Experimental Study of Wide Area SIMO for Ionospheric HF Radio Links

Zhu Jin[*1] *,Yinsheng Ma*[1] *,and Yonghong Wu*[1]

[1] China Research institute of Radiowave Propagation (CRIRP), Qingdao 266107, P. R. China. E-mail: bg_islang@163.com, wyh7426@sina.com

Abstract

We propose a wide area cooperative communication scheme for ionospheric HF links in order to increase communication reliability and throughput under a given range and power. By exploiting multiple radios in a collaborative fashion, we can obtain diversity gains similar to Single Input Multiple Output (SIMO).Based on experimental results, this paper demonstrates the benefits of wide area cooperative communication strategies, and gives correlation function of diversity channels with different distance by measuring channel parameters.

1. Introduction

Current HF communication systems are not used only for traditional voice transmission, but also for data communication (including file transfer, facsimile, email, Internet access), still image transmission, and even real-time video conferencing [1, 2]. However, demands for high-speed data communication are still imposing new requirements on HF system design, and innovative approaches are required.

Currently technologies of wireless networks are far ahead of HF communication systems in the scale. Contrary to some predictions, within the last decade, we have witnessed exciting developments in the area of wireless communication theory, most notably multiple input multiple-output (MIMO) and cooperative communication techniques. MIMO systems involve the deployment of multiple antennas at the transmitter and/or receiving side and achieve significant improvements in transmission reliability and throughput. Multiple-antenna systems have been studied extensively in the context of transmission in the UHF and SHF bands. the process of accommodation of technical solutions from the area of wireless communication systems to the HF area is possible[3].

2. Difficulty and Goals

There are relatively few papers devoted to the use of the cooperative SIMO technology in HF channels [4,5]. The majority of them are devoted to the use of MIMO, based on the polarization diversity of the received signal. Reportedly, in the accessible literature there is few information about the possibility of use of cooperative SIMO in HF channels. It is traditionally considered that MIMO technologies can't provide significant improvement of HF communication channel characteristics because of: 1) For a visible de-correlation of received signal by each antenna, antennas with big geometrical size are needed. 2) Low value of a signal-to-noise ratio (SNR) complicates the estimation of a channel matrix even on the receiving side. 3) Using HF channels as a feedback channel, transmission of channel state information from receiving side to the transmitting side is carried out with a big time delay and a rough quantization, because of a relatively low transmission rate in a communication channel. It decreases the efficiency of the pre-coding methods on the transmission side. 4) The channel is almost always a multipath and frequency selective. A big delay interval between beams of the received signal does not permit the use of optimal algorithms of time domain equalization even of Single-In-Single-Out channel because of the exponential dependency of their complexity on the delay. The necessity of an additional use of space equalization algorithms for MIMO causes even bigger deviation from the use of optimal receiving procedures [6].

However, It includes the following methods to overcome the huge disadvantage cooperative MIMO used in the range of HF bands: 1) information pre-detecting, the removal of low SNR signal can avoid the deterioration of the synthetic signal. 2) on merge of the several set correspondents for formation of the virtual receiving and transmitting antenna array, using the fixed-site network resources and broadcast characteristics of HF communication. An option of cooperative MIMO in HF range based on the use of retranslation was described in [7]. This paper will consider Wide Area cooperative SIMO.

Our goal is to extract the channel impulse response functions through experiments, then calculate the correlation of cooperative diversity channel, and verify the reliability of cooperative diversity communication in HF bands.

3. System Description

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

The testing was implemented in November, 2012 under the condition of quiescent state of the middle-latitude ionosphere. Communication interval was 10 minutes.

3.1 Device description

Table 1 shows the most relevant parameters about the transmitting station and receiving stations. The transmitting radio station is located in Qingdao with capacity 1000W involved, The receiving station is located in Beijing, Hangzhou, and Xi'an Respectively. In Beijing there are two receiving sites which are separated up to 50 km. The involved antennas are shown in TABLE 1. The distance of three receiving stations and launching stations were 550Km, 1060Km, 650Km.

TABLE 1 Transmitting and receiving station descriptions

	Transmitter side	Recevier side			
		A	B	C	D
Location	QIng Dao	Bei jing (Suburb)	Bei jing (center)	Hang zhou	Nan jing
Antenna	dipole	whip	dipole	dipole	dipole
Amplifier	1Kw				
Distances	550Km	50Km			
	1060Km				
	650Km				

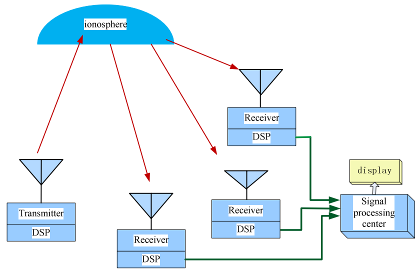

Fig.1 Structure block diagram experimental system.

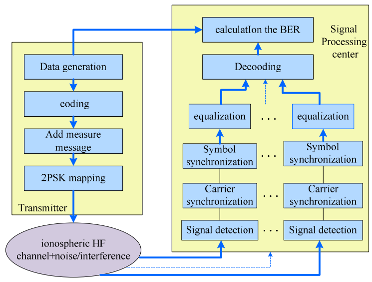

Fig.2 block diagram of of entire reception side

Entire experimental system shown in Fig.1, The signal is emitted through broadcast, and is received by four receiving stations simultaneously. Carrier frequency and signal receiving time of each receiving site are controlled by signal processing center. The received audio signal is sampled by DSP module of each receiving site. Sampling rate is 96kHz, and then added time label, Transmitted to the signal processing center via a wired network.

3.2 waveform description

Each packet data format used in the experiment includes three parts of automatic gain control (AGC), channel parameter measurement data and information data. The signal was carried out at deactivation of AGC mode and specially selected attenuator on the input of the receiving capacity amplifier for providing sufficient dynamic range, which guaranteed the acceptable level of nonlinear distortions.

Channel parameter measurement data was Barker code which was spread spectrum using PN sequence, Spread spectrum sequence length of 255 bits, bark codes of length 11, mainly were used for carrier synchronization, symbol synchronization and channel impulse response calculation. The choice of the length was made by criterion of the highest accuracy of measurements on the assumption of measured values of doppler dispersion and the SNR. In real time, by means of the matched filtering, the response signal was generated for each of the transmitted signals.

Information data was 2PSK signal with forward error correction (FEC). The process of signal generation and receiving signal are shown in Fig.2. Signal generated by transmitter was added noise/interference via the ionosphere reflection channel, The signal received by four sites at the same time via detection, carrier frequency synchronization, symbol synchronization and equalization respectively, and then merged to be decoded for BER calculation. Meanwhile, after the symbol synchronization, channel impulse response can be extracted from channel parameter measurement data,and to calculate the cooperative diversity channel matrix.

4 Principle of channel analysis

Transmitted signal is represented as $x(t)$, Receive data in either receiving can be expressed as $y(t)=\int_{-\infty}^{\infty} c(\tau,t)x(t-\tau)\,d\tau+n(t)$,where $c(\tau,t)$ is channel impulse response， $n(t)$ is noise/interference.When duration of PN sequence is T, The received signal is divided into segments in time length T. The lth segment signal and the input signal are done correlation operations: $R_{xy_l}\left(\tau'\right)=\frac{1}{T}\int_{l}^{l+T} y_l(t)x\left(t+\tau'\right)dt \approx c\left(\tau',t_l\right)$. Based on the above equation, we can get impulse response function $c(\tau,t)$ through τ' and t_l change. In multipath channel, fading and delay are considered to be not relevant, So the auto-correlation function is: $R_c(\tau,\Delta t)=E\left[c(\tau,t)c^*(\tau,t+\Delta t)\right]$. Fourier transforming $R_c(\tau,\Delta t)$ can obtain scattering function. Delay power spectrum is a function of additional delay τ which refer to constant delay τ_0 ,which is the first arriving time of detectable signal.

As noise floor threshold, $-XdB$ is used to distinguish the received multipath component and additive noise.

$$d_\tau = \max\left(\tau\left|\left(P(\tau)-\max\left(P(\tau)\right)\right)>-X\right)-\min\left(\tau\left|\left(P(\tau)-\max\left(P(\tau)\right)\right)>-X\right) \quad (1)$$

Where $p(\tau)$ is delay power spectrum, Dispersive Characteristics in frequency domain of channel can be described as doppler spread, Which can be obtained by doppler power spectrum. Doppler spread is the square root of the second central moment of doppler power spectrum.

$$D = 2\,\mathrm{sqrt}\left(\frac{\int_{-\infty}^{+\infty}\left(\upsilon-\bar{\upsilon}\right)^2 Q(\upsilon)\,d\upsilon}{\int_{-\infty}^{+\infty} Q(\upsilon)\,d\upsilon}\right) \quad (2)$$

where $\bar{\upsilon}$ is doppler shift, $Q(\upsilon)$ is doppler power spectrum.

5 Experimental results

Processing of measurement results not in real time was implemented in MATLAB. Based on channel parameter analysis formulas of the previous section, channel impulse response function is calculated by utilizing the received channel measurement data, then correlation function of channel impulse response and correlation function of channel parameters between different diversity channel were analyzed.

In measurements campaigns, more than 600 signals were registered and analyzed. For signals of two Beijing receiving sites separated 50km, focus on analyzing the correlation between the channel parameters of two sites. Correlation about delay spread is shown in Fig.3, Correlation about doppler spread is shown in Fig.4.

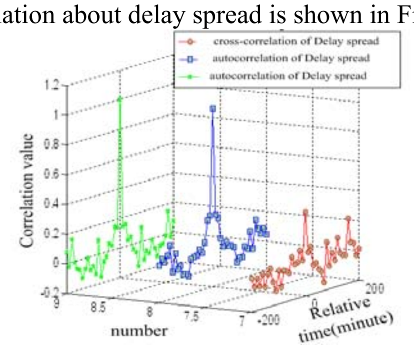

Fig.3 correlation diagram about delay spread

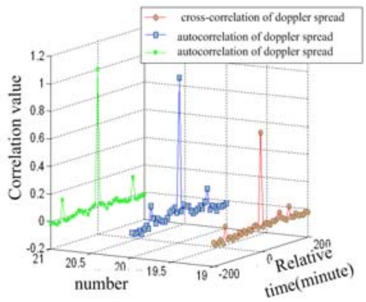

Fig.4 correlation diagram about doppler spread

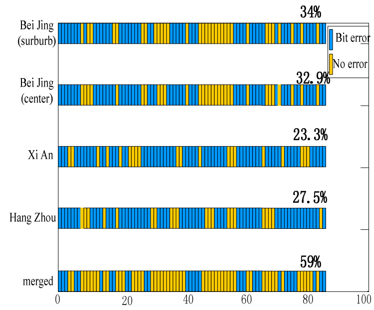

Fig.5 Analysis for no error bit statistics

As can be seen, for the delay spread parameter, cross-correlation of receiving data by two sites separated 50km less than auto-correlation of receiving data with interval of ten minutes. For the doppler spread parameter, The result show just the opposite.

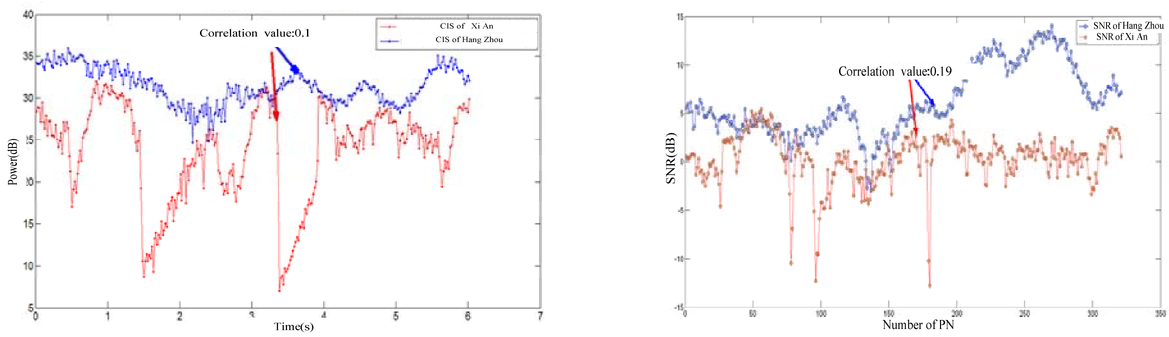

Fig. 6 Comparison between Xi'an and Hangzhou(left: CIS correlation, right: SNR correlation)

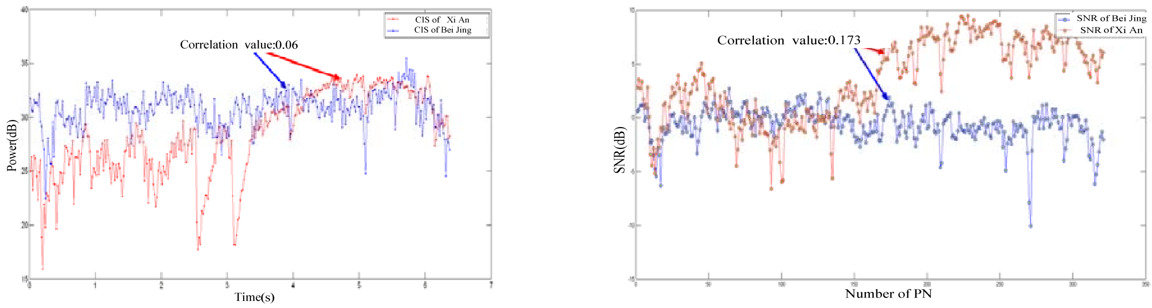

Fig. 7 Comparison between Xi'an and B(left: CIS correlation, right: SNR correlation)

For more distant Beijing, Xi'an and Hangzhou receiving station, focuses on the correlation analysis of channel impulse response and instantaneous SNR between receiving data of different receiving sites. The correlation of channel impulse response and instantaneous SNR between receiving data of Hangzhou and Xi'an is shown in Fig. 6. auto-correlation value is 0.19 and 0.1 respectively. Similarly, correlation about receiving data between Beijing and Hangzhou is shown in Fig.7. Auto-correlation value is 0.06 and 0.173 respectively. Each of the four receiving end data retranslation can be considered completely irrelevant.

Each of the receiving data in four sites and merged data are translated according means shown in Fig.2. Bit error statistics is shown in Fig.5. It is easy to see that correlation of bit error between two sites in Beijing is very great. Joint decoding of receiving data in four sites can significantly improve the reliability of communication.

6. Conclusions

As a result of experimental data processing, on the basis of direct measurement of channel matrix elements, HF range wide area SIMO channel characteristics were obtained.

In small time scales: (1) The instantaneous fading and SNR between different wide area receiving sits have no correlation simultaneously. (2)Receiving data from several sites separated distantly joint decoding can significantly improve the reliability of communication. In large time scale , correlation of data available between different receiving sites is very small when sites are separated about 500km, By contrast, which is very great when sites are separated about 50km.

7. References

1. E. E. Johnson, "Interoperability and Performance Issues in HF E-Mail," *IEEE Military Communications Conference,* Oct. 2001, pp. 442–446.

2. A. Navarro et al., "Video Conference over HF Packet Radio Channels," *IEEE Military Communications Conference,* Oct. 2003, pp. 393–97.

3. Murat Uysal, Mohammad R. Heidarpour "Cooperative Communication Techniques for Future-Generation HF Radios" *IEEE Communications Magazine* ,Oct. 2012, pp. 393–97.

4. S. D. Gunashekar, E. M. Warrington, S. Salous, S. M. Feeney,N. M. Abbasi, L. Bertel, D. Lemur, and M. Oger, "Investigations into the feasibility of multiple input multiple output techniques within the HF band: Preliminary results," *Radio Sci.*, 44, RS0A19, 2009.

5. Nasir Mehmood Abbasi. "An experimental investigation into the feasibility of MIMO techniques within the HF band" PhD Thesis. Department of Engineering, University of Leicester, August 2011.

6. Vasily Yu. Doroshenko, Inna O. Dvorakova, "Experimental Study of Cooperative MIMO at HF Band" *IEEE Military Communications Conference,* August 2013. pp. 159–165.

7. H.J. Strangeways, "Estimation of signal correlation at spaced antennas for multi-moded ionospherically reflected signals and its effect on the capacity of SIMO and MIMO HF links," *The IET 10th International Conference on Ionospheric Radio Systems and Techniques,* London, UK, 2007, pp. 306 - 310.