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Simulation of Doppler Frequency Estimation in Satellite Communication Using MIMO-OFDM Technique

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Abstract

Application of spread spectrum for satellite land mobile systems is difficult in satellite link because of synchronization and providing code or considerable Doppler shift. This is particularly high for LEO satellites. So that, a Doppler shift carrying a frequency in band S can reach to several tens of kHz. To estimate and compensate Doppler, a CW pilot carrier is used. The aim of this study is simulate Doppler frequency estimation using MIMO-OFDM technique. Finally, the proposed algorithm is compared to MMSE algorithm in order to insure its performance.

Keywords: Doppler frequency estimation, real channel, white Gaussian noise channel.

Introduction

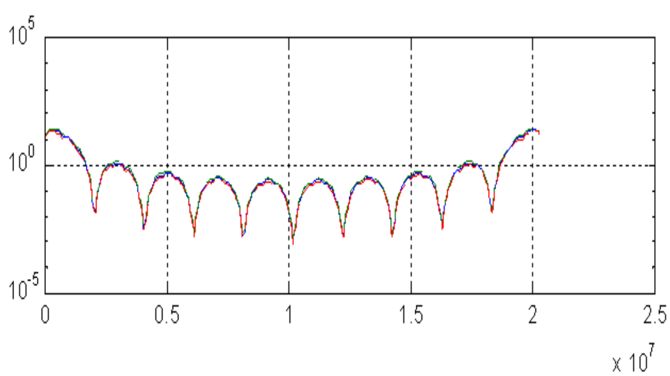
Undermulti-satellite conditions (for three-satellite LEO satellites), frequency estimation error ratio (FEER) indicates that at least one of these estimated pilot carriers is not probably valid in given accuracy. While, P_e represents that a pilot frequency is not correctly identified. Let errors be independent for different pilots and likelihood of error be P_e for three pilots; then FEER is calculated for total system as follows[1]:

$$\text{FEER} = 1 - (1 - p_e)^3 \quad (1)$$

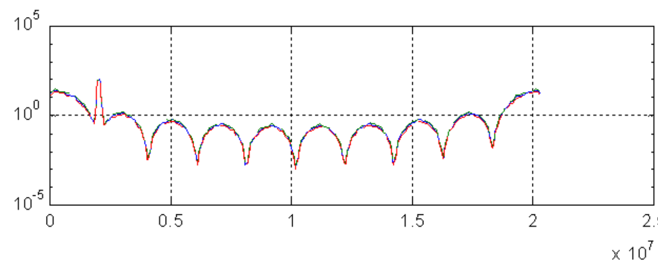
Given that,power of received pilots is not equal, FEER needs to be directly calculated using three pilots or using different probabilities of P_{ei} (i = 1,2,3) for different received powers; so that, FEER canthenbe calculated:

$$\text{FEER} = 1 - (1 - p_{e1})(1 - p_{e2})(1 - p_{e3}) \quad (2)$$

To remove Doppler frequency, as figure 1 shows, a CW pilot is placed in the first CDMA spectrum zero[2].



Frequency
a-Power spectral density transmission signal



Frequency
b-Power spectral density transmission signal with pilot

Figure-1
a) spread spectrum signal, b) spread spectrum signal along with CW pilot in the first spectrum zero

As a result, some interference is generated between traffic channels and CW pilot signal. To emit a low-frequency pilot with low interference, CDMA signal needs to be prenotched in order to prevent pilot frequency estimation influenced by number of users existing in the network. A notch filter is used to prenotch, as figure-2 shows. Given that, bandwidth of Doppler frequency changes is almost 100 kHz (table-1 shows Doppler frequency changes); then, only pilot is required to estimate Doppler estimation rather than other data. Therefore, received information passthrough a band-pass filter in 100 kHz bandwidth around center frequency of the first spectrum zero (table-1 shows frequency properties of emitted data)

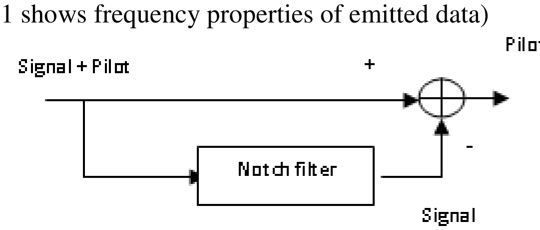


Figure-2
Used method to prenotch emitted signal

Base-Band System Model to Estimate Doppler Frequency

According to figure-3, three LEO satellites are linked to land station in any time; therefore, information are received from three different channels. MIMO-OFDM input includes three CW signals by Doppler shift frequency each possessing independent fading and shadowing along with white Gaussian noise. MIMO-OFDM output is given to a post-processer in which Doppler shift is estimated[3].

To obtain FEER, a single-pilot model is used for simulation, as shown in Figure-3 containing a channel and a pilot. Error rate for three-pilot condition can be calculated by equation (1) and equation (2). An averaging method is used for post-processing. Post-processing includes simple sum of MIMO-OFDM output set. Average spectrum range is calculated as follows:

$$Bi = \sum_{k=1}^{Nav} b_{ki} \qquad (3)$$

where, b_{ki} represents absolute value of i[th](i=1,...,M) bin size for FFT output in K[th] moment; N_{av} represents number of MIMO-OFDM successive outputs which are averaged[3]. Doppler estimation of f_{D1}, f_{D2}, f_{D3} is adjusted to outputs of $i_1, i_2 .i_3$ which have the largest size of B_i . Under single-pilot conditions, the output with the largest B_i should be selected. Performance of Doppler estimating FEER is simulated by Monte Carlo method. As a result, a vector is obtained by three elements containing estimated frequencies as described above. This vector is compared to a vector containing valid points. Valid points are equal to frequency of CDMA first spectrum zero in white Gaussian noise channel and equal to the Doppler frequency multiplied by signal through LOS path in the actual channel. For a single-pilot model, only one estimated point is compared to valid point. An error is detected in Doppler estimation when estimated point varies more than error threshold (adjusted to required estimation accuracy) from valid point[4].

Results of Doppler Frequency Estimation Using MIMO-OFDM Technique

Generally, simulation has been conducted for both white Gaussian and real channels. In summary, parameters of LEO satellite used in simulation and parameters used for simulation are provided in table 1 and table-2, respectively[5,6].

Given that, maximum Doppler frequency is ~40 kHz sampling rate is selected as 10 kHz for MIMO-OFDM considering Nyquist rate[7,8]. Also given that, there are 10 bits valid points for frequency errorlessness and the purpose is to achieve 250 Hz accuracy in this simulation; therefore, MIMO-OFDM bin size is considered as 4096. If lower MIMO-OFDM bin size is considered in the same accuracy, result of simulation will be worsened, as shown in figure-4.

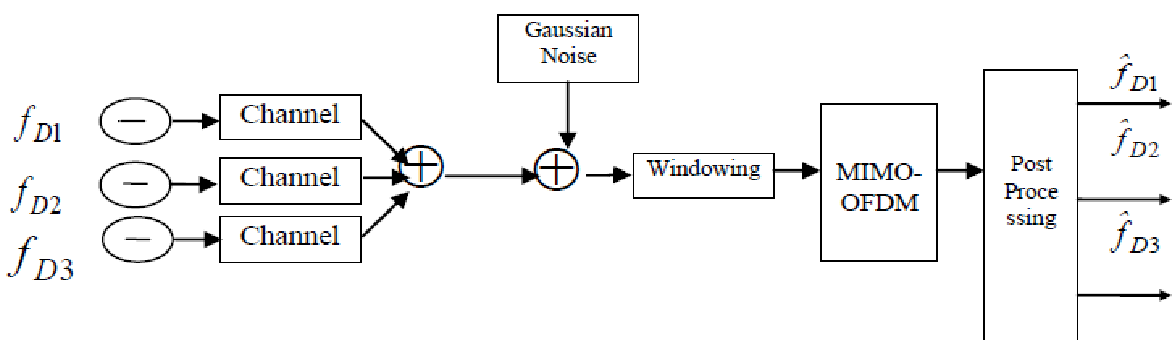


Figure-3
Simulation system to estimate Doppler frequency

Table-1
Parameters of LEO satellite

Doppler spread	Doppler shift range	Code chip rate	Carrier center frequency
200Hz	-40.1…39.3 KHz	2.034 Mchip/s	2.2GHz

Table-2
Parameters of simulation

Accuracy	Acceptance band	Post-processing	MIMO-OFDM sample rate	MIMO-OFDM point size	Constellation	System model
250 Hz	10 bits	6-fold averaging	100 KHz	4096	LEO	1-pilot baseband

Simulation of White Gaussian Noise Channel Using MIMO-OFDM Technique: First, FEER is simulated in terms of SNR (pilot power to noise power) for different SIRs (pilot power to data power) (SIR=-5,-10,-15&-20dB) for white Gaussian noise channels. Figure-5 and figure-6 represent simulation resulted from MIMO-OFDM technique and from MIMO-OFDM technique with processor, respectively. According to these figures, MIMO-OFDM technique better performs by averaging processor. So that, 250 Hz accurate FEER approaches to zero in MIMO-OFDM with averaging processor for SIR=-5dB in SNR >-5dB; while, it approaches to zero in MIMO-OFDM without averaging processor for SIR=-5dB in SNR >0dB.

Simulation of Real Channel Using MIMO-OFDM Technique: A real channel was used for simulation. Table 3 shows parameters required for simulation regarding measured values. Table-4 represents parameters of three MP paths considered for this simulation. Figure-5 and figure-6 show simulation of MIMO-OFDM and simulation of MIMO-OFDM with processor, respectively. According to these tables, MIMO-OFDM better performs by averaging processor.

Table-3
Parameters of simulating real channel

k_c	k_0	m	S	σ_0	Parameters
50	0.3925	-1.3215	0.4038	0.2288	Value

Table-4
Parameters of land MP part

3	2	1	Number ofsatellites: i
0.3	0.2	0.1	Torque : τ_i[μs]
0.071	0.225	0.704	Powerof eachsatellite: P_i

Conclusion

The present study initially introduced base-band system model to estimate Doppler frequency; then, Doppler frequency estimation was studied for both real and white Gaussian noise channels. Simulation was conducted using MIMO-OFDM with and without post-processing for both channels. Results from simulation showed that MIMO-OFDM better performs with averaging processor in both channels. So that, FEER approaches zero sooner in lower SNR but in the same accuracy.

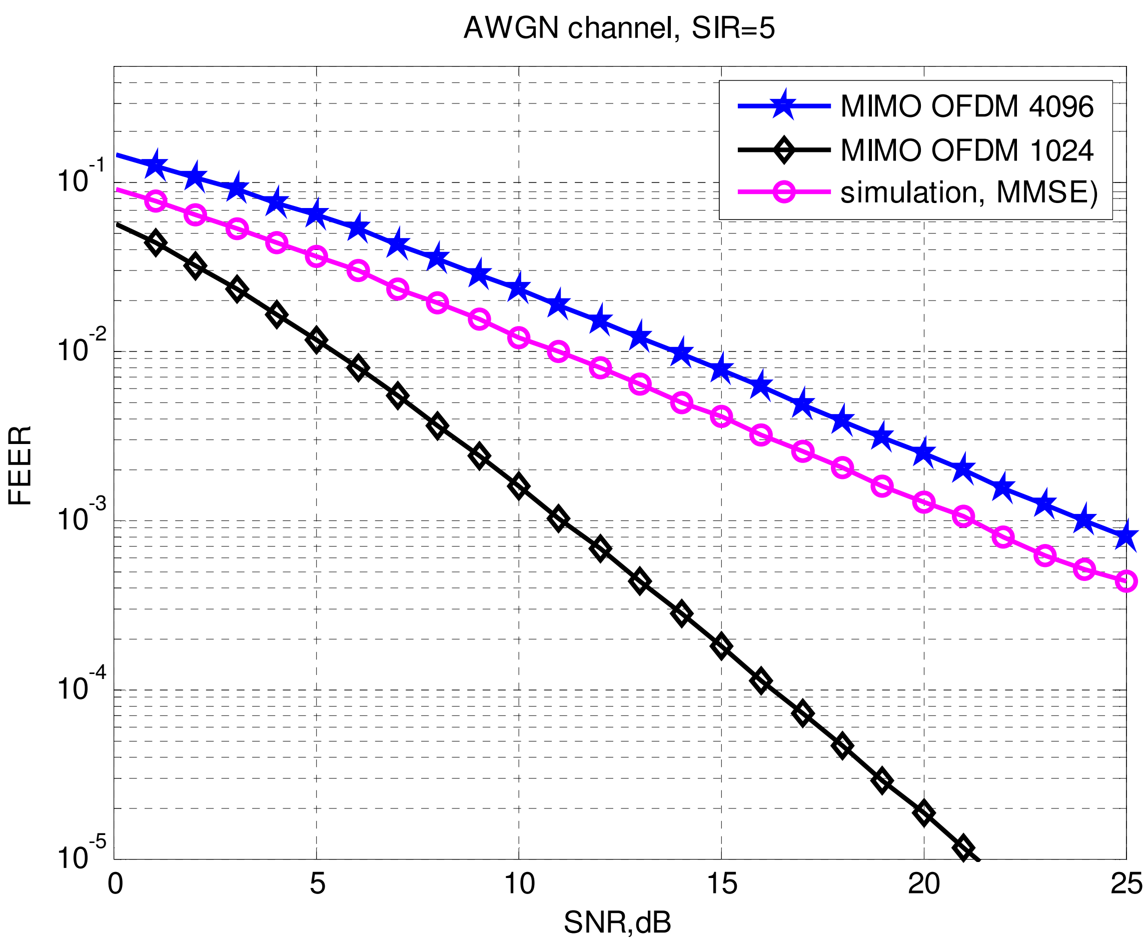


Figure-4
Simulating the comparison between MIMO-OFDM bin sizes

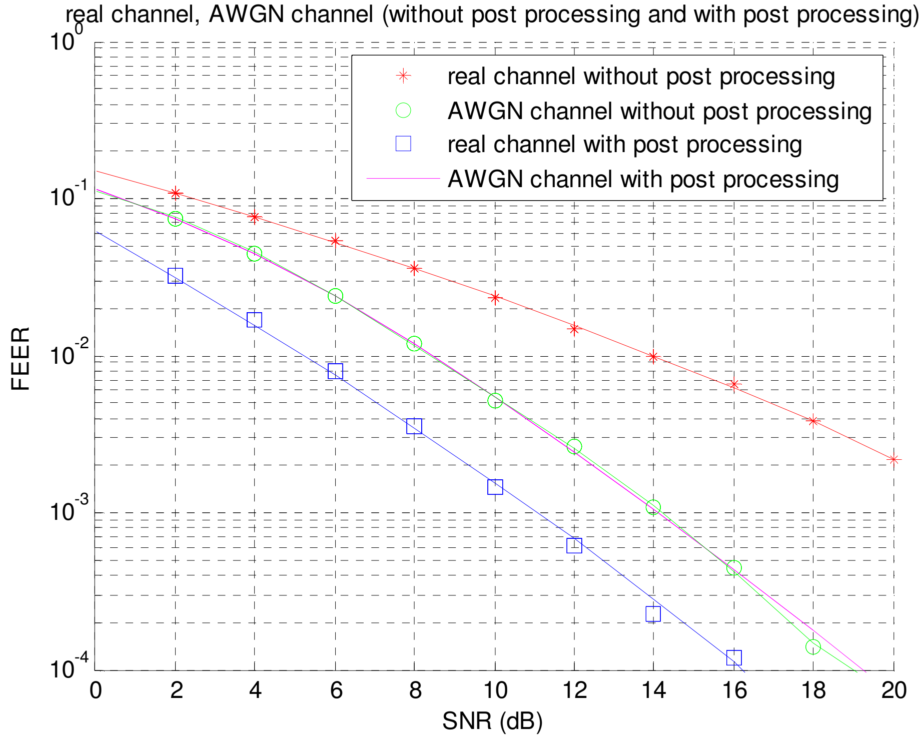


Figure-5
Result from simulating MIMO-OFDM without post-processor and with processor in white Gaussiannoise channel and real channel

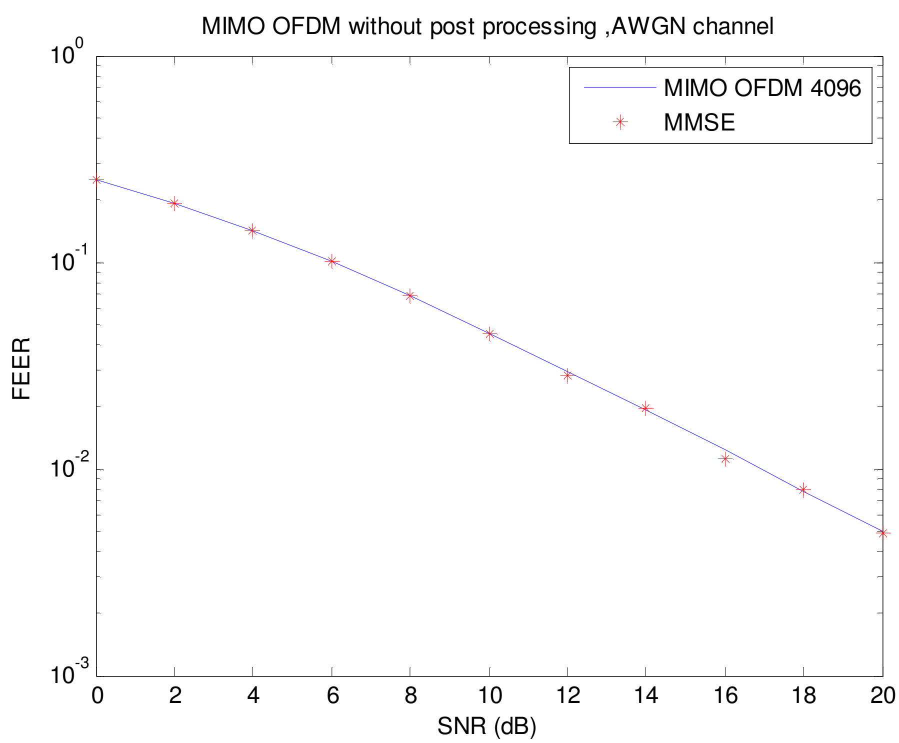


Figure-6
Comparing MIMO-OFDM and MMSE in calculating FEER

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