STBC Decode-And-Forward OFDM Relay for Unmmaned Aircraft System

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***Abstract* — In a large scale disaster, many areas may lose a means of communications and become isolated. Unmanned aircraft system (UAS) is able to quickly provide the communications means to isolated areas. In this paper, STBC decode-and-forward OFDM relay for UAS is presented. A group of UAs forms an OFDM single frequency network (SFN) for STBC decode-and-forward relay. STBC decode-and-forward OFDM relay achieves large spatial diversity gain and can improve the relay communication quality. In this paper, after describing the STBC decode-and-forward OFDM relay, computer simulation result is discussed in terms of throughput.**

Index Terms — Unmanned aircraft system, cooperative relay communication, space-time block coding.

I. INTRODUCTION

Recent advancement in wireless communications technology makes it possible for everyone to communicate with other people from anywhere or access to any databases distributed over the world anytime from anywhere. Now, our society is heavily relying on modern communications network infrastructure. The Great East Japan Earthquake damaged seriously the Tohoku area facing Pacific Ocean in March 2011 [1]. If such a large scale disaster happens again, communications networks may be paralyzed due to electric power supply outage, communication cable cutoff, etc. and as a consequence, some areas may be isolated. This may cause serious disorder in our society. To prevent this, the communications networks should be made resilient against natural disasters such as earthquake, tsunami, typhoon, etc. Right after the Great East Japan Earthquake, we initiated several projects to develop disaster-resilient communications networks [2, 3]. Among them is the unmanned aircraft system (UAS).

A large scale disaster like the Great East Japan Earthquake may cause many isolated areas which have lost a means of communications. In such a case, UAS may be able to quickly provide the communications means to isolated areas [4-6]. A group of unmanned aircrafts (UAs) can be used as relay nodes to connect an isolated area with normal (not damaged) area. However, UAs are flying over the isolated area, the channels between ground station (GS) and UA become unstable [6]. Furthermore, UA based relay communications may suffer from interference from other wireless communications networks using the same frequency. Therefore, the relay communications quality degrades. Applying space-time block coded (STBC) decode-and-forward relay can remedy this problem. In this paper, STBC decode-and-forward OFDM relay for UAS is presented and its throughput performance is evaluated by computer simulation.

The remainder of this paper is organized as follows. The STBC decode-and-forward relay is introduced in Sect. II. Sect. III discusses the computer simulation results and Sect IV offers conclusions.

II. STBC DECODE-AND-FORWARD RELAY

Fig. 1 illustrates the conceptual structure of UAS relay. A group of UAs forms a single frequency network (SFN) for STBC decode-and-forward relay. STBC decode-and-forward relay achieves large spatial diversity gain and can improve the relay communications quality.

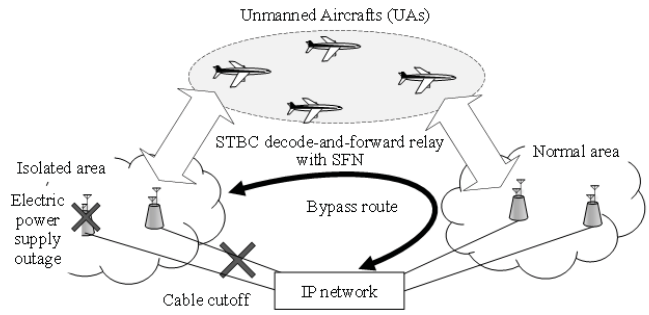

Fig. 1. UAS relay network.

Multiple UA antennas serve as spatial diversity antennas to improve the decode-and-forward relay performance. Well-known diversity scheme is the maximal-ratio transmit diversity [7]; however, the channel state information (CSI) is required at UA relay node. On the other hand, the use of STBC diversity in relaying may be able to alleviate the complexity problem at UA relay node. There are two types of STBC diversity: space-time block coded transmit diversity (STTD) [8, 9] and space-time block coded joint transmit/receive diversity (STBC-JTRD) [10, 11]. STTD is a combination of STBC and receive frequency-domain equalization (receive FDE) while STBC-JTRD is a combination of STBC and transmit frequency-domain equalization (transmit FDE). In this paper, the former and the latter are called STBC-RE and STBC-TE, respectively.

Two types of STBC relay scheme are considered: STBC TE/RE relay and STBC RE/TE relay. STBC TE/RE relay applies STBC-TE and STBC-RE to the source GS-to-UA link and UA-to-the destination GS link, respectively. On the other hand, STBC RE/TE relay applies STBC-RE and STBC-TE to the source GS-to-UA link and UA-to-the destination GS link, respectively. Their OFDM transmitter/receiver structures are illustrated in Figs. 2 and 3. The source and destination GSs and UA relay are assumed to have N_{GS} and N_{UA} antennas, respectively.

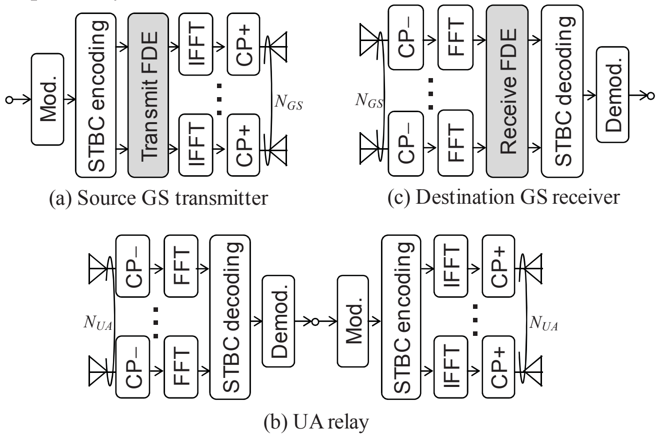

Fig. 2. STBC TE/RE relay.

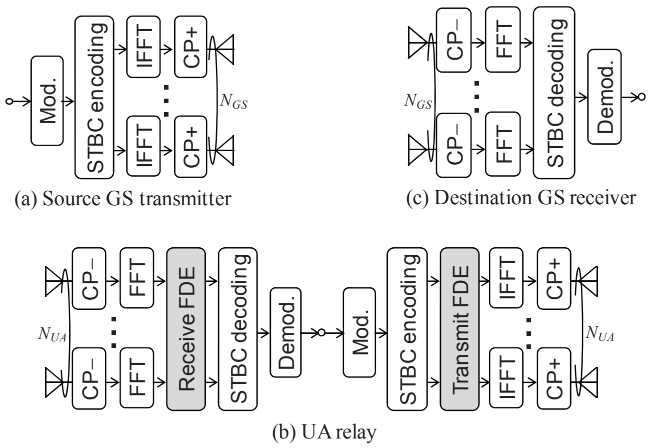

Fig. 3. STBC RE/TE relay.

Below, the STBC TE/RE relay operation is described. At the source GS transmitter, a sequence of J blocks of N_c data modulated symbols each is encoded into N_{UA} streams of Q coded block each by STBC encoding and then transformed into N_{GS} streams of Q coded signal blocks each by transmit FDE. Denoting $N_{UA}\times Q$ STBC coded signal matrix at each OFDM subcarrier (the subcarrier index is omitted) as $\mathbf{X}$, $N_{GS}\times Q$ transmit signal block matrix $\mathbf{Y}$ after the transmit FDE is given as $\mathbf{Y}=\mathbf{W}_t\mathbf{X}$ where $\mathbf{W}_t = \mathbf{H}_{S-U}^H \Big/ \sqrt{\mathrm{tr}\left(\mathbf{H}_{S-U}^H \mathbf{H}_{S-U}\right)}$ is an $N_{GS}\times N_{UA}$ transmit FDE weight matrix with $\mathbf{H}_{S\text{-}U}$ being $N_{UA}\times N_{GS}$ channel transfer matrix of the link between source GS and UA relay. After performing N_c-point inverse fast Fourier transform (IFFT) and cyclic prefix (CP) insertion, the source GS transmits the encoded signal to UA relay node in the first time-slot.

At UA relay receiver, after CP removal, a received sequence of superimposed Q signal blocks on each of N_{UA} receive antenna is transformed into the frequency-domain signal by N_c-point FFT and then, STBC decoding and data demodulation is carried out. The recovered data blocks are re-modulated and re-encoded into N_{UA} streams of Q coded signal blocks each by STBC encoding. After performing N_c-point IFFT and CP insertion, the UA forwards the encoded signal to the destination GS in the second time-slot.

At the destination GS receiver, a received sequence of superimposed Q signal blocks on each receive antenna is transformed into the frequency-domain received signal by N_c-point FFT. The destination GS receiver performs the receive FDE to the received signal. Denoting $N_{GS}\times Q$ frequency-domain received signal matrix at each OFDM subcarrier as $\mathbf{R}$, $N_{UA}\times Q$ received signal matrix $\hat{\mathbf{R}}$ after the received FDE is given as $\hat{\mathbf{R}} = \mathbf{W}_r\mathbf{R}$ where $\mathbf{W}_r = \mathbf{H}_{U-D}^H$ is an $N_{UA}\times N_{GS}$ receive FDE weight matrix with $\mathbf{H}_{U\text{-}D}$ being $N_{GS}\times N_{UA}$ channel transfer matrix of the link between UA relay and destination GS. The destination GS receiver performs STBC decoding to obtain STBC decoded signal, and finally, data demodulation.

STBC TE/RE relay requires CSI at source GS transmitter and destination GS receiver while STBC RE/TE relay requires CSI at UA relay receiver and transmitter. Therefore, the former can alleviate the complexity problem of the UA rely node. The STBC coding rate R_{STBC}=J/Q depends on N_{UA} for STBC TE/RE relay while on N_{GS} for STBC RE/TE relay as shown in Table I.

Table II compares the STBC TE/RE relay and STBC RE/TE relay. STBC TE/RE relay requires no CSI at UA relay node while STBC TE/RE relay requires CSI at both source and destination GSs. The STBC coding rate depends on the number N_{UA} of UA relay node antennas only. On the other hand, STBC RE/TE relay requires CSI at UA relay node while it requires no CSI at source and destination GSs. The STBC encoding rate depends on the number of GS antennas.

TABLE I

COMBINATION OF N_{UA}, N_{GS}, J, Q, AND R_{STBC}

STBC TE/RE relay				STBC RE/TE relay			
N_{UA}	J	Q	R_{STBC}	N_{GS}	J	Q	R_{STBC}
2	2	2	1	2	2	2	1
3	3	4	3/4	3	3	4	3/4
4	3	4	3/4	4	3	4	3/4

TABLE II

COMPARISON OF STBC TE/RE RELAY AND STBC RE/TE RELAY

Relay scheme	Station	No. of antennas w/o reducing STBC encoding rate	CSI
STBC TE/RE relay	UA	≤ 2	Not required
	GS	Aibitrary	Required
STBC RE/TE relay	UA	Aibitrary	Required
	GS	≤ 2	Not required

III. Computer Simulation

The throughput performance of STBC decode-and-forward relay is evaluated by computer simulation. Packet transmission of 1,536 bits/packet using QPSK data modulation is considered. OFDM with N_c=64 subcarriers and N_{cp}=16-symbol CP is assumed. The channel is assumed to be a symbol-spaced L=8 path frequency-selective block Nakagami-Rice fading with K factor of 10dB. Perfect CSI is assumed.

Fig. 4 shows the throughput S for the case of N_{GS}=N_{UA}=2, where $\Gamma_{S\text{-}U}$ and $\Gamma_{U\text{-}D}$ denote the SNR of source GS-to-UA relay link and that of UA relay-to-destination GS link, respectively. Throughput S is defined as $S=(1-PER)N_c/(N_c+N_{cp})$, where PER is the packet error rate. For comparison, the throughput for the case of N_{GS}=N_{UA}=1 is also shown in Fig. 4. It is seen from Fig. 4 that STBC decode-and-forward relay using N_{GS}=N_{UA}=2 improves significantly the throughput compared with the case of N_{GS}=N_{UA}=1. STBC decode-and-forward relay can reduce by about 4dB the transmit power required for S=0.72bps/Hz. Also seen from Fig. 4 is that STBC TE/RE relay achieves the same throughput as STBC RE/TE relay while alleviating the complexity problem of UA relay node.

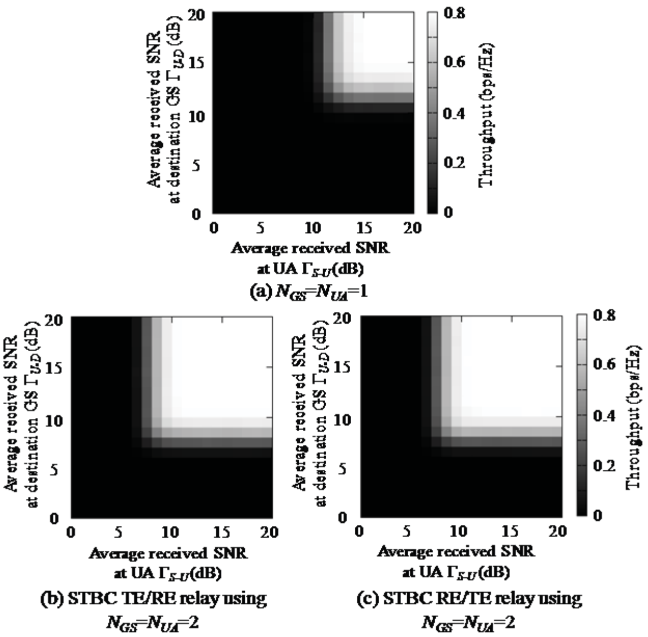

Fig. 4. Throughput.

IV. Conclusion

In this paper, we described the STBC decode-and-forward relay for UAS. Two types of STBC relay were presented: STBC TE/RE relay and STBC RE/TE relay. It was shown by computer simulation that STBC TE/RE relay achieves the same throughput as STBC RE/TE relay while alleviating the complexity problem of UA relay node.

Acknowledgement

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References

[1] http://japan.kantei.go.jp/incident/index.html.97-2402, Dec. 2000.

[2] F. Adachi, et al., "R&D Project of Multilayered Communications Network -For Disaster-resilient Communications-," Proc. 15th International Symposium on Wireless Personal Multimedia Communications (WPMC2012), Taipei, Taiwan, 24-27 Sept. 2012.

[3] T. Sakano, et al., "Disaster Resilient Networking - A New Vision based on Movable and Deployable Resource Units (MDRUs)," IEEE Network Magazine, Vol. 27, Issue 4, pp. 40-46, Jul.-Aug. 2013.

[4] E. W. Frew and T. X. Brown, "Airborne communication networks for small unmanned aircraft systems," Proc. IEEE, Vol. 96, No. 12, pp. 2008-2027, Dec. 2008.

[5] R. Miura, et al., "Disaster-resilient wireless mesh network – experimental test-bed and demonstration-," Proc. 2013 16th International Symposium on Wireless Personal Multimedia Communications (WPMC2013), USA, June 2013

[6] K. Takizawa, et al., "Performance evaluation on path diversity in radio links between unmanned aerial vehicles," Proc. 2013 IEEE 24th Annual International Symposium on personal, Indoor, and Mobile Radio Communications (PIMRC2013), UK, Sept. 2013.

[7] P. A. Dighe, et al., "Analysis of transmit-receive diversity in Rayleigh fading," Proc. IEEE GLOBECOM'2001, Vol. 2, pp. 1132-1136, Nov. 2001.

[8] S. M. Alamouti, "A simple transmit diversity technique for wireless communication," IEEE J. Sel. Areas. Commun., Vol. 16, No. 8, pp. 1451-1458, Oct. 1998.

[9] V. Tarokh, et al., "Space-time block coding for wireless communications: performance results," IEEE J. Sel. Areas. Commun., Vol. 17, No. 3, pp. 451-460, Mar. 1999.

[10] H. Tomeba, et al., "Space-time block coded joint transmit/receive diversity in a frequency-nonselective Rayleigh fading channel," IEICE Trans. Commun., Vol. E89-B, No. 8, pp. 2189-2195, Aug. 2006.

[11] H. Tomeba, et al., "Frequency-domain space-time block coded joint transmit/receive diversity for direct-sequence spread spectrum signal transmission," IEICE Trans. Commun., Vol. E90-B, No. 3, pp. 597-606, Mar. 2007.