFO is computed in Eq.(15).

$$
P_S(m) = \left| \begin{aligned} & r_0 S_m + \frac{1}{T_S}(\sum_{p=1}^{P} r_p S_m e^{-j2\pi(m\tau_p/T_S)} \\ & \int_0^{T_S} e^{j2\pi t(f_{d_p}-\tilde{f}_{d_0})} dt) \end{aligned} \right|^2 \tag{14}
$$

The SNR on the signal power on the m*th* subcarrier after the elimination of DFO is computed in Eq.(16). $P_N = E(w_d^2(m))$, is power of white noise.And the average SNR is computed in Eq.(17).

$$
P_I(m) = \left| \begin{aligned} & \frac{1}{T_S}(\sum_{p=1}^{P}\sum_{\substack{k=0\\k\neq m}}^{N-1} r_p S_k e^{-j2\pi(k\tau_p/T_S)} \\ & \int_0^{T_S} e^{j2\pi t(f_{d_p}-\tilde{f}_{d_0}+(k-m)/T_S)} dt) \end{aligned} \right|^2 \tag{15}
$$

$$
\overline{SNR} = \frac{1}{N}\sum_{m=0}^{N-1} SNR(m) \tag{17}
$$

IV. SIMULATION RESULT

In this section, performance varying with erros of DFO of IAADO, the method of only channel estimation and the method combining channel estimation and IAADO, in typical scenarios, is compared by simulation. Two channel estimation methods are investigated. One is LS (L-ESTI) estimation on channel response of pilot signal, and the other is MMSE (M-ESTI), and then linear interpolation estimation on channel response of others. L-CMB is the LS estimation combined with IAADO, that the received signal is processed by IAADO and then processed by L-ESTI, and M-CMB is alike.

The parameters of OFDM are set according to [9], that consist of 128 subcarriers, each spaced 2.083kHz from each other, giving a total bandwidth of 267kHz and an OFDM symbol duration of 480μs. A guard interval of 70μs consisting of a cyclic repetition is added to the front of the OFDM symbol to avoid ISI. Each frame contains 44 OFDM symbol. The carrier frequency is 120MHz. The intervals of inserted pilot are *Nt*=4 on time dimension, and *Nf*=5 on frequency dimension respectively. Modulation QPSK is investigated. The parameters of scenarios in simluation comply to values in [8]. The parameters of each scenario change every 20 frames, and 1000 frames are simulated totally. Fig.4, Fig.5 and Fig.6 show the performance of IAADO, L-ESTI, M-ESTI, L-CMB and M-CMB varying with $\boldsymbol{\delta f_d}$ in the typical scenarios.

Fig.4 shows the performances of IAADO, L-CMB, M-CMB, L-ESTI and M-ESTI under the typical conditions in Enr Air-Ground Scenario, where the normal velocity is 250 meter per second and the max velocity is 440 meter per second. Obviously, the performance of only IAADO varies with $\boldsymbol{\delta f_d}$ more greatly than that of L-CMB, M-CMB. The performance of only IAADO is not inferior to that of L-CMB, M-CMB, L-ESTI and M-ESTI, no matter under the condition of normal speed or max speed, when $|\boldsymbol{\delta f_d}|$ is less than 0.01, but it degrades fast when $|\boldsymbol{\delta f_d}|$ increases. The performances of only estimation methods, L-ESTI and

$$
SNR(m) = \frac{P_S(m)}{P_I(m)+P_N} = \frac{\left| r_0 S_m + \frac{1}{T_S}(\sum_{p=1}^{P} r_p S_m e^{-j2\pi(m\tau_p/T_S)} \int_0^{T_S} e^{j2\pi t(f_{d_p}-\tilde{f}_{d_0})} dt) \right|^2}{\left| \frac{1}{T_S}(\sum_{p=1}^{P}\sum_{\substack{k=0\\k\neq m}}^{N-1} r_p S_k e^{-j2\pi(k\tau_p/T_S)} \int_0^{T_S} e^{j2\pi t(f_{d_p}-\tilde{f}_{d_0}+(k-m)/T_S)} dt) \right|^2 + P_N} \tag{16}
$$

M-ESTI, are good enough under the normal speed, but they degrade much when the velocity increases, and BER falls to 0.03 in the case of the max speed, no matter what L-ESTI or M-ESTI. The performances of combined methods, L-CMB and M-CMB, are more stable than that of the only IAADO, and are superior to those of the only estimation methods, although they degrades slowly when $|\delta f_d|$ becomes large.

Fig.5 shows the performances of IAADO, L-CMB, M-CMB, L-ESTI and M-ESTI under the typical conditions in Enr Air-Air Scenario, where the min relative velocity is 17 meter per second, the normal relative velocity is 250 meter per second and the max relative velocity is 620 meter per second. The curves are similar with those in Fig.4, although the power delay expand is larger. The performances of only estimation methods, L-ESTI and M-ESTI, are good enough under the min speed and the normal speed, but they degrade much when the velocity increases, and BER falls to 0.4 in the case of the max relative speed, no matter what L-ESTI or M-ESTI is. The performances of combined methods, L-CMB and M-CMB, are more stable than those of the only IAADO, and are superior to those of the only estimation methods, although they degrade slowly when $|\delta f_d|$ becomes large. Also, the degradation speed of the combined methods becomes high and the stable range becomes small.

Fig.6 shows the performance of IAADO, L-CMB, M-CMB, L-ESTI and M-ESTI under the typical condition in Arrival Scenario. The performance variety with δf_d, of only IAADO, is similar with those in Enr Scenarios. The performances of M-ESTI and M-CMB are superior to those of L-ESTI and L-CMB, but they are all good enough. However, the performaces of combined methods, L-CMB and M-CMB, are better than those of the only estimation methods, L-ESTI and M-ESTI, i.e. the combined methods benefit from the IAADO.

In summary, the performace of IAADO is good if the aid information is veracious enough. And the combined methods, L-CMB and M-CMB, which benefit from IAADO and estimation, performance better than the only estimation methods, L-ESTI and M-ESTI, although the uncertainty of aid information is within some range.

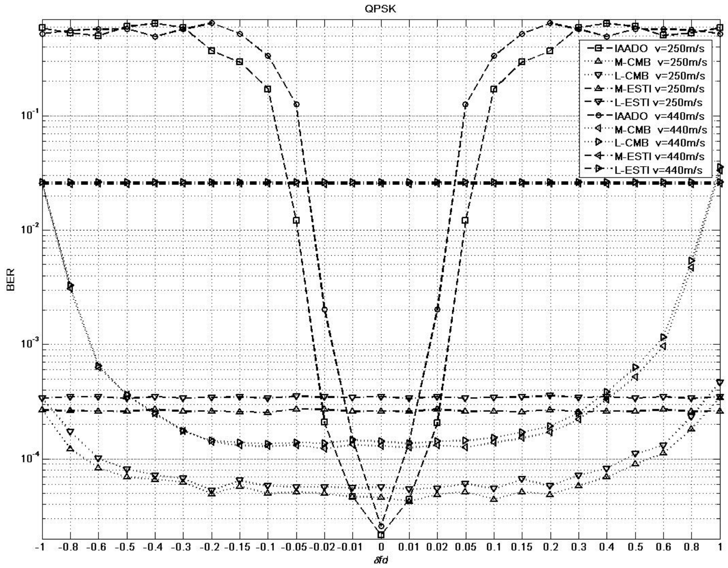


Fig. 4 Performance of IAADO/ L- M- CMB / L- M- ESTI varying with δf_d in En_route AIR-GOUND Scenarios

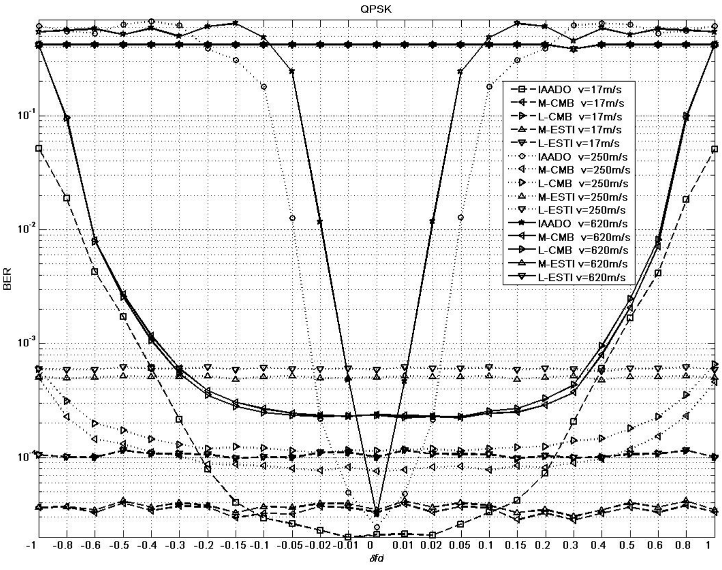


Fig. 5 Performance of IAADO/ L- M- CMB / L- M- ESTI varying with δf_d in En_route AIR-AIR Scenarios of typical velocities

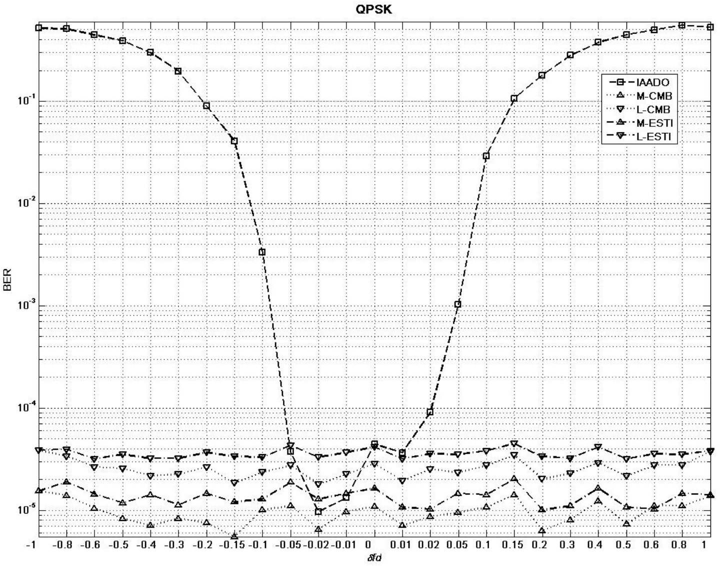


Fig. 6 Performance of IAADO/ L- M- CMB / L- M- ESTI varying with δf_d in Arrival Scenarios

V. CONCLUSION

In this paper, a method of eliminating the ICI caused by DFO rooting in the high-speed movement in AMBC using aid information, IAADO, is presented, that is compensating the DFO of the direct path with main power, which is computed by the postion and velocity information with uncertainty derived from navigation equipments and surveillance equipments onboard. Simulatioin result shows that the combined method, which combines IAADO and the estimation method, no matter what L-CMB or M-cmb is, provides to AMBC good performance in both En_route and Arrival phases, although the aid information is uncertain within some range.

REFERENCES

[1] www.B-VHF.org

[2] Rohit N ,John C. “Pilot tone selection for channel estimation in a mobile OFDM system”,[J] . IEEE TRANS. Consumer Electronics, 1998 ,44 (3) :1122-1128.

[3] ZHANG Ji-dong , ZHENG Bao-yu “Overview of pilot-aided channel estimation in OFDM” [J] JOURNAL OF CHINA INSTITUTE OF COMMUNICATIONS, 2003, 24 (11): 116-124

[4] Byung-Chul Kim and I-Tai Lu, “Doppler Diversity for OFDM Wireless Mobile Communiealions: Parl I: Frequency-Domain Approach,” [C] IEEE VTC 2003 Spring, Korea, Ape1 2003 : 2677-2681

[5] Wang Xin; Zhu Gang; Chen Xia; Tan Zhen-hui, “Doppler Diversity for OFDM High-Speed Mobile Communi- cations”, [C] IEEE ICC on June 2006, Volume 10:4665 - 4669

[6] Y. Zhao and S-G. Haggman, "Intercarrier Interference Self-cancellation Scheme for OFDM mobile communication systems," IEEE Trans. Commun., 2001, 49(7):1 185-1191.

[7] Hen-Geul Yeh and Yuan-Kwei Chang, "A conjugate operation for mitigating intercarrier interference of OFDM systems," IEEE VTC fall Atlanta, 2004: 3965-3969

[8] Erik Haas, “Aeronautical Channel Modeling” ,[J] IEEE TRANS. Veh Technol, , 2002 ,51(2):254-264.

[9] “D10_Req BVHF_SysParam _10”, www.B-VHF.org