Direct Spectrum Division Transmission for High-capacity Satellite Communications

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Abstract

We investigated direct spectrum division transmission (DSDT) for satellite communications. A DSDT-based satellite communication system can be made by modifying the design of the existing satellite communication system by inserting a DSDT adapter between the modem and antenna. On the transmitter side, the DSDT adapter divides the modem's output signal into multiple sub-spectra and assigns them to unused frequency resources. On the receiver side, the divided sub-spectra are combined and the original signal is regenerated. Therefore, the DSDT system utilizes existing satellite communication system components and achieves higher frequency utilization efficiency. Experiments on a prototype DSDT adapter show that its resulting bit error rate performance is close to that in the case without spectrum division. The results demonstrate that the DSDT adapter achieves flexible spectrum division and hence enables high-capacity satellite communications.

1. Introduction

Much of eastern Japan was severely impacted by the Great East Japan Earthquake on March 11, 2011. Many cities were destroyed by tsunami, liquefaction, and subsidence. Since terrestrial communication systems were also seriously damaged, satellite communications became essential in afflicted areas. Before the disaster, satellite communications was being used to provide telephone and fax services, but after the disaster, Internet connectivity was the dominant demand [1]. However, since frequency resources are limited, Internet connection services must share the bandwidth with existing telephone and fax services.

In typical satellite communication systems, demand assigned multiple access (DAMA) provides the frequency resources of the satellite transponder to user earth stations (UESs). Since each UES releases its assigned frequency resources after disconnection, the transponder's unused frequency resources, which may not be wide enough to be reallocated to new users, become scattered. This fragmentation of the frequency resources seriously degrades frequency utilization efficiency. Moreover, existing satellite communication devices need to be used efficiently because of their long life cycle.

This article introduces the concept of direct spectrum division transmission (DSDT) for satellite communications [2], [3]. A DSDT-based satellite communication system can be made by modifying the design of the existing satellite communication system by inserting a DSDT adapter between the modem and antenna. On the transmitter (Tx) side, the DSDT adapter divides the output signal of the existing modem into multiple sub-spectra in the frequency domain and assigns them to unused frequency resources according to the frequency usage load on the satellite transponder. Therefore, the DSDT system has higher frequency utilization efficiency than the existing system. On the receiver (Rx) side, divided sub-spectra are combined and the original signal is

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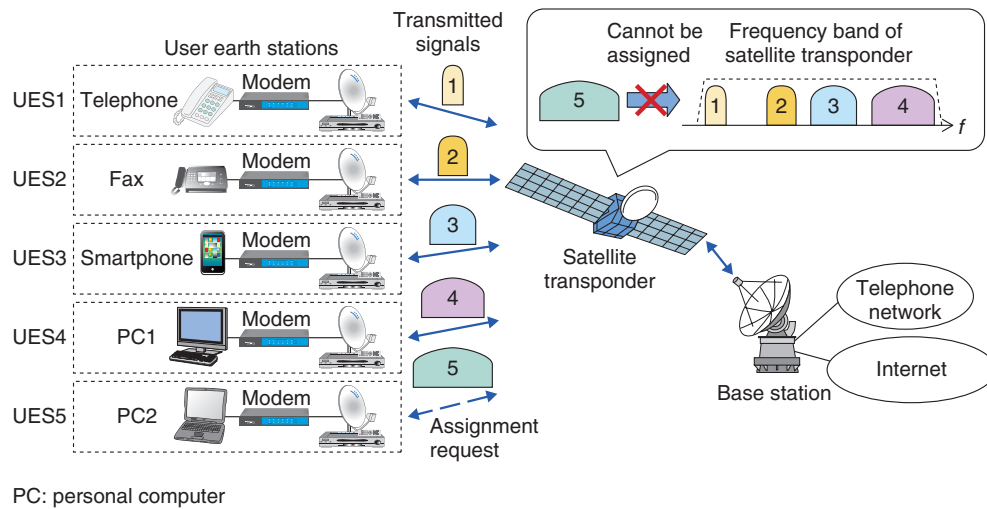
PC: personal computer

Fig. 1.   Overview of current satellite communication system.

regenerated in the DSDT adapter. The regenerated signal is demodulated by the existing Rx modem.

This article explains the concept and principle of DSDT and describes an experimental evaluation of the performance of a prototype DSDT adapter.

2.   Key issue

The conventional DAMA-based satellite communication system is shown in **Fig. 1**. User terminals, such as telephones, faxes, smartphones, and personal computers, are connected to the UESs. Telephone and Internet connections are provided via the satellite transponder and the base station. For the duration of its communication session, each user is assigned a transmission channel with a different frequency, and the modem of the UES outputs a signal with a single carrier frequency modulated by the data to be transmitted. Consider the case in which UES5 requests a contiguous wide frequency band for broadband communications. Since the unused resources are fragmented, no frequency resource can be assigned to UES5 even though the total available capacity is sufficient to meet the demand. To have higher efficiency, each UES must be able to use fragmented frequency resources in the most flexible manner possible.

3.   System concept

The concept of the DSDT system is shown in **Fig. 2**. On the Tx side, the DSDT adapter converts the output signal of the existing modem into a frequency-domain signal by applying a fast Fourier transform (FFT) and divides it into multiple sub-spectra by using a spectrum dividing filter bank (**Fig. 3(a)**). The satellite assigns the divided sub-spectra to unused frequency resources and converts them into a single time-domain signal by applying an inverse FFT (IFFT).

On the Rx side, the DSDT adapter converts the received sub-spectra into the frequency domain by an FFT and re-shifts and combines all the sub-spectra by using its spectrum combining filter bank (**Fig. 3(b)**). It converts the combined signal into the time domain by an IFFT. The output signal of the DSDT adapter is demodulated by the existing modem.

4.   Technical problem and novel approach

In the DSDT system, since received sub-spectra undergo independent phase offsets owing to the propagation delay, each Rx sub-spectrum undergoes phase distortion, as shown in **Fig. 4(a)**.

In the Rx filter bank, sub-spectra k (k=1, 2, …, n, n: number of spectrum divisions), which are shifted by fs_k on the Tx side, are re-shifted by $-fs_k$ to regenerate the original signal. This frequency shift makes the phase characteristics of the regenerated signal become discontinuous, which invalidates the distortionless condition; consequently, the bit error rate (BER) performance is degraded, as shown in **Fig. 4(b)**.

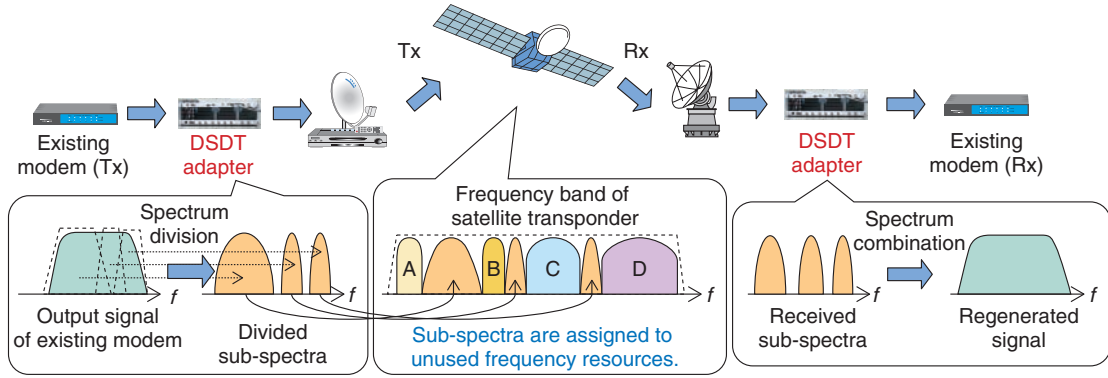In addition, the DSDT system does not know the frame format of the existing modem because of its
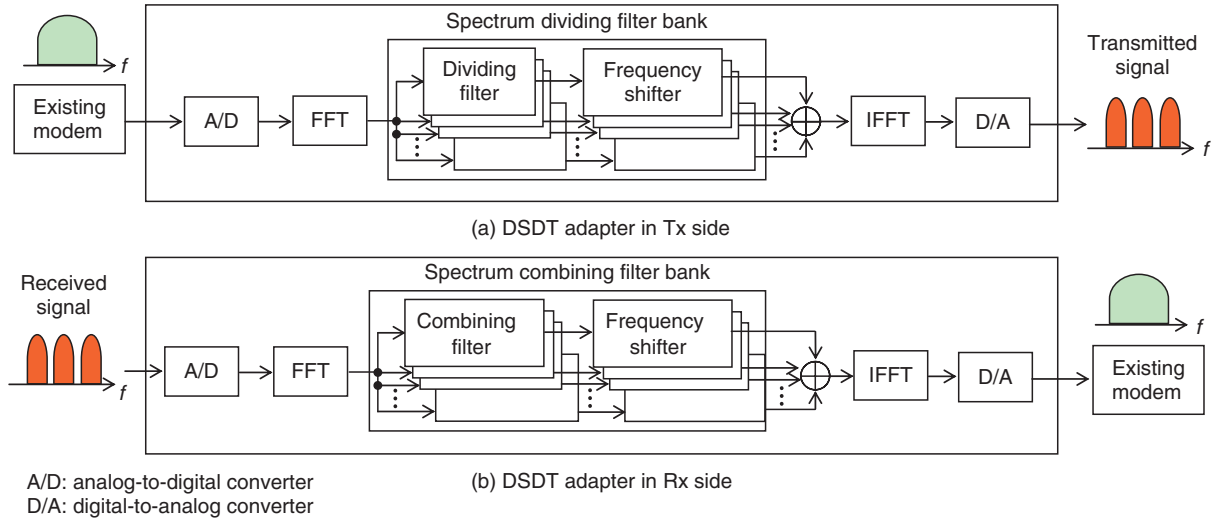
Fig. 2.   Overview of DSDT system.

(a) DSDT adapter in Tx side

(b) DSDT adapter in Rx side

A/D: analog-to-digital converter
D/A: digital-to-analog converter

Fig. 3.   Configuration of DSDT adapter.

Phase characteristics
(a) Rx signal

Phase characteristics
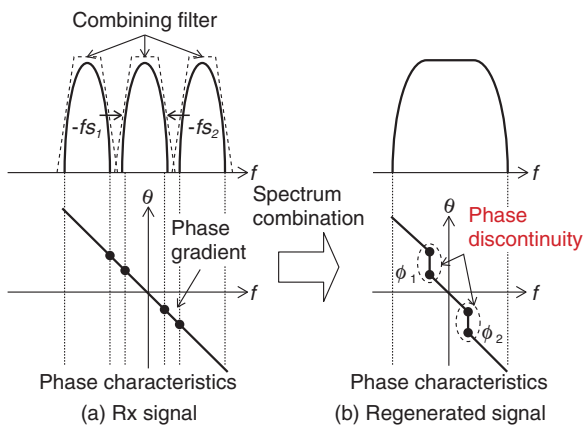(b) Regenerated signal

Fig. 4.   Phase distortion after spectrum combination.

adapter-based design. Therefore, the phase distortion cannot be compensated for by using a specific frame pattern.

For phase distortion compensation, we use a blind phase compensation method (**Fig. 5**). Since the Rx-filtered and re-shifted sub-spectra undergo a phase shift due to the propagation delay, adjacent sub-spectra exhibit significant phase difference ϕ_k, as shown in Fig. 5(c). This compensation method estimates and compensates for ϕ_k for each pair of sub-spectra independently [4].

Since the blind phase compensation method estimates the phase compensation values regardless of the modulated signal spectrum patterns, no pilot signal or specific frame format is required.
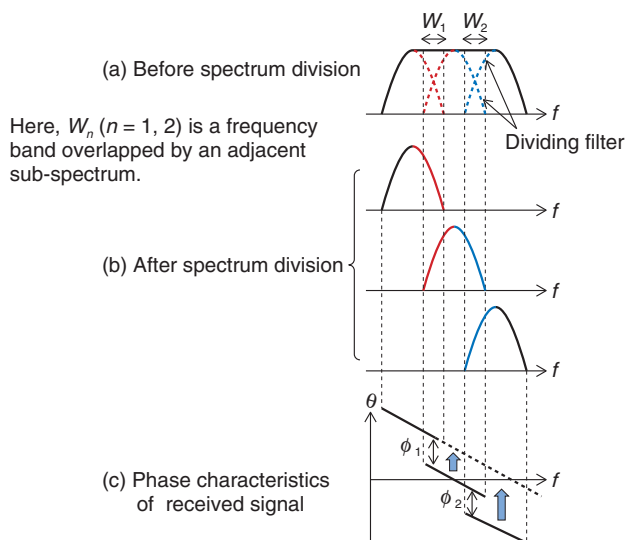
(a) Before spectrum division

Here, W_n (n = 1, 2) is a frequency band overlapped by an adjacent sub-spectrum.

Dividing filter

(b) After spectrum division

(c) Phase characteristics of received signal

Fig. 5.   Blind phase compensation method.

Table 1.   Experimental parameters.

Modulation scheme	QPSK, 16QAM
FEC	LDPC code (code rate: 3/4)
Symbol rate	3.2 MHz
Sampling rate	25.6 MHz
Roll-off factor	0.25
Number of spectrum divisions (n)	No division, 2, 4, 8
FFT size	2048 points

16QAM: 16-state quadrature amplitude modulation
FEC: forward error correction
LDPC: low-density parity check
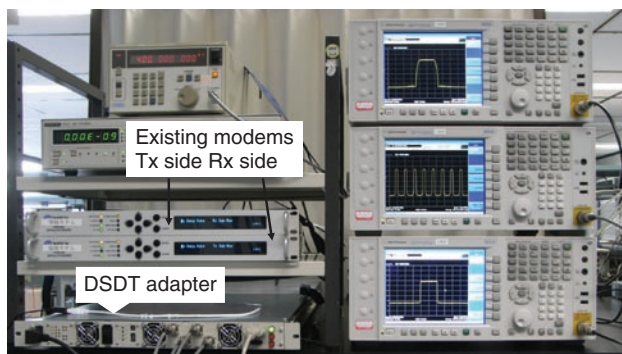QPSK: quadrature phase shift keying

Existing modems
Tx side Rx side

DSDT adapter

Fig. 6.   Experimental system.

5.   Experimental evaluation

The performance of the DSDT system was evaluated in several experiments using a prototype DSDT adapter. As the existing satellite modem, we used Comtech EF Data CDM-625. The experimental parameters are shown in **Table 1** and the experimental configuration is shown in **Fig. 6**.

The output signal of the existing modem is shown in **Fig. 7(a)**. The DSDT adapter divided the signal into multiple sub-spectra, as shown in **Fig. 7(b)**. Received sub-spectra were combined and the original signal was regenerated by the combining filter bank, as shown in **Fig. 7(c)**. These observations confirm that the modulated signal was regenerated.

The quadrature phase shift keying (QPSK) constellations before and after phase compensation by the blind phase compensation method are shown in **Fig. 8**. The phase shift compensation was satisfactory. The BER performance is shown in **Fig. 9**, where the BER is plotted against the ratio of the energy per bit to noise power spectral density (E_b/N_0). For both of the modulation schemes tested, QPSK and 16-state quadrature amplitude modulation, the degradation in carrier-to-noise ratio was negligible compared with the undivided case.

These results demonstrate that the DSDT system can compensate for phase distortion satisfactorily and achieve flexible spectrum division.

6.   Conclusion

This article described direct spectrum division transmission (DSDT) for satellite communications and an experimental evaluation of the DSDT system. Experiments on a prototype showed that the system's BER performance was close to that in the undivided case. Thus, we conclude that the DSDT system can divide the output signal of an existing modem flexibly and achieve high-capacity satellite communications.
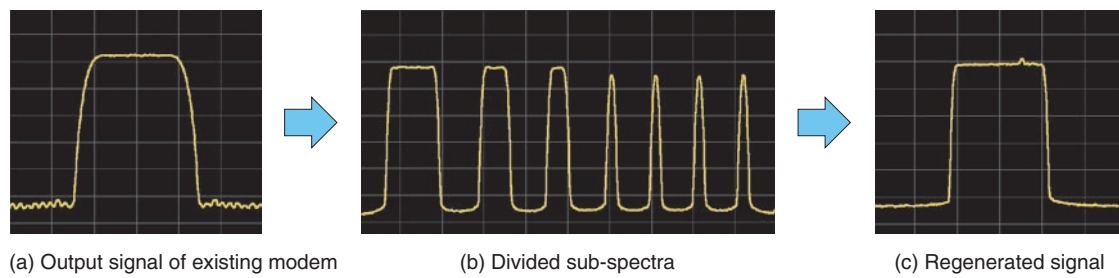
(a) Output signal of existing modem   (b) Divided sub-spectra   (c) Regenerated signal

Fig. 7. Spectrum division and combination.

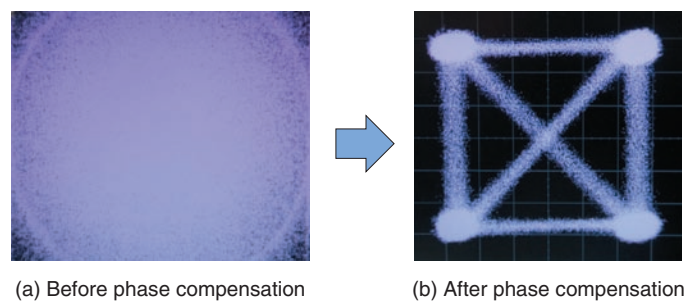(a) Before phase compensation   (b) After phase compensation
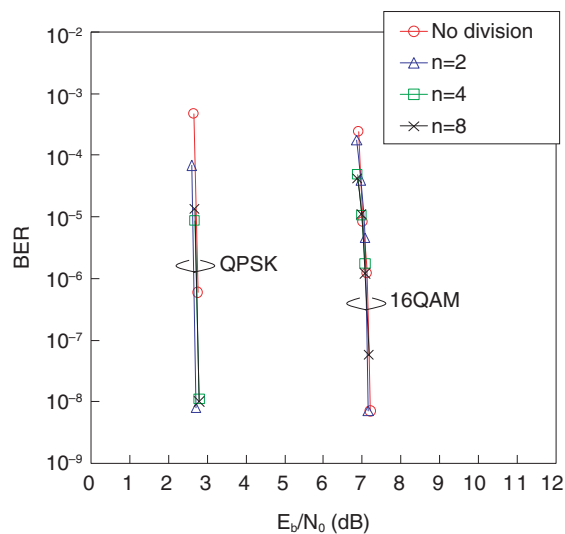
Fig. 8. Rx constellations.

Fig. 9. Bit error rate performance.

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