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Distributed Coding for OFDM based Cooperative HF Radio Communication System

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Abstract*: High frequency (HF) radio system now-a-days used to establish the communication in an area which is isolated from the outside world due to natural calamities. Conventional HF systems are associated with analog voice communication systems; is now shifted to digital voice communication to meet the demands as expected for high data rates for transmission. Cooperative communication is different from conventional relay-assisted HF systems and aims to support the challenging expectation of future generation HF communication systems. Recent days distributed coding is a variety of channel coding developed in a distributed manner for cooperative wireless networks. In this paper we present an overview of various distributed coding design in OFDM based cooperative HF radio communication system.

Index: cooperative Communication, Distributed Coding, High Frequency, OFDM.

I. INTRODUCTION

Basically High Frequency (HF) band (2 – 30MHz) has been considered as principal way for long-range communication (wireless), using a simple inexpensive equipment, for both internationally and with in a country which are isolated areas now due to disaster. Radio communication using this HF band is referred to as HF communication. In past few years HF technology was considered out dated when the satellite communication (SC) has emerged. But, because of vulnerability of base stations in natural calamity situations, high investment and maintenance cost for satellites were not the universal solution. With its stable behavior, HF communication has survived and placed itself as a powerful complementary and/or alternative technology to SC. Now a day there is a need for long range communication without relying on existing infrastructure in military applications. In favor of such long range communications; radio communications using HF band is the only alternative.

First HF modem typically uses single sideband (SSB), frequency shift keying (FSK) and continuous wave (CW) modulation to convey voice signals, teletype and morse respectively based on OFDM [1] which requires manual operation for the identification of suitable transmission frequencies and maintain transmission in the presence of ionospheric layers. Automatic link establishment (ALE) was introduced to continuously monitor the available channels and grade them accordingly to its quality and make sure the high quality of the transmission form source to destination. ALE system typically emits energy on each band of frequencies and other node appraises and records the arriving signal quality from each station on each frequency band that is assigned. The HF standard MIL-STD 188-141A was introduced based on asynchronous ALE which examine the spectrum at a rate of 2 to 5 channels/sec and provide the data rate up to 75 - 2400bits/sec in different configurations. Data rates in the range 75bps – 120Kbps can be obtained by using physical layer standard MIL-STD 188-110C (released in 2011). It includes different protocols i.e., low and high rate data link protocols for short and large messages respectively. The PHY layer various burst waveforms (BW) at 2400 bauds use the basic 8-PSK modulation [2].

In HF system, both the communications i.e., direct link (LOS) and non line of sight communications typically in the range 100 – 150km can be established via direct wave and surface wave respectively [2]. In HF transmission a signal is projected vertical toward the ionosphere which upon refraction a coverage of 300 km at most. HF communication is used beyond mountain and forests. In sky wave propagation the slanted transmission toward the ionosphere lets HF radio achieves over-the-horizon (OTH) communications with nearly worldwide coverage. Because ionosphere consists of three layers E, F1 and F2 which varying in its altitude from 100 km to 400 km. depending on whether the operating frequency is above or below the maximum usable frequency (MUF) of the layer, each layer reflects the various amount of signals. However fading, time variation and dispersion effects the OTH-HF communications.

Diversity has been an effective technique to mitigate the effect of fading, which can be achieved by MIMO technique by providing more radio terminals at the transmitter and at receiver. System with Multiple-antennas have been studied especially message transmission in both SHF (3–30 GHz) and UHF (300 MHz–3 GHz) bands which are allocated for mobile phones, cordless phones, WiMAX and Wi-Fi systems etc. [13,14]. Multiple antennas cannot be deployed at each node in HF communication because the separation between antennas is nearly with an order of several hundred meters (λ=10 to 150m).

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In [3,4] authors given the importance of this emerging concept by demonstrating the performance analysis of cooperative HF system.

Rest of the paper organizes as: link establishment between cooperative communication and High Frequency bands is presented in section II, Section III describes various distributed coding schemes available and section IV concludes with comparing various cooperative modes vs. non cooperative mode and different distributed coding schemes along with the advantages brought to us by using mixed version of both cooperative communication and HF communication.

II. Cooperative HF Communication

Figure.1 represents a cooperative HF communication model in which source and destination terminals are separated apart communicating via sky wave propagation and used to establish communication with outside world. We assumed that there are L neighboring nodes equipped with single radio terminal to the destination which act as relaying nodes. Because of the single radio terminal, all the nodes can transmit or receive the information at a time. Within orthogonal (i.e., TDMA based cooperation) cooperative phenomenon source broadcast the information x to destination and relay nodes in first phase and during second phase relays processes the information based on relaying protocols (i.e., Amplify and Forward or Decode and forward relaying protocols) and re-transmit to the destination.

The information received by the destination and i^{th} relay node in the first phase is given by [9]

$$y_{sd} = \sqrt{P} h_{sd} x + \eta_{sd}$$

$$y_{sr_i} = \sqrt{P} h_{sr_i} x + \eta_{sr_i}$$

Where P is the transmitted power, h_{sr_i} is the channel co-efficient between the link source and i^{th} relay node, η_{sr_i} is the zero mean AWGN for the link source and i^{th} relay node.

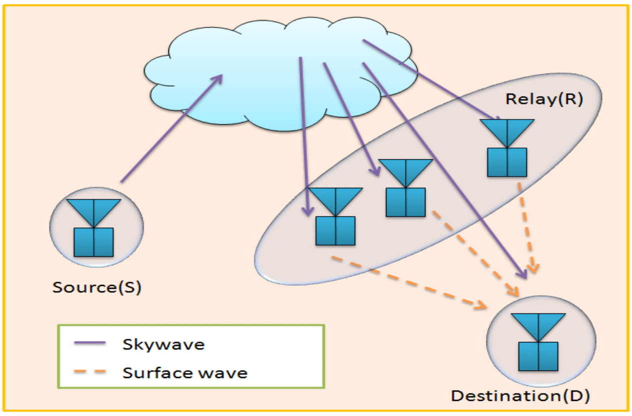

Figure 1. Cooperative HF Radio communication system

A. Propagation

Propagation in the HF mainly depends on the reflection of the radio waves that are transmitted from source towards ionosphere layers. The ionosphere is divided into three layers known as D, E and F as shown in the Figure 2. There are sub-layers F1 and F2 in the F layer during day-light hours. The F and E layers act primarily as radio reflectors, but D layer acts mainly as an absorber [5]. The ionosphere layers condition vary with time of the day, month of the year, solar position and geomagnetic situation.

The broadly adopted HF channel model for ionospheric transmission is Watterson model [6-8] which is based on a tapped delay-line with L taps. In Watterson's model the transmitted signal is delivered at several taps with adjustable delays, the received signal is given by the discrete approximation detailed in [9] as

$$y(t) = \sum_{i=1}^{L} g(t, T_i) s(t - T_i) \quad + \quad \eta(t) \qquad (1)$$

Where $\eta(t)$ is additive white Gaussian noise and $s(t)$ is the modulation signal and i is number of taps, τ_i is the time delay of the i^{th} tap where each tap gain (fading coefficient) is given by

$$g(t) = G_{ia}(t)\exp(j2\pi f_{ia} t) + G_{ib}(t)\exp(j2\pi f_{ib} t) \qquad (2)$$

Where $G_{ia}(t)$ and $G_{ib}(t)$ are sample functions of two independent complex Gaussian random processes, each with zero mean values. f_{ia} and f_{ib} represent the corresponding frequency (Doppler) shifts.

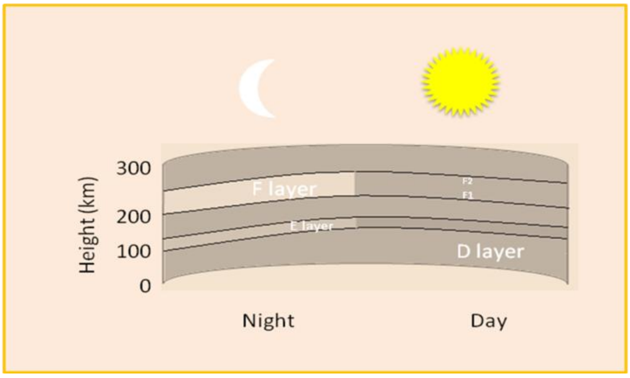

Figure 2. Ionospheric Layers

Addition of two Gaussian components results in bi-Gaussian Doppler power spectral density of each tap is as follows:

$$P_{Gi}(w) = \frac{1}{\alpha_{ia}\sigma_{ia}\sqrt{2\pi}} \exp\left(\frac{-(w - w_{ia})^2}{2\sigma_{ia}^2}\right) + \frac{1}{\alpha_{ib}\sigma_{ib}\sqrt{2\pi}} \exp\left(\frac{-(w - w_{ib})^2}{2\sigma_{ib}^2}\right) \qquad (3)$$

Where σ_{ia} and σ_{ib} represent each components Doppler spread.

The HF band path losses models are considerably different from higher frequency band (i.e., SHF and UHF) models. Every sky-wave in return path is affected by different amount of loss factors like: spherical spreading loss L_s , absorption loss L_A, ground reflection loss L_G and the polarization mismatch loss L_P. The path loss model for skywave return is approximated as

$$L_b = 32.5 + 20\log w_c + 20\log \overline{L} + 2(L-1) + L_z \qquad (4)$$

Where w_c is the frequency of carrier in MHz, The virtual slant range $\overline{L}$ which is a function of total path length D_k and elevation angle θ, is given by $\overline{L} = 10\log\left(\frac{D_k}{\sin\theta}\right)$, and L_z is the loss term which includes ionospheric absorption, maximum usable frequency (MUF) loss. The surface wave path loss is proportional to dis^{δ} where dis is the link distance, and δ is the path loss exponent. At smaller distances, δ takes 2 and it tends to increase to 4 as the distance increases when the distance is less than $10\lambda^{1/3}$ else, the path loss is exponential.

III. Distributed Coding

The relay transmission performance can be improved further if signal design and coding are communally performed at both source node and relay nodes; such enciphering strategy is referred as distributed coding. In this section we present a summary of various distributed coding strategies which are implemented successfully in wireless cooperative relaying networks.

A. Distributed space time coding

In cooperative wireless networks, spatial diversity and gain can be achieved by distributed space time coding strategies. There are two strategies (i) distributed space time block coding strategy and (ii) distributed space time trellis coding strategy. Most of the wireless relay networks employ DSTTC because of its higher coding gain. In DSTTC scheme, the relay employs either AF or DF protocol.

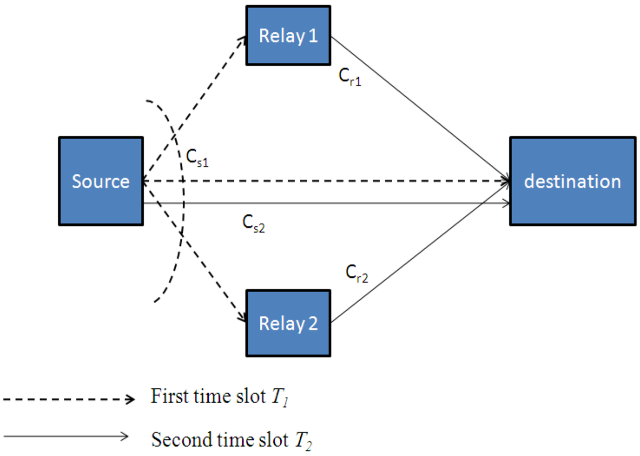

Figure 3. DST coding scheme

Figure.3 represents the generalized structure of DSTTC, in which the communication takes two phases or time slots. In the specified first phase it broadcast the encoded information (codeword C_{s1}) to both the destination and relay. After receiving the codeword, each relay generates a new codeword C_{ri} which is the estimated version of C_{s1} [12]. Simultaneously, source generates a new codeword C_{s2} of same information using another encoder. The source and relays transmit C_{s2} and C_{ri} to the destination in the 2nd time slot (T_2). The received signal at the destination in these two time slots forms a codeword C, given by

$$C = \begin{matrix} \overbrace{C_{s1}}^{T_1} & \overbrace{C_{s2}}^{T2} & ---\,Source \\ 0 & C_{r1} & ---\,Relay\ 1 \\ 0 & C_{r2} & ---\,Relay\ 2 \end{matrix}$$

B. Distributed turbo-coding (DTC)

The general block representation of distributed trellis coding strategy is presented in figure 4. In distributed turbo coding strategy, all the relay nodes employ DF relaying protocol. In first phase source broadcast the message in coded form towards destination and relays. Relay nodes decode the received message and detect and correct the errors. After the error correction, it re-encodes the message and transmits to the destination during second phase. After the second phase, distributed trellis codeword formed at the destination based on these two messages. The main issue with this strategy is error propagation which occurs because of imperfect decoding at the delay nodes. One of the easy ways to overcome the error propagation in relay protocols is to use distributed turbo-coding strategy with soft information (DTC-SIR) which gives better performance than distributed turbo-coding with adaptive relay protocol (DTC-ARP) [10].

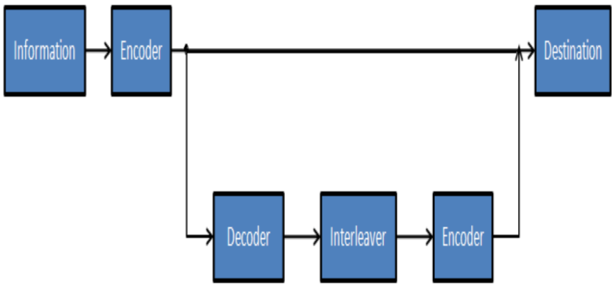

Figure 4. DTC Encoder and Decoder

This new approach consists of applying the soft information (SIR) protocol to DTC, when relays were unable to decode the codeword correctly. In this strategy, relay node has two main functionalities. First and foremost function of the relay node is to calculate the posteriori probabilities (APPs) of information symbols based on sequence of message symbols from source node by using a posteriori probability (MAP) decoding algorithm. Second function of the relay node is to calculate the Parity Symbol Soft Estimates for the Interleaved Source Information by using APPs of the information. The parity symbol soft estimates of $\tilde{p}_i$ is given by [14]

$$S_i = P(\tilde{p}_i = 0|y_{rs}, P_{\tilde{x}}).1 + P(\tilde{p}_i = 1|y_{rs}, P_{\tilde{x}}).(-1)$$

Where $P_{\tilde{x}}$ is the APPs of information symbols. The block representation of the said strategy is presented in figure 5.

C. Distributed Low Density Parity Check Code

Distributed Low density parity check coding strategy has been proposed to additional enhance the performance of the

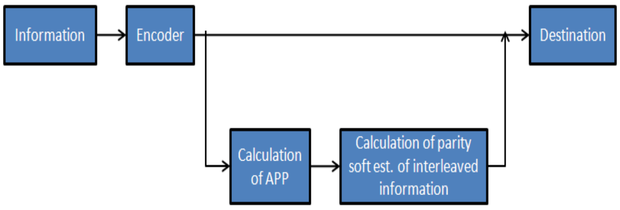

Figure 5. Block diagram of DTC-SIR.

wireless relay network [11]. In this coding strategy source transmit the message codeword X_{SR1} to the relay node in first phase. Relay node decodes the received codeword, and corrects the errors if any and re-encodes the message. During the second phase, source and relay nodes pass on the message codeword's to the destination. The joint optimization of codeword's X_{SR} and X_{SD} forms DLDPC. Because of high performance than the turbo coding strategy at higher modulation, LDPC coding strategy has been widely used in modern wireless networks.

IV. Simulation Results

Performance of various distributed coding strategies is presented in this section. The essential assumptions and parameters used for the simulation are listed in table I.

TABLE I. Simulation Parameters

Parameter	Value
Band width	9KHz
FFT length	1024
Subcarriers	192
Frequency Spacing (Δf)	46.5Hz
Carrier Frequency (w_C)	5MHz
Path loss	105dB
Path length	700Km
Modulation	16-QAM
Path loss Exponent (δ)	2-4

Figure 6 shows the performance comparison of OFDM based cooperative HF communication system in two elementary cooperative modes (AF and DF). From the simulation result, we conclude that the performance of the network can be improved by cooperative diversity. And also we observed that the performance of the network is improved by 9-11dB w.r.t direct link.

Figure.7 shows the BER performance of various Distributed coding schemes. To make a fair comparison; assuming that the relays decode the received signals correctly. From the results, we observed that the performance of DLDPC is 2-5dB higher than DTC-ARP and DTC-SIR is 2–3 dB higher than DTC-ARP strategy.

We analyse the performance of cooperative HF system by increasing number of relaying nodes i.e., L=1,2,3 under DLDPC strategy and figure 8 gives the simulation results. From the results we conclude that the performance of the system is improves with the number of relaying nodes.

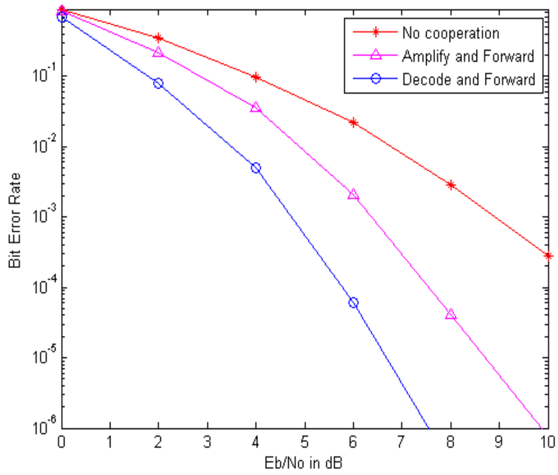

Figure 6. BER Performance of Coopearaitive HF System in Two Fundamental Cooperative Modes

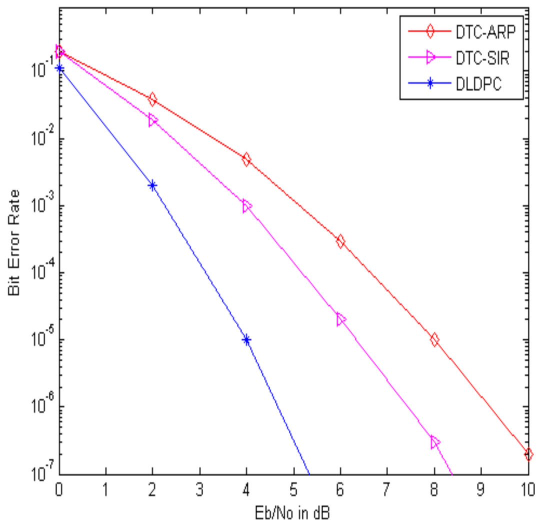

Figure 7. BER Performance Comparision of Various Distributed Coding Schems

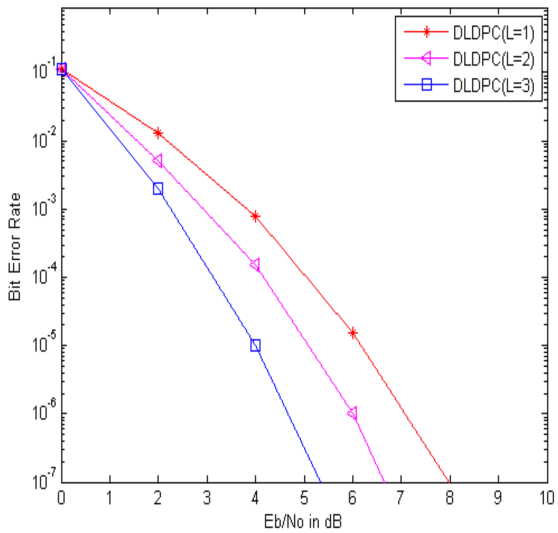

Figure 8. Performance of DLDPC strategy

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V. CONCLUSION

Cooperative communication is a major performance boosting technique for future-generation HF radio systems. In this paper we implemented various distributed coding schemes in cooperative HF communication systems. We compared different scenarios and observed significant error rate performance improvement. There are some practical issues to be taken in to account in implementing OFDM based cooperative HF radio communication systems such as, relays synchronization, power optimization, estimation of channels, and timing constraints which can be future analyzed in near future OFDM based cooperative HF radio communication systems.

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