The SNR Performance of Cooperative Diversity in HF Skywave Communication Systems

Muhammad Said¹, Saiful Do, Abdullah²,

¹Department of Electrical Engineering, ²Department of Informatics, Faculty of Engineering, Universitas Khairun, Indonesia
E-mail: saidsanatu@gmail.com¹, syaiful.abdullah@unkhair.ac.id²

Abstract. High Frequency (HF) communication systems uses the ionosphere to reflect signals from the source (S) to the destination (D) on earth. Variation of the height of the earth’s ionosphere layer causes the received signal also to fluctuate and affects the signal-to-noise ratio (SNR) at the destination. To maintain the SNR remains good value at the destination, cooperative communication system can be a solution. In cooperative communication system, all sources cooperate and coordinate with the relay (R) to improve the quality of the signal at the destination. In this communication system, the destination receives two signals, each derived from source and from relay. This paper divides the simulation observation time into 3 categories, namely midnight to dawn (00:00 and 04:00), morning to noon (08:00 and 12:00) and afternoon to evening (16:00 and 20:00). In all categories of midnight to dawn, morning to noon and afternoon to evening, cooperative communication systems with maximal ratio combining (S-R-D) provide greater diversity gain than non cooperative communication systems (S-R-D).

Keywords: High frequency, cooperative diversity, maximal ratio combining

1. Introduction

Amateur radio communication has so far been limited to voice or text and low speed data communication. Whereas for higher speed data communication, a better quality communication system is needed. Quality improvement is very dependent on the condition of the propagation medium used. HF channels are very susceptible to environmental propagation conditions due to changes in canal response that is very fast due to variations in ionospheric conditions. Diurnal variation of Maximum Usable Frequency (MUF), Lowest Usable Frequency (LUF) and limited bandwidth make the communication system performance on this channel difficult to be relied on for point to point HF communication systems. Several methods have been developed to improve the performance of HF communication systems including the use of Automatic Link Establishment (ALE) [2] [6], where the system tunes regularly so that communication between the source and receiver can continue. However, the relatively expensive device price constraints and the use of many HF frequency channels make this system not widely used and only used for limited purposes. Multiple Input Multiple Output (MIMO) technology has also been investigated to improve the quality of HF skywave channels. This technology has advantages in terms of increasing channel capacity and communication reliability compared to single antenna technology [5] [12]. However, the application of this technology to the HF communication system is very difficult because it requires a large space for mounting multiple antennas with spaces in the order of wavelengths, where the wavelengths on the HF channel range...
from 10 - 150 meters with a very long propagation path [4] [11]. To overcome the weaknesses of ALE and MIMO technology as explained earlier, this paper proposes the use of a cooperative diversity system on an HF communication system that aims to improve the quality of the receiving power level at the receiver. The application of a cooperative communication system requires a minimum of three (3) single antennas where each one is located on the transmitter or source (S), Relay (R) and receiver or destination (D) [3] [7] [8] [10].

2. System and Model Channel
The cooperative communication system reviewed involves three nodes, namely (S), (R) and (D). Figure 1 shows a simple model of the cooperative communication system. This model uses two phases or time slots namely phase I for communication on S-D and S-R links and phase II for R-D links assuming DF (decode and forward) relays are used.

![Figure 1. A Simple Model of Cooperative Communication Systems](image)

In phase I, S transmits the information signal received by D and R. If it is assumed that the channel is frequency-flat, the signal received by D and R can be modeled as [1].

\[ y_{sd} = \sqrt{P_1 h_{sd} x_s} + v_{sd} \]  
\[ y_{sr} = \sqrt{P_1 h_{sr} x_s} + v_{sr} \]

Where \( P_1 \) is the power transmit power by S, \( h_{sd} = \alpha_{sd} e^{j\beta_{sd}} d\) and \( h_{sr} = \alpha_{sr} e^{j\beta_{sr}} d \) is the channel coefficient of HF from S to D and from S to R where \( \alpha_{sd} \) and \( \alpha_{sr} \) in a row is the channel phase shift S-D and S-R, \( x_s \) is the signal that is transmitted, and \( v_{sd} \) and \( v_{sr} \) is thermal noise (noise thermal) [1].

In phase II, assuming the relay is DF and without error, R forwards the signal to D. The signal received by D originating from R can be modeled as [1]:

\[ y_{rd} = \sqrt{P_2 h_{rd} x_r} + v_{rd} \]

where \( P_2 \) is the signal power sent from R, \( h_{rd} \) and \( x_r \) each is the channel coefficient of HF from R to D and the signal sent by R and \( v_{rd} \) is thermal noise on the S-R link that is transmitted. The power of the R-D link is \( \gamma_{rd} = P |h_{rd}|^2 / \sigma_d^2 \), where \( \sigma_d^2 = k_B T B \) is noise power \( k_B \) is Boltzman’s constant, \( T \) is absolute room temperature and \( B \) is the system bandwidth [9].

In the system evaluated in this paper, diversity combining is done on D, where the two input branches are the S-D link in phase I and the R-D link in phase II. The output signal from the combiner can be expressed as:

\[ Z = w_{sd} y_{sd} + w_{rd} y_{rd} + v \]
Where $k = 1, 2$ respectively represent the S-D channel in phase I and the R-D channel in phase II, and $v$ is the combined noise received by D in phase I and II, while $w_k$ is weight for channel to $k$. In the system under review it is assumed that the maximum ratio of combining (MRC) with block diagrams is generally shown in Figure 2.

\[
= \sum_{k=1,2}^{2} w_k y_k^* + v \tag{4}
\]

Maximal Ratio Combining is a diversity merging technique that can maximize SNR in the receiver because it can fully utilize the diversity of space by several receiving antennas. The weighting factor on the MRC can be written down [3].

\[
w_k = \frac{h_k}{\sigma_k} = \frac{|h_k|}{\sigma_k} e^{-j\phi_k}, \text{ untuk } k=1,2 \tag{5}
\]

so the output signal on the MRC can be written:

\[
Z_{MRC} = \sqrt{\sum_{k=1}^{2} \frac{|h_k|^2}{\sigma_k^2}} x_s + \sum_{k=1}^{2} \frac{h_k}{\sigma_k^2} v_k \tag{6}
\]

SNR at receiver output can be calculated by the equation:

\[
\gamma_{MRC} = \sum_{k=1}^{2} \gamma_k \tag{7}
\]

3. Methods
System simulation with 1 relay which is assumed to connect the city of Surabaya (7.284941S, 112.796151E) and Merauke (8.531852S, 140.417236E) in Indonesia, which is 3048 km apart, with a DF (decode and forward) relay located in Ternate (0.762599S, 127.336543E), which is 1843 km from Surabaya and 1778 km from Merauke. The three cities are located near the geomagnetic equator so that they have the characteristic ionosphere type [13].
4. Simulation Result and Discussion
Configuration of HF cooperative communication system simulation refers to fig. 2 where the distance between S and D is 3048 km, the distance between S and R and the distance between R and D are 1843 km and 1778 km respectively. $P_s = P_r = 25$ watt, bandwidth system (B) = 200 KHz, Noise (N) = K.T.B, where K is Boltzmann constant = $1.38066 	imes 10^{-23}$ J/K, and T is 290 K.
Figure 4  CDF of SNR at (a) Midnight to dawn, (b) Morning to noon and (c) Afternoon to Evening
Figure 4 shows the comparison of CDF between cooperative communication systems with maximal ratio combining (MRC) with non-cooperative (S-D) and non-cooperative (S-R-D). The simulation observation time is every four hours, divided into three parts: (a) 00:00 and 04:00 (midnight to dawn), (b) 08:00 and 12:00 (morning to noon) and (c) 16:00 and 20:00 (afternoon to evening). Figure 4 (a) shows that signals sent using a non-cooperative link (S-D) cannot be received at the receiver for either 00:00 or 04:00 because the SNR at the receiver is below the threshold (9 dB).

Figure 4 (a) and table 2 (a) show the diversity gain of cooperative communication systems with MRC against non-cooperative (S-D) for 00:00 and 04:00 are 7.61 dB (60%) and 6.58 dB (respectively 40%). Figure 4 (a) and table 3 (a) show the diversity gain of a cooperative communication system with MRC against non-cooperative (S-R-D) for 00:00 and 04:00 respectively 1.69 dB and 1.92 dB.

Figure 4 (b) shows that only the non-cooperative link (S-D) for 08:00 has an SNR below the threshold. Whereas at 12:00 a.m. non-cooperative (S-D) links have an SNR above the threshold, meaning that this link can be used for data communication between source and destination without the need to utilize a relay. Utilization of communication systems with relays both non-cooperative and cooperative can increase the power level at the receiver. From Figure 4 (b) and table 2 (a) it can be seen that the diversity gain of cooperative communication systems with MRC against non-cooperative (S-D) for 08:00 and 12:00 is 6.81 dB (30%) and 5.74 dB (50%).

Figure 4 (b) and table 3 (a) also show that diversity gain cooperative communication systems with MRC against non-cooperative (S-R-D) for 08:00 and 12:00 respectively 1.95 dB and 1.61 dB.

Figure 4 (c) has a trend similar to Figure 4 (a) where data communication on non-cooperative links (S-D) for both 16:00 and 20:00 both have an average SNR value at the receiver below the specified threshold so the information data sent cannot be received. By using a relay system both for non-cooperative links (S-R-D) and for cooperative communication systems can increase the SNR at the receiver. The simulation results as in Figure 4 (c) and table 2 (a) show the diversity gain in the cooperative link with the MRC for non-cooperative (S-D) is 6.69 dB (20%) for 16:00 and 6.34 dB (10%) for 16:00 and 20:00 p.m. Figure 4 (c) and table 3 (a) show the diversity of cooperative link gain versus non-cooperative (S-R-D) 1.45 dB (10%) for 16:00 and 1.87 dB (50%) for 20 o’clock : 00.

5. Conclusions and Recommendations
This paper simulates HF Skywave cooperative communication systems based on LAPAN Ionosonde data in 2014 with a transmit power of 25 watts. From the simulation results it can be concluded as follows:
- Signals cannot be sent directly from source to destination within 3000 km, both for the midnight to dawn category, morning to noon and for the afternoon to evening category.
- To overcome this, non-cooperative communication systems (S-R-D) and cooperative communication systems are used using diversity combining MRC techniques. Where the relay is placed at a location in Ternate which is about 1800 km from the source and 1700 km from the destination.
- In the midnight to dawn category, cooperative communication systems provide diversity gain for non-cooperative (S-D) of 7.61 dB and 6.58 dB for 00:00 and 04:00 respectively. While for non-cooperative (S-R-D), cooperative communication systems provide diversity gain of 1.69 dB and 1.92 dB for 00:00 and 04:00 respectively.
- In the morning to noon category, cooperative communication systems provide diversity gain to non-cooperative (S-D) of 6.81 dB and 5.74 dB for 08:00 and 12:00 respectively. Whereas for non-cooperative (S-R-D), cooperative communication systems provide diversity gain of 1.95 dB and 1.61 dB for 08:00 and 12:00.
- In the afternoon to evening category, the cooperative communication system gives diversity gain to non-cooperative (S-D) of 6.69 dB and 6.34 dB for 16:00 and 20:00 respectively. As for non-cooperative (S-R-D), cooperative communication systems provide diversity gain of 1.45 dB and 1.87 dB for 16:00 and 20:00 respectively.
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