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Multi-User Communications in HF Band with Power Control

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Abstract

A long-distance communication system with low-cost infrastructure and easy installation is required in isolated areas, especially for emergency case. High frequency (HF) communication system (3-30 MHz) is proposed as emergency communication, which can achieve long-distance signal transmission by utilizing the ionospheric reflections. However, the channel bandwidth of a single HF radio transmission is limited to 3-20 kHz typically. Therefore more ingenuity is required to achieve sufficient channel capacity. To overcome the limitation, this paper attempts to make possible multi-user communications with low interference in HF digital radio communications. The study reported herein investigates the potential use of time-reversal division multiple access (TRDMA) uplink scheme to implement HF multi-user communications. Simulation results show that SIR is relatively uniform in a range of 4 dB by employing a power control mechanism, regardless of the distance between a base transmitter and the user.

1 Introduction

While wireless telecommunication networks and satellite communication systems may be available in major cities and wealthier areas, these are often not realized in more isolated areas. Furthermore, these systems often break down when a natural disaster occurs [2]. HF radio communication systems occupying 3 – 30 MHz is proposed as an emergency communication for long distance area by utilizing the ionospheric reflections [3]. However, the channel bandwidth of a single HF radio transmission is limited around 3-20 kHz [4].

More ingenuity is required to achieve sufficient channel capacity, especially since the ionospheric radio channel suffers from multipath fading and time and frequency dispersion. To maximize the utilization of HF communication for an emergency situation, the multiple access schemes that allow multiple users in the same channel is necessary. Conventional multiple access schemes, such as FDMA, TDMA and CDMA [5], require larger bandwidth consumption to accommodate the aggregate user information rate and are designed to serve communications among many users. Therefore, these schemes are not preferable in this case due to the very limited bandwidth available [4] in the HF bands, and inter-symbol interference (ISI) due to ionospheric reflections [6].

The time-reversal division multiple access (TRDMA) scheme, which was originally proposed by Han and Liu [1] for wireless communication applications is suggested as a new ideal multiple access techniques based on high spatial focusing, which utilize low correlation among HF channel impulse responses (CIR).

With the orthogonally spatial variations of O and X waves of over ionospheric channel [7], there might be orthogonality between complex impulse responses of two different HF channels located quite distant apart. This potential orthogonality can be exploited for realizing multiple accesses by adopting the TRDMA.

This paper proposed the implementation of TRDMA uplink scheme for the use of multi-user communication in the HF band. The intended evaluation lies in the use of TRDMA for hubs or base stations, to minimize the interference effects between user terminals that access the base stations using ionospheric channels. Before we implement TRDMA, the low correlation should be achieved by computing the spatial correlation between links. The authors in [8] have shown that the correlations between HF channels are low.

The evaluation shows the near-far effect between users when identical transmit powers are used for all users located in different locations with different ranges from the transmitter. The power control mechanism proves to compensate for the effect of distance-dependent propagation loss.

2 TRDMA Uplink Scheme Concept

TRDMA utilizes time reversal (TR) signal transmission technique in multi-user communication system over multipath channels [9], where signals from different users are separated independently by TRDMA. The TR technique has been proposed as a new scheme which enables multi-user to send an independent message simultaneously by utilizing spatial focusing methods in a multipath environment.

Consider multi-user communications using the TRDMA system, as depicted in Figure 1, consist of a base station (BS) and N simultaneously active users in the multi-path environment. The BS maintains a copy of the channel impulse response, $h_n(t)$ between user and BS, called time reversal mirror (TRM).

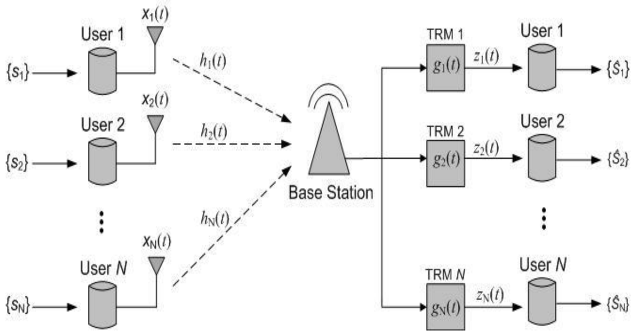

Figure 1. Block diagram of multi-user communications using the TRDMA system.

The signal $x_n(t)$ transmitted by the n-th user is received by the BS after passing through the channel $h_n(t)$. The TRM for the n-th user has an impulse response copy of the form [1]:

$$g_n(t) = \frac{h_n^*(T-t)}{\sqrt{\int_0^T |h_n(t)|^2 dt}} \quad (1)$$

where $h_n^*(T-t)$ is the conjugate of the mirrored copy of the channel impulse response $h_n(t)$ for the n-th user.

The following step after recording channel response copy is the transmission phase. In this phase, each user transmits signal $x_n(t)$ to the base station through their respective multi-path channels.

3 Power Control Mechanism

In an uplink multi-user communication scheme, there are multiple transmitters (users) and one receiver (base station) [1]. If we assume that N users operate in the same frequency band and simultaneously transmit independent bit streams to the BS with identical transmit power, but they are located in different range from the BS, while the multi-access system applies TRDMA to separate them the near-far effect will occur. To mitigate it, a power control mechanism is proposed to compensate for the propagation loss related to the distance between the transmitter and the receiver (see Figure 2).

First, we assume the transmit power, Pt is 30 Watt or 14.77 dBW for each transmitter in Kupang and Merauke. Then calculate the received power for each link obtained from ITU-R P-533-11 [10] indicated with a black-dashed line in Figure 2. Note that ITU-R P-533-11 calculates the propagation losses due to propagation for each reflection mode {1F2, 2F2, ... 6F2}, so the total propagation losses listed in Figure 3 are the accumulation of propagation losses by the ionosphere reflection. The average received power on each link, Pr_{ave} = -120 dBW. In case for a link with $Pr < Pr_{ave}$ 120 W, it is necessary to calculate the required transmit power. Regarding Figure 3, since the propagation loss in the dB scale is almost linearly increased with the distance between the transmitter and the receiver, we calculate the linear regression between propagation losses and trajectory distance.

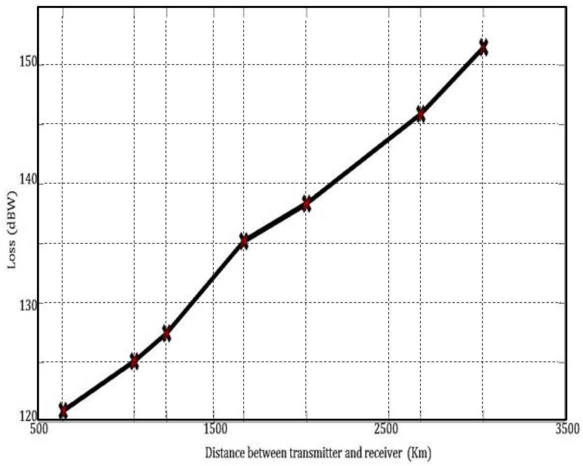

Figure 2. Propagation loss related to the distance between transmitter and receiver.

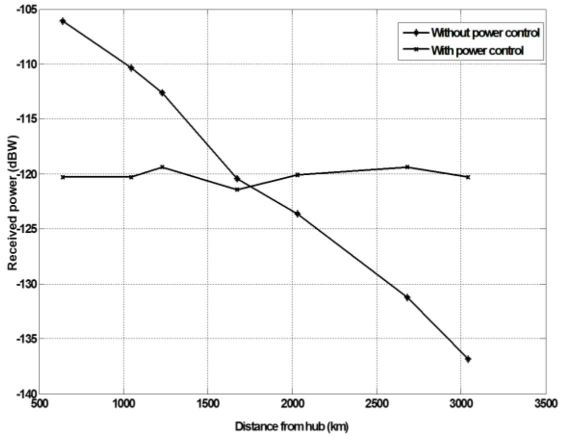

Figure 3. Received power related to the distance between transmitter and receiver.

It was found that the magnitude of the gradient m is approximately 0.0128 dB/km. The propagation loss at the reference distance is L_0 = 112.3125 dB.

To deal with this distance-varying loss, the new transmit power for each transmitter is expressed as:

$$\dot{P}_t = P_{r\,ave} + L_o + d \times m \quad (2)$$

where $\dot{P}t$ denotes the new transmit power used for each link (dBW), Pr_{ave} = -120 dBW denotes the received power estimation for each link which is obtained from the average received power, L_0 denotes propagation loss at the reference distance (dB), d denotes the distance between transmitter and receiver (km), m denotes gradient of the linear regression approach, which is equal to 0.0128 dB/km.

4 Results and Discussions

The SIR performance was evaluated using the TRDMA scheme that has been explained. The investigations were performed in this study by evaluating signal-to-interference power ratio (SIR) performance on the Merauke-Surabaya link situated in the equatorial zone of Indonesia (see Figure 4).

Figure 4. A map showing the links of users.

The links of users that serve as interferers are Surabaya-Dompu, Surabaya-Maumere, Surabaya-Kupang, Surabaya-Leti Island, Surabaya-Saumlaki, Surabaya-Timika, and Surabaya-Merauke links. We assume the interference transmitter works using the same TRDMA multiple access techniques at the same frequency and the transmitted signal radiates toward the same receiver in Surabaya.

For the desired user (user 0-th), the SIR value in the TRDMA uplink can be calculated as:

$$SIR_o = \frac{|g_o * h_o|^2}{\sum_{n=1}^{N-1} |g_o * h_n|^2} \tag{3}$$

where SIR_o denotes SIR experienced by the desired transmitter on the Kupang-Merauke link, g_o denotes TRM for the corresponding channel (Kupang-Merauke), h_o denotes the channel response for Kupang-Merauke, while h_n denotes the channel response for the n-th transmitter.

We compare the SIR performance of each transmitter with and without power control mechanism. Assume that a desired transmitter experiences from only two interferences, whereas the other transmitters are non-active. The results shown in Figure 5 are average SIR obtained over ten runs with random multipath phases. As expected, without power control, the SIR performance is worse, whereas, for the case with power control, all links experience nearly uniform SIR, regardless of the length of the link (distance between the transmitter and the receiver). It can be observed that the SIR suffers from the near-far effect, especially for the furthest transmitters, whenever all transmitters assume the same transmit power.

5 Conclusions

The potential of multi-user schemes, by adopting TRDMA uplink schemes to evaluate the hub infrastructure in HF digital communication has been reported. This system utilizes orthogonally spatial variations of O and X waves to obtain low correlation among users in regional areas, with distances up to 3000 km. By carrying out the power control mechanism for each transmitter, the received power obtained at the receiver is nearly uniform, with average SIR varying only

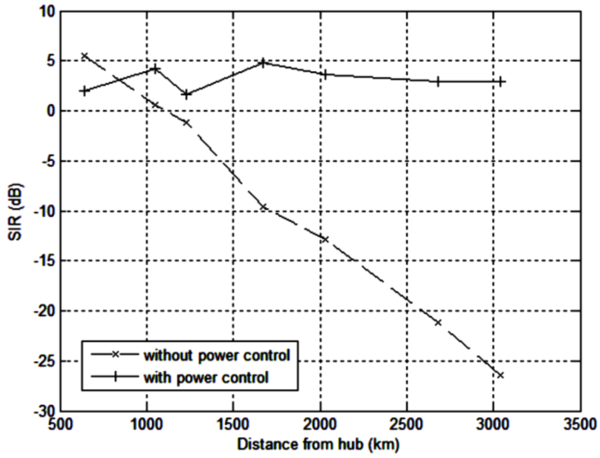

Figure 5. SIR performance with and without power control mechanism.

in the range of 4 dB for all transmitters, regardless of the distance between the transmitter and the receiver.

6 Acknowledgements

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7 References

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