Feasibility Verification of Direct Spectrum Division Transmission over Multiple Satellite Transponder

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Abstract:
We have been proposing a direct spectrum division transmission (DSDT) technique that can divide a single carrier signal into multiple sub-spectra and assign them to dispersed frequency resources of a satellite transponder to improve spectrum utilizing efficiency. This letter overviews the concept of DSDT and shows the results of feasibility verification on DSDT via satellite experiments. In a past study, we carried out fundamental satellite experiments on DSDT over a single transponder. This time, we conduct satellite experiments on DSDT over multiple transponders by using the latest DVB-S2X format signal. The BER performances of signals divided by the DSDT technique were almost the same as that of a single-carrier. We confirmed that DSDT was practical.

Keywords: direct spectrum division transmission (DSDT), satellite experiments

Classification: satellite communications

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1 Introduction

The rapid adoption of network services requires more efficient wireless network infrastructures. Broadband satellite links are needed to establish IP access networks or mobile backhaul systems because satellite communications are the sole access network for aircrafts, vessels, and disaster-struck areas [1][2]. In typical satellite communications systems, Demand Assigned Multiple Access (DAMA) assigns the satellite transponder’s frequency resources to user earth stations (UESs) independently, so the total usage of the satellite transponder changes over time [3]. The repeated acquisition and release of frequency resources among various services makes the unused frequency resources on the satellite transponder scatter and become individually insufficient to accommodate new broadband users, degrading the frequency utilization efficiency. Several transmission schemes to minimize the discontinuity in unused frequency resources have been studied. Multi-Frequency TDMA (MF-TDMA) [4] utilizes multiple frequency and timing slots. However, a MF-TDMA user cannot use multiple discontinuous frequency slots simultaneously. OFDMA [5] and Single-Carrier FDMA (SC-FDMA) [6] can utilize multiple frequency slots concurrently and improve frequency utilization efficiency when the frequency and timing of all the UESs are synchronized. However, precise synchronization control is difficult and complicated because satellite channels have long transmission delays.

To tackle these problems, we have been proposing “Direct Spectrum Division Transmission (DSDT),” a new transmission method based on a spectrum editing technique that better utilizes unused frequency resources on the satellite transponder. The transmitter divides the single carrier modulated signal into multiple “sub-spectra” in the frequency domain and arranges the sub-spectra to match the unused frequency slots. Conversely, the divided sub-spectra in the receiver are combined in the frequency domain and demodulated. Unlike OFDMA and SC-FDMA, the guard band between the DSDT user’s sub-spectrum and the
primary user’s signal can be reduced because the bandwidth of each sub-spectrum on the Tx side is shaped by a root roll-off filter and its side lobes are sufficiently suppressed. Basically, DSDT signals do not have to be synchronized with adjacent signals. In a previous paper, we introduced feasibility verification of DSDT over a single satellite transponder [7]. We expect using DSDT over multiple transponders to provide a new type of satellite communication service by raking unused frequency resources dispersed over multiple transponders. Since the satellite on-board analog equipment performance differed transponder to transponder, practical satellite experiments can effectively verify DSDT over multiple transponders. Therefore, this letter reports the DSDT performance over multiple transponders.

2 Overview of Direct Spectrum Division Transmission

Figure 1 shows the overall system concept using DSDT. On the Tx side, the DSDT adapter is inserted between the existing RF equipment and the existing modem. On the Rx side, the other DSDT adapter is inserted between the existing RF equipment and the existing modem. In the DSDT adapter on the Tx side, a single carrier modulated signal output from the existing modem is converted into the frequency domain by using a fast Fourier transform (FFT), then divided into multiple sub-spectra with arbitrary bandwidth by a spectrum dividing filter bank. The dividing filters have a special frequency response that reduces the roll-off factor of each sub-spectrum to generate sub-spectra with root roll-off characteristics and decrease the occupied bandwidth after spectrum division [8]. The divided sub-spectra are set on unused frequency resources and converted into the time domain by using inverse FFT (IFFT).

On the Rx side, received sub-spectra are converted into the frequency domain by FFT, and all sub-spectra are re-shifted and recombined by the spectrum
combining filter bank. In the combining filter bank, root roll-off filters are the combining filters. Since both sub-spectra and combining filters have root roll-off characteristics and the cutoff frequencies between combining filters are the same, the signal after the spectrum combination has a flattened pass band and exhibits the full roll-off characteristics of the original single carrier modulated signal. After phase compensation, the combined signal is converted into the time domain by IFFT.

The phase characteristics of the combined signals become discontinuous because each Rx sub-spectrum undergoes independent phase offset due to the unsynchronized clock timing between Tx and Rx side. The DSDT adapter estimates the phase differences between Rx sub-spectra from the transition band of adjacent sub-spectra and compensates them [9]. Thus, the phase characteristics become continuous. Existing modems can realize the phase synchronization of the combined signals.

3 Feasibility verification of DSDT performance via satellite experiments

For feasibility verification, we developed DSDT adapters. Figure 2 (i) shows the experimental setup for Ku-band satellite experiments. We used typical DVB-S2X formatted signals to check if the DSDT adapter could divide/combine the latest commercial signal. Figure 2 (ii) shows the representative spectrum arrangement patterns for satellite experiments. First, we measured the BER performance without spectrum division for reference, as shown in Fig. 2 (ii)-(a). Next, we measured the BER performance of signals evenly divided into 2 sub-spectra over a single transponder, as shown in Fig. 2 (ii)-(b). Finally, we measured the BER performance of signals divided and arranged over multiple transponders, as shown in Fig. 2 (ii)-(c). As Fig. 2 (ii)-(c) shows, the guard band between adjacent transponders was 4 MHz.
(i) Experimental setup

(a) Spectrum arrangement without spectrum division

(b) Spectrum arrangement over a single transponder

(c) Spectrum arrangement over multiple transponders

(ii) Spectrum arrangement over satellite transponders

Fig. 2 Configuration of satellite experiments
Detailed signal conditions are as follows. In Fig. 2(ii)-(a), the symbol rate was set at 20M-baud. Its roll-off ratio is 0.05. However, DSDT divides 20M-baud single carrier signals into two 10M-baud sub-spectra, as shown in Figs. 2 (ii)-(b) and (c). QPSK, 8PSK, 16APSK, 32APSK, and 64APSK modulation types changed. LDPC (R = 3/4) was applied for FEC. Figure 3 shows the measured BER performances in the satellite experiments. As Fig. 3 shows, BER performances over satellite transponders were almost the same regardless of spectrum division. This demonstrates that spectrum division by DSDT is feasible and practical in satellite communications.

4 Conclusion

We have been proposing a direct spectrum division transmission (DSDT) technique that can divide a single carrier signal into multiple sub-spectra and assign them to dispersed frequency resources of a satellite transponder to improve the spectrum efficiency of a whole system. For its feasibility verification, we introduced the results of satellite experiments with DSDT over multiple satellite transponders. Our experiments confirmed that DSDT was practical because BER performances of divided signals were almost the same as that of a single carrier.