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Doppler ambiguity analysis and suppression for LTE-based passive bistatic radars

Key words: Passive bistatic radar (PBR); Long term evolution (LTE); Doppler ambiguity; Range-Doppler processing

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Motivation

1. Long term evolution (LTE) is a wireless communication technology that offers last-mile broadband wireless access with predictable extensive accessibility. The specific structure of LTE gives rise to undesired deterministic peaks in the cross-ambiguity function (CAF), which will cause false alarms and/or missing alarm.

2. Current Doppler ambiguity suppression methods all require prior information of the LTE signal. However, the transmitter information changes according to the external environment, which is beyond the control of the passive bistatic radar (PBR) designer and thus degrades the target detection performance.

Main idea

1. The specific features of the cell-specific reference (CSR) signal and physical downlink control channel (PDCCH) in the LTE signal cause ambiguities in the CAF. The ambiguities are located every 1 kHz, and the signal-to-noise ratios (SNRs) of the ambiguities at 2, 4, and 6 kHz are greater than others.

2. The appearance of these peaks due to the CSR signal and PDCCH satisfies two conditions: codeword power $E[|\boldsymbol{S}_{mk}|^2]\neq 1$ and its specific location feature

$$\Xi_{\mathrm{csr}}[0,p]=\sin\left(\frac{\pi p H_{\mathrm{csr}} J_{\mathrm{csr}}}{M_{\mathrm{csr}}}\right)\Big/\sin\left(\frac{\pi p J_{\mathrm{csr}}}{M_{\mathrm{csr}}}\right)$$
$$\cdot\sum_{m_{\mathrm{csr}}=0}^{J_{\mathrm{csr}}-1}\sum_{k_{\mathrm{csr}}=0}^{K_{\mathrm{csr}}-1}\left|S_{m_{\mathrm{csr}}k_{\mathrm{csr}}}\right|^2\exp\left(\frac{-\mathrm{i}2\pi m_{\mathrm{csr}}p}{M_{\mathrm{csr}}}\right).$$

Method

1. An adaptive mismatched method is proposed to pre-process the original reference signal to suppress the ambiguities caused by specific CSR signals and PDCCH.

2. A Tikhonov regularization optimal model is established between the template signal and the original reference signal to solve the modified weights of the CSR signal and PDCCH.

3. The proposed method can calculate the modified factor without prior information of the transmitting signal and the matched cross-correlation results.

Major results (suppression)

Table 1 Simulation parameters for the FDD LTE DL signal

Parameter	Symbol	Value
Sampling rate (MHz)	f_s	30.7
Transmission type		FDD
Coherent integration time (ms)	T_c	50
Bandwidth (MHz)	B	20
Cyclic prefix type		Extended
Cyclic prefix duration (μs)	T_g	16.67
Data symbol duration (μs)	T_u	66.67
Number of data subcarriers	K	1800
Number of symbols per radio frame		120
CSR/PDCCH SNR (dB)		6
Reference signal SNR (dB)		20

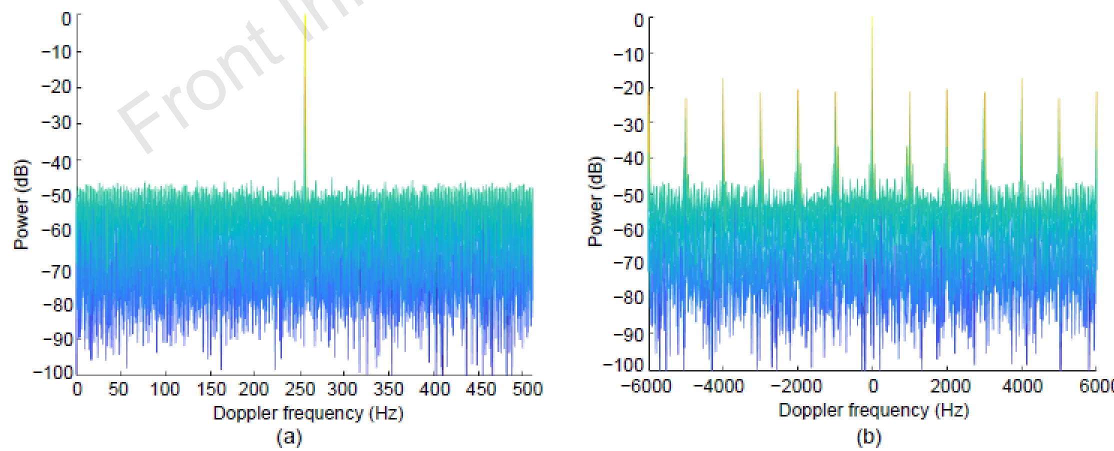


Fig. 5 Cross-correlation range-Doppler frequency outputs of the mismatched reference signal (a) and the original reference signal (b)

Major results (detection)

Table 2 Target return simulation parameters

Signal	SNR (dB)	Range (km)	Doppler frequency (Hz)
Target 1	−20	10	1000
Target 2	−40	10	2000
Target 3	−35	10	4000
Target 4	−30	15	1200
Target 5	−35	15	2200

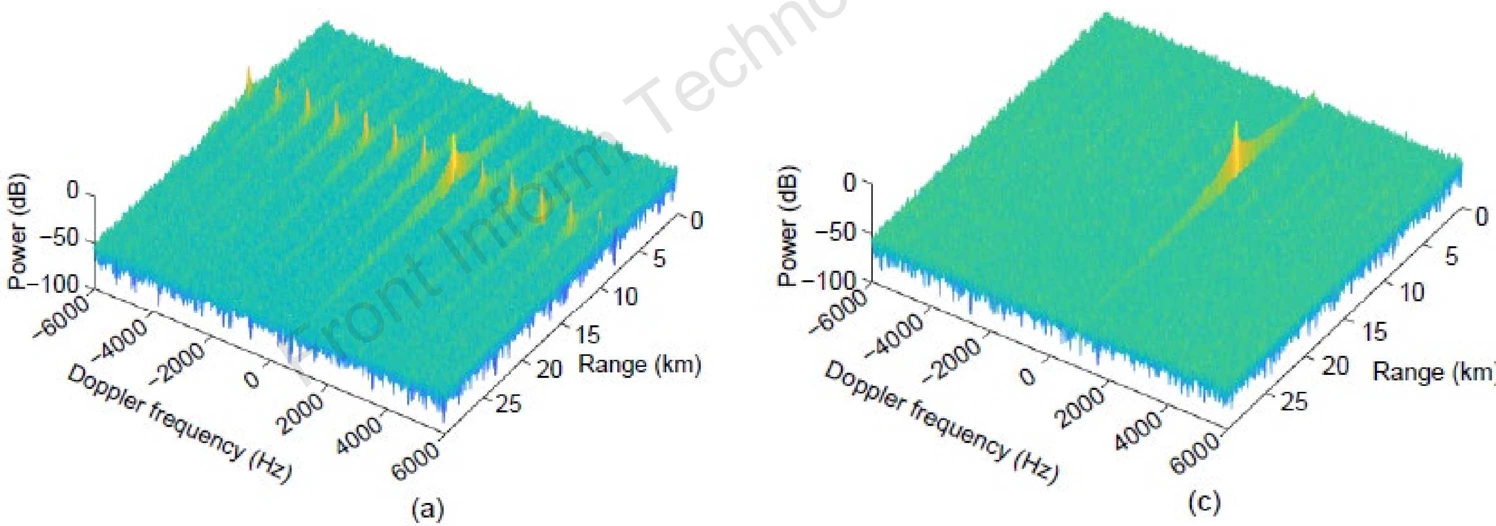


Fig. 6 One strong return target detection results from two methods: (a) 3D RD result of the matched filter; (c) 3D RD result of the proposed method

Major results (performance)

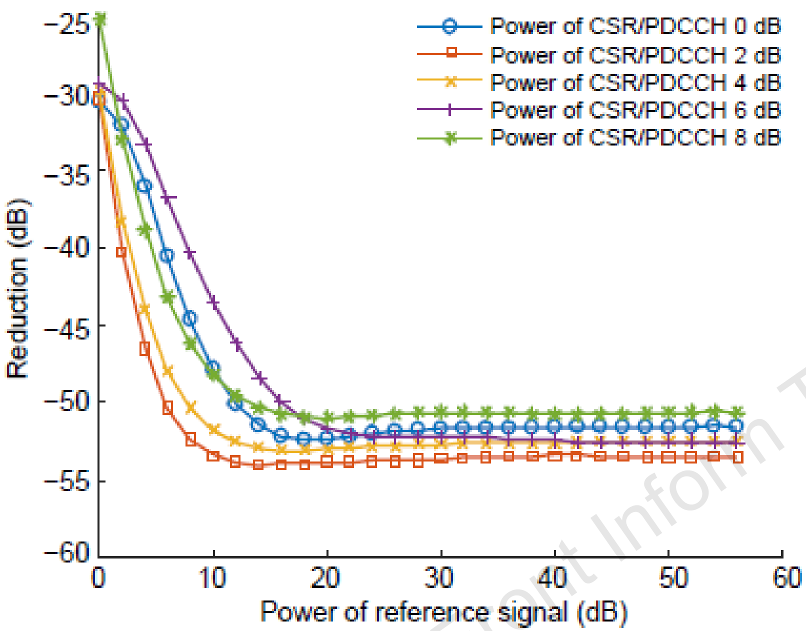


Fig. 8 Reduction versus different reference signals and CSR/PDCCH power: ambiguity peak reduction

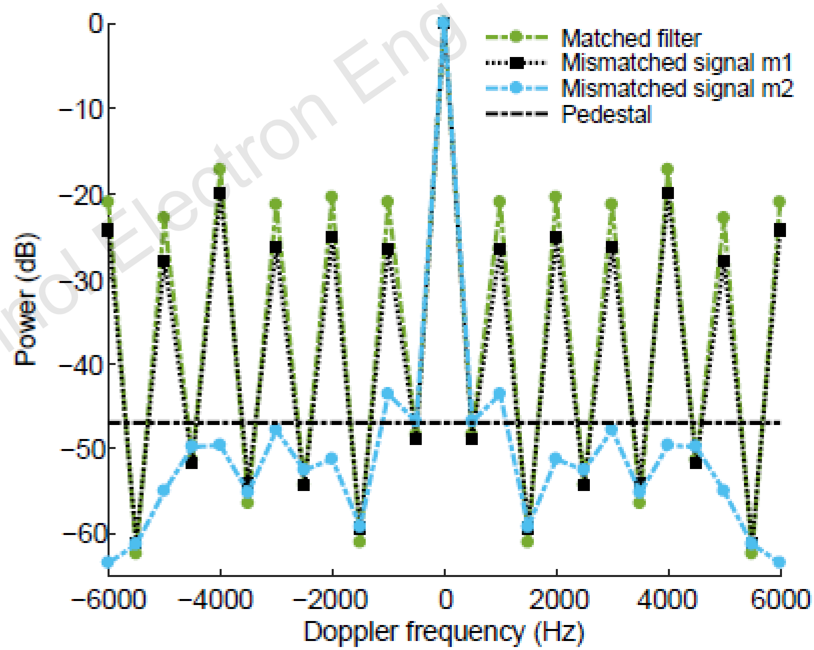


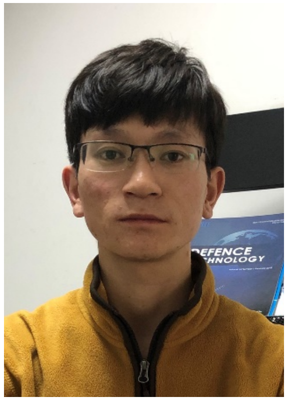
Fig. 9 Comparison of the suppression capability of different methods

Conclusions

1. The two-stage pulse-Doppler compression method was adopted to approximate the FDD LTE DL signal CAF, and the reason for the undesired peaks was confirmed and explained in detail.

2. A new adaptive mismatched filtering method was proposed to pre-process the original reference signal to suppress these undesired deterministic peaks in the range-Doppler processing.

3. The effectiveness of the proposed method was evaluated using simulations. The results showed that all undesired peaks were suppressed below −40 dB, and that the SNR loss in the main peak was only 1.7 dB.



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