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A novel frequency-protection interval adjustment method based on Doppler frequency offset pre-compensation for space-based Internet of Things

Key words: Protection interval; Spectrum utilization; Doppler frequency offset pre-compensation; Massive user access

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Motivation

1. As a leading narrowband satellite communication application, space-based Internet of Things (IoT) offers global short message services with cost-effective spectrum use. Yet, it now confronts the twin issues of surging terminal users and limited, underutilized frequency resources.
2. The high relative velocity of satellites to ground objects causes significant Doppler frequency offset (DFO) in satellite–ground communication, demanding more channel frequency resources for protection intervals.
3. Taking the ultrahigh-frequency (UHF) band as an example, the DFO generated by satellite-to-ground communications at an orbital altitude of 500 km is approximately $\pm$12.8 kHz, while the bandwidth required for narrowband communications at a transmission rate of 10 kb/s is approximately 12.5 kHz. This will result in less than 1/3 frequency utilization.

Main idea

1. In response to the problem of large DFO in satellite-to-ground communications, this paper proposes a segmented DFO pre-compensation scheme.
2. In order to reduce the computing pressure and energy consumption of terminal equipment, the optimal DFO pre-compensation value and frequency-protection interval are determined based on the characteristics of DFO changes in ground terminals.
3. The scheme can determine the number of message splits and the corresponding pre-compensation values based on the message length and transmission rate.

Method

1. In order to improve the spectrum utilization efficiency, DFO compensation is proposed to reduce the frequency-protection interval. The freed frequencies are then reused for channel division.

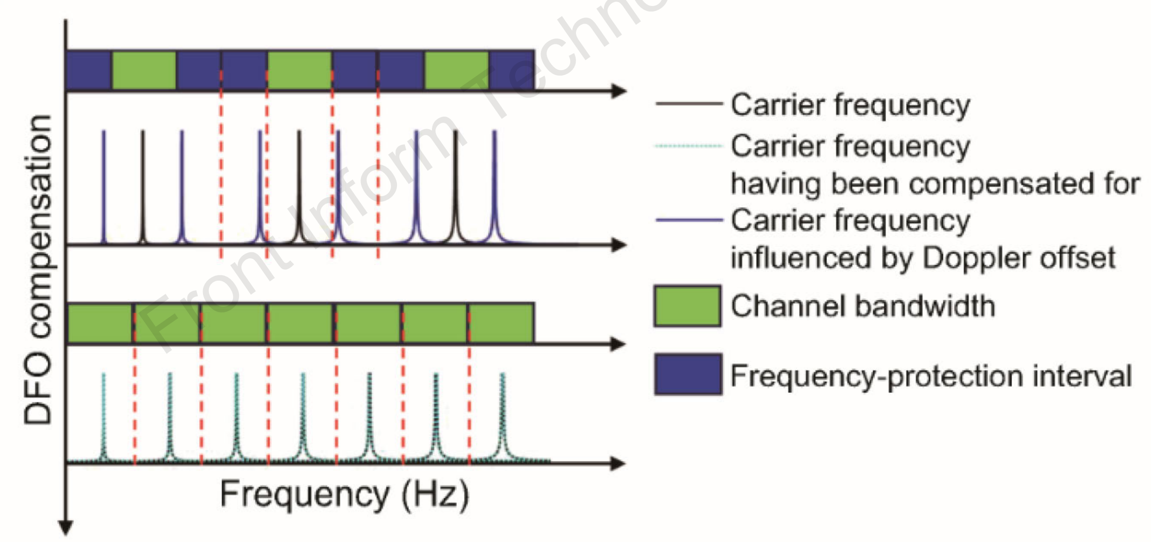


Fig. 3 Protection interval setting after DFO compensation in the ideal case

Method (Cont'd)

2. Comprehensively considering the performance conditions of the terminal equipment, we propose one-time computation with continuous compensation to reduce the DFO protection interval.

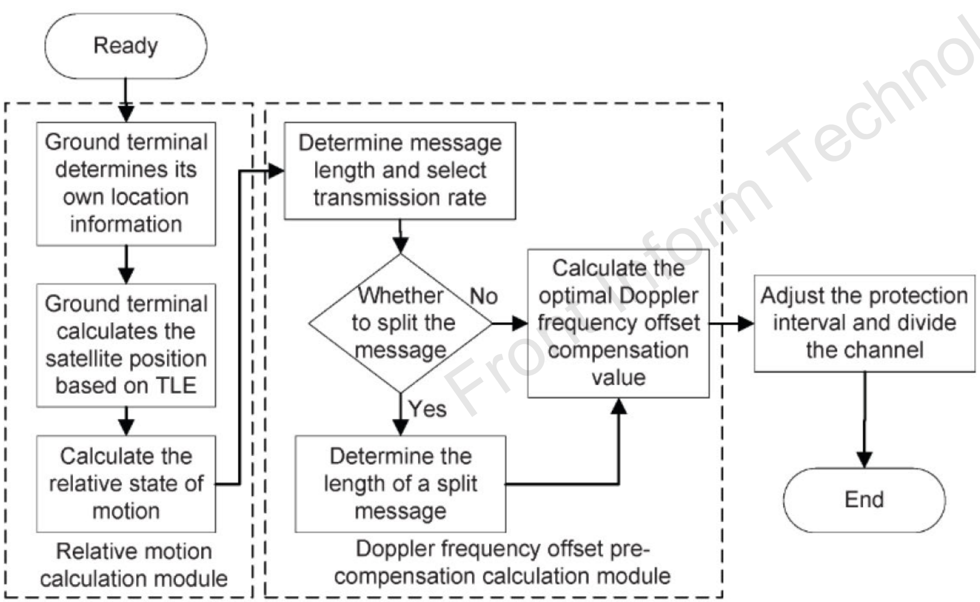


Fig. 2 Spectrum resource utilization scheme based on DFO pre-compensation

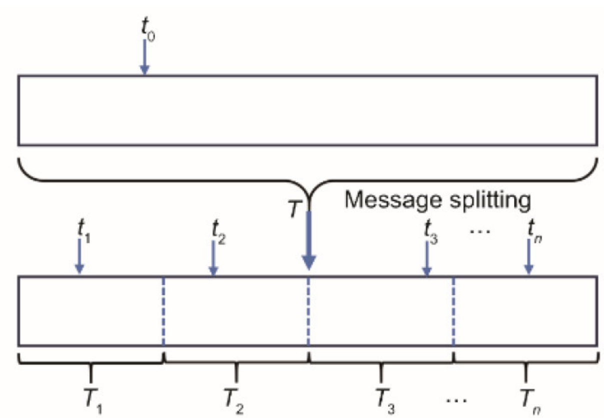


Fig. 4 Schematic diagram of splitting a long message into multiple short messages

Method (Cont'd)

3. Select the appropriate number of message splits based on the message length and transmission rate, and determine the optimal DFO pre-compensation value and frequency-protection interval.

$$f_{\mathrm{c,best}} = \frac{f_{\mathrm{Doppler},2} + f_{\mathrm{Doppler},1}}{2}.$$

$$\Delta f = \max\left(\left|f_{\mathrm{Doppler},i_1} - f_{\mathrm{c},i}\right|, \left|f_{\mathrm{c},i} - f_{\mathrm{Doppler},i_2}\right|\right), \quad i = 1, 2, \ldots, n,$$

Major results

The variation law of DFO for different terminal types is the same.

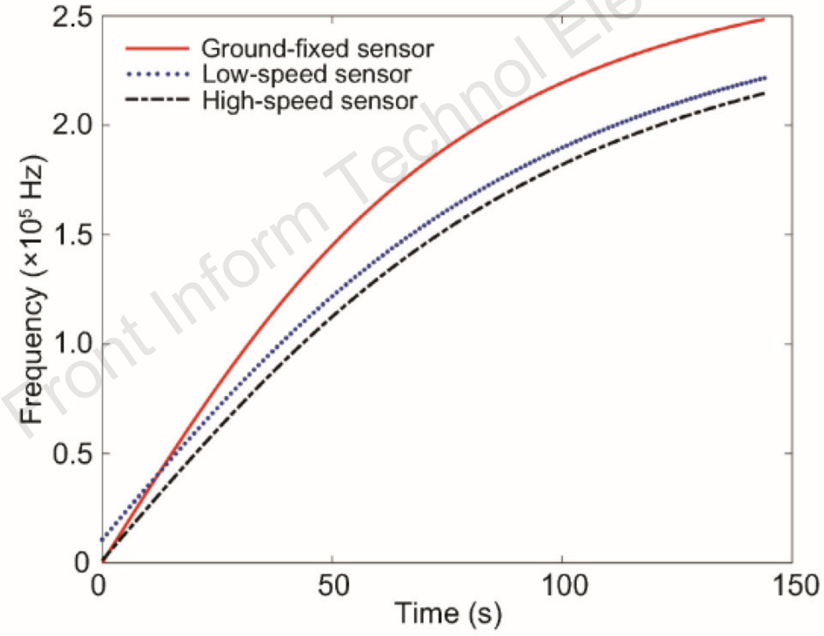


Fig. 5 DFO over time for different terminal types

Major results (Cont'd)

Number of users accessed and user growth

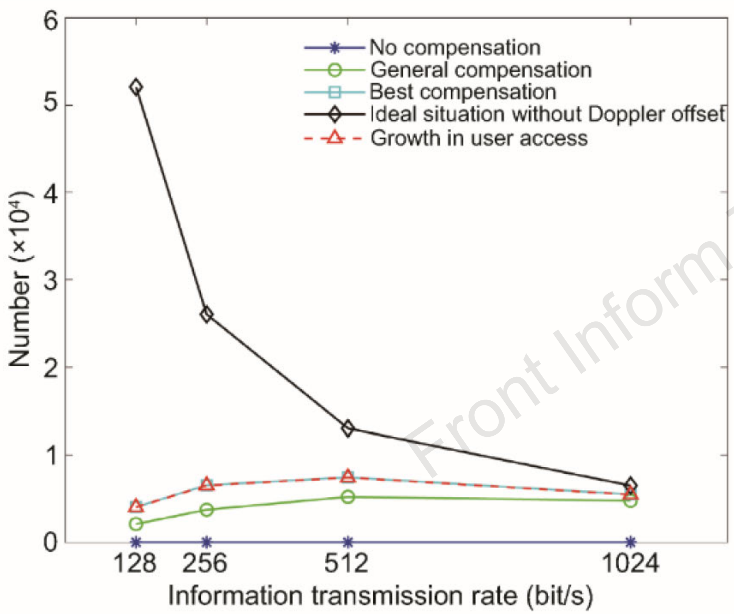


Fig. 6 Variation in the number of DFO pre-compensated access users at different information transmission rates

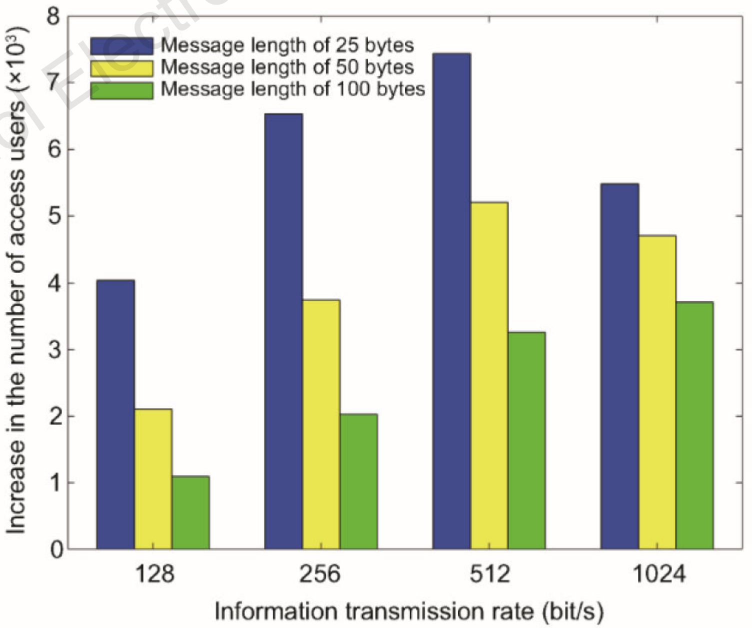


Fig. 7 DFO pre-compensated access user number increment for different message lengths

Major results (Cont'd)

Message splitting and time complexity

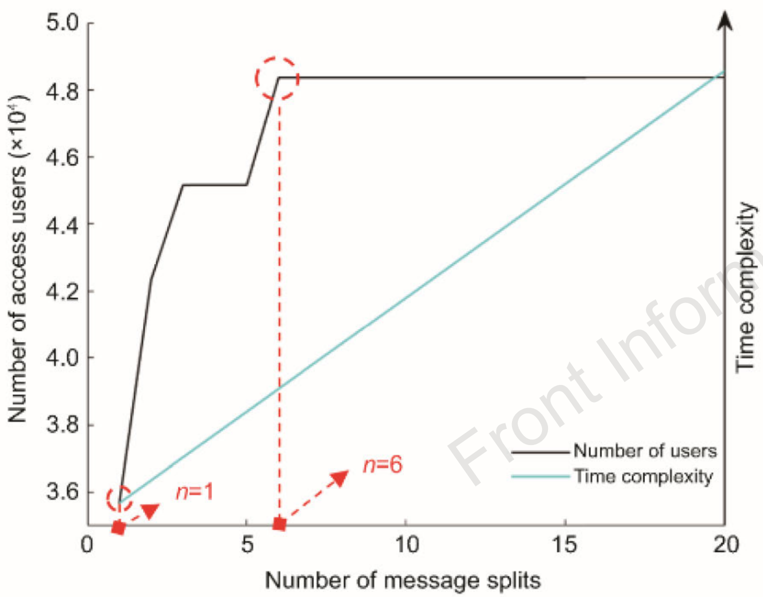


Fig. 8 Relationship between the number of message splits and the number of access users and time complexity

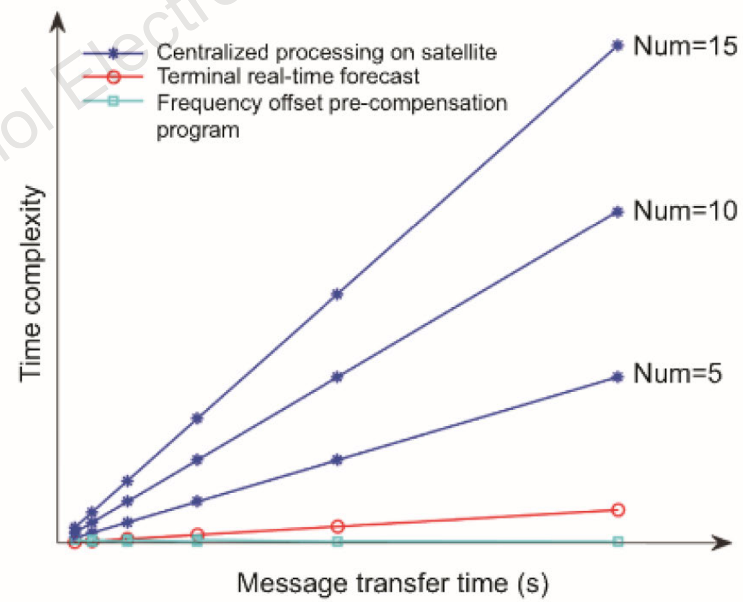


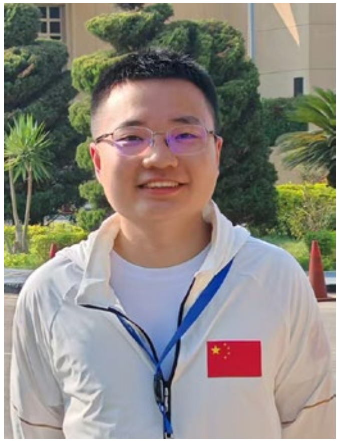
Fig. 9 Variation of time complexity with transmission time for the three methods

Conclusions

1. A single DFO compensation is more effective for short messages than for long messages.

2. An increase in transmission speed will increase the number of users, but after a certain speed is reached, excessive transmission speeds will actually reduce the number of users.

3. After splitting long messages and then performing calculations and pre-compensation, the number of ground-fixed terminal users increased by 35.6% compared with performing only one DFO calculation and compensation without splitting.



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