HIERARCHICAL MODULATION OVER COOPERATIVE SYSTEM UTILIZING CODED OFDM

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ABSTRACT: *Wireless communication system requires a higher data rate and a more robust transmission link between source and destination against noise and multipath fading effect while keeping a good quality of service. A cooperative communication system utilizing OFDM is considered an effective technology to enhance system performance. By taking advantages of cooperative diversity utilizing relays, this paper investigates the performance of the cooperative system with coded OFDM over two types of a cooperative protocol such as Decode and Forward (DF) and Amplify and Forward (AF),) utilizing Hierarchical modulation.*

The main goal of this work is to integrate the hierarchical modulation (HM) with cooperative communication focusing on unequal degradation of the two data streams transmitted on the direct link between source and destination and in-direct link through the relay. The main idea is to use different constellations order at the relay and destination according to the difference of SNR values. Using different constellations enhances system flexibility and manipulate this difference to improve the system performance

For a relay network with one source, one relay, and one destination the BER performance is investigated when coded cooperative system employs HM over Rayleigh fading channel with OFDM system with distributed convolutional code.

Simulation results showing that the proposed cooperative Coded OFDM system with Hierarchical modulation outperforms the reference system (Cooperative DF coded OFDM with MRC) with 3dB at 10^{-4}. Also, the proposed system outperforms (Cooperative coded OFDM with EGC) with 5 dB at 10^{-4} BER. Moreover, simulation results show that the proposed system outperforms (Cooperative AF coded OFDM with MRC) with about 4dB at 10^{-4} BER.

1. INTRODUCTION

The basic idea of cooperative communication by utilizing several relays between source and destination was proposed in [1, 2, 3]. In which relay acts as a booster to expand the transmitter coverage area and improve the achievable rate for users implementing cooperative communication system. Other techniques were adopted such as AF, DF, and dynamic DF in [3, 4].

Cooperative diversity was integrated with other diversity schemes such as channel coding as in [5, 6, 7]. Instead of using simple repetition relays the message is encoded and split into many parts. These parts are transmitted by many users according to certain scenarios and conditions to achieve extra diversity to impact wireless channel impairments.

Hierarchical modulation (HM) was developed in [8, 9] as one of the cooperative relaying communication applications. The main idea behind HM is to take advantage of the relay link which suffers from fewer impairments and deep fading than the direct link. Extra information is sent via relay link and resends again to enhance the performance of received data at destination [10, 11]. Moreover, in [12] Cyclic redundancy check (CRC) and selective modulation were deployed and integrated with HM at the relay. More investigation was carried in [13, 14] about HM. It was mainly about merging between channel coding schemes such as turbo code that was applied in source and relay.

Modulating different data streams into a single stream that contains a base layer and an enhanced layer is a model of HM which is presented in [14, 15]. Where the receiver with good channel condition can modulate all data streams while the receiver in bad coverage area can modulate only base or low layer. Moreover, HM was optimized into three schemes to achieved high throughput and power efficiency by rotating a constellation of different layers. The previous scheme is considered an efficient solution to satisfy the huge increase in demand by compatibility with older service by switching between different modulation schemes [16].

In [17], HM was further improved by combining it with time-sharing. hierarchical 16-APSK was utilized to improve the DVB-S2 standard. Hierarchical Modulation Utilizing the OFDM scheme was proposed [18, 19]. The merging between convolutional coded OFDM and HM scheme to attain further performance gain due to the good spectral efficiency and robustness to fading environment. Also, joint use of hierarchical modulation and relays also were presented in [20] where dynamic use of relay was utilized with hierarchal modulation

In this paper, we merge coded OFDM with HM and the cooperative relay diversity system. The idea is to take advantage of HM flexibility by using a different modulation scheme. relay channel is considered more reliable than a direct link to destination so high order of modulation is used at the relay and low order is used at the destination.

OFDM with HM over cooperative diversity system is implemented in this paper. Distributed encoding of convolutional codes between relay and source are utilized by using different modulation schemes. In addition to the merging between OFDM and convolutional code which provide the system with high spectral efficiency and robustness to signal in a fading channel.

Simulation results show that the application of hierarchical modulation with Coded OFDM with HM over the cooperative system can improve the performance in terms of bit error rates compared OFDM cooperative relay system with ordinary modulation.

2. SYSTEM MODEL

Coded (OFDM) with HM over cooperative system employing one relay is implemented. in the following subsections cooperative communication system, HM, and HM with OFDM will be proposed in detail.

2.1 Cooperative Communication System

Cooperation diversity occurs by utilizing in-between boosting nodes between source and destination. This boosting node is called a relay (R).

Figure 1 describes a general model for a cooperative Relay communication system which contain source (S), Relay (R), and Destination (D), as an assumption, the relay is centered in the distance between source and destination.

Using the following notation, to describe the transmission between nodes., for the cooperative communication system as in [21] :

X ϵ (S, R) to a node Y ϵ (R, D)
$d_{XY} > 0$ Distance between X and Y
$\alpha_{XY} > 0$ Path loss coefficient
$h_{XY} \epsilon$ C Channel fading coefficient
$n \epsilon$ C AWGN

where C denotes the set of complex numbers

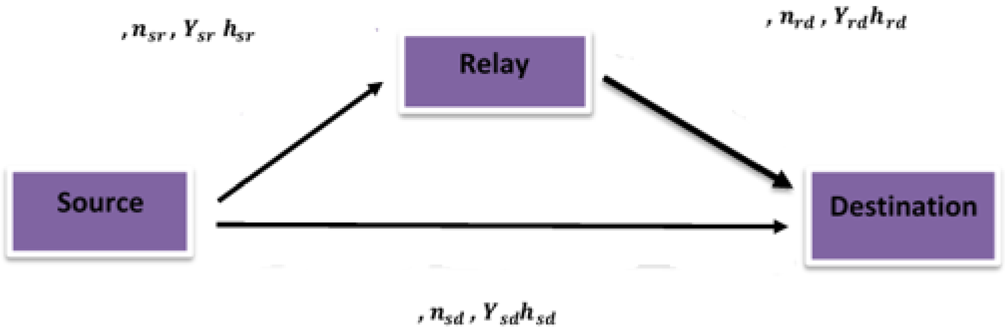

Fig 1. Cooperative Relay System with Distances between nodes.

The received signals Y_{sd}, $Y_{sr,}$ and Y_{rd} can be written as in [21], [22], and [23]:

$Y_{sd} = \alpha_{sd} h_{sd}\, X + n_{sd}$ (1)
$Y_{sr} = \alpha_{sr} h_{sr}\, X + n_{sr}$ (2)
$Y_{rd} = \alpha_{rd} h_{rd}\, q y_{rd} + n_{rd}$ (3)

Where α is the path-loss attenuation proportional to the distance between nodes, which can be expressed as:

$$\alpha_{XY} = \left(\frac{d_{xy}}{d_o}\right)^{-\mu}$$

Where μ is the path loss exponent, d_o is denoted as the reference distance assuming the path loss between S and D is unity, i.e., $d_o = d_{sd}$, and the relay is located at half distance between S and D.

X is the transmitted coded signal from the source, and n_{sd}, n_{sr} are additive white Gaussian noise. In the above equations h_{sd}, h_{sr} and h_{rd} are the channel fading showed in Figure 1, which are assumed Rayleigh fading channels where the distribution of rayleigh describes statistical time-variation of received an envelop of flat fading signal [22]. The probability density function of Rayleigh distribution is given by [24] :

$$f(r) = \frac{r}{\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \; for\ 0 \le r \le \infty$$
$$= 0\,,\ otherwise \quad (4)$$

Where r is the amplitude of the received signal over a rayleigh channel and σ^2 is the average power of the received signal. The noise terms n_{sd} and n_{sr} are modeled as zero-mean complex Gaussian random variables with variance .

The function $q(Y_{sr})$, depends on the type of processing implemented at the relay node.

In this paper two models of the cooperation protocol are employed: Amplify and forward (AF) and Decode and forward (DF). The Amplify and Forward at realay are described as in [4]:

$Y_{rd} = \beta\ \alpha_{rd}\ h_{rd}\, Y_{sr}\ +\ n_{rd}$ (5)

Where β is the amplification factor at the relay. The amplification factor β normalizes the average energy of the signal transmitted from the relay to be equal to Es. which is denoted by

$$\beta = \frac{\sqrt{E_S}}{\sqrt{E[|y_{sr}|]^2}} == \frac{\sqrt{E_S}}{\sqrt{\alpha_{sr}^2 |hsr|^2\, E_S + \sigma^2}}$$

In Decode and Forward Protocol the relay nodes decode the received signal and then re-encoded and retransmitted it to the destination, assuming that the relay uses the same encoder as the source and the same decoder as the destination.

The received signal at the destination from the relay can be modeled as in [4]:

$Y_{rd} = \sqrt{E_S}\, \alpha_{rd}\, h_{rd}\, \hat{X}\ + n_{rd}$ (6)

Where $\hat{X}$, is the re-encoded symbol at the relay.

2.2 Hierarchical Modulation

As mentioned before the idea of HM is to Modulate different data streams into a single stream which contain a base layer and an enhanced layer is a model of HM where receiver with good channel condition can modulate all data streams while receiver in a bad coverage area can modulate te only base or low layer.

The basic idea of the HM is to use different constellations in different links according to the reliability of transmission on that link. link with high reliability and resistance to channel impairments and deep fading such as relay link is equipped with high order modulation and constellation. And link with low reliability and resistance to channel impairments and deep fading such direct link between S and D is equipped with a low order of modulation and constellations at D.

2.2.1 4/16QAM Hierarchical Modulation

The main idea in HM is to split data into two sets primary and secondary and both sets are encoded. The principle of HM which has been followed in this work is that both basic and secondary information bits are channel encoded. The coded basic information bits (L1) are mapped to the 4QAM constellation as a red dot in figure2. The minimum distance between constellation points is denoted by 2d1. The basic hierarchical constellation is next modified according to the coded secondary information bits in the blue dot, and the combined hierarchical constellation is formed as shown in figure 2. The combined constellation is a 16QAM constellation with the minimum distance between two points denoted by 2d2.

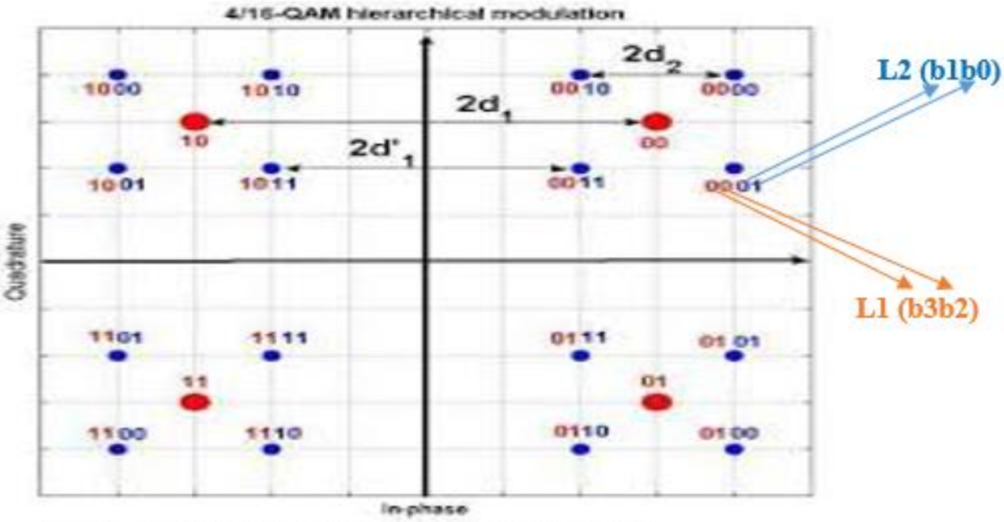

Fig 2. basic 4/16QAM Hierarchal Constellation

2.3 Hierarchical Modulation with OFDM System.

The large increase in high data rate application system is the main feature of today's wireless communication system. So the multipath effect in wireless channels became the major difficulty in a single carrier system. As the data rate is limited by intersymbol interference (ISI). To overcome this OFDM system with multi-carrier is the alternative to provide a higher data rate with ISI reduction in a deep fading channel. The IFFT and FFT are used for modulating and demodulating Hierarchical QAM constellation with orthogonal carriers. The resulting output of IFFT consists of complex hierarchal modulated QAM signal that can be written as [21] and [25] :

$$x(n) = \sum_{K=1}^{N-1} X(K) \exp(\frac{j2\pi Kn}{N}) \, .\, 0 \le n \le N-1 \qquad (7)$$

Where N is the number of subcarriers, x(K) is the data symbol in each carrier, K shows the subcarrier index $k = (0.1. \cdots . N-1)$, and n is the time domain sample index of an OFDM signal. The complex Hierarchal modulated signal is transmitted through a fading channel and presented as in:

$$r(n) = h(n) * x(n) + w(n)$$

(8)

At the receiver side, the complex modulated signal is recovered by forming FFT. The estimated signal in the frequency domain is [4]:

$$Y(k) = \frac{1}{N} \sum_{k=1}^{N-1} r(n) \exp(\frac{j2\pi kn}{N}) = X(k)H(k) + +w(k). 0 \le k \le N-1 \qquad (9)$$

2.3.1 Relay Communication with Coded OFDM Hierarchical Modulation

Using HM in a cooperative relay system leads to a clear dilemma about using the suitable modulation scheme either on relay or destination. As in relay, the link is more reliable and higher SNR is obtained so high order of modulation can be used, however, the destination cannot use the same high order of modulation due to the channel impairments in the direct link. On the other hand using lower modulation according to bad conditions in the direct link and low SNR values at the destination will affect the throughput of the system. The solution to the previous dilemma is to utilize distributed channel coding in the system in a way that different modulation orders can be used on relay and destination which leads to better performance for the whole system.

2.3.2 Principle of coded OFDM Hierarchical Modulation with relay

In this section, a proposed system is introduced as convolution code HM with OFDM assisted DF cooperative communication. The S transmits a message u of K bits to D. The information bits' u is channel coded using convolution code of rate ½ to produce a codeword c with length N. The code word C is punctured into two subsets L_1 and L_2. The block L_1 contains the common bits or systematic bits and block L_2 contains the enhancement bits which include the redundancy bits for each codeword *C*. The hierarchical modulation maps 2 bits from L_1 *(b3,b2)* and 2 bits from L_2 *(b1,b0)* to one symbol according to the in-phase/quadrature (I/Q) constellation of 16 QAM shown in Fig. 2.15 to produce 16 QAM s1 symbols. *s1* symbols are modulated by the OFDM transmitter to produce x1(n) symbols.

During the first time slot, the S would transmit x1(n) symbols to both R and D,. then at R the *x1(n)* symbols are demodulated by an OFDM receiver to produce 16 QAM s1 symbols, which are modulated using 16 QAM demodulator to produce the codeword C that contains L_1 and L_2. The codeword C is decoded using a convolutional decoder and encoded again to produce C', which is punctured again to L_1' and L_2'. The enhancement bits L_2' are modulated using

4 QAM modulator and OFDM transmitter at R again to produce x2(n) symbols. These symbols are forwarded to the D during the second time slot. At destination x1(n) is modulated by an OFDM receiver at the first time slot and fed to 4 QAM demodulators to generate again L_1 bits.

At the second time slot x2(n) symbols are received at D from R where they are demodulated by OFDM reviver and then by 4QAM demodulator to produce L_2. Then both systematic bits from S and enhancement from R are joined and entered the decoder to recover u'.

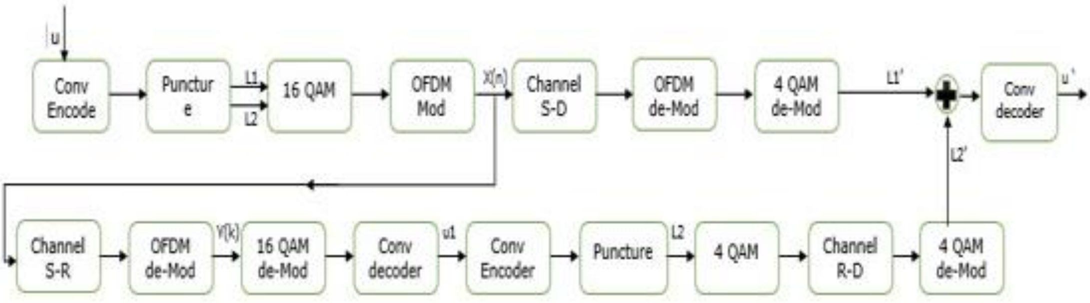

Fig 3. Coded Cooperative Relay with OFDM Hierarchal modulation.

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3. RESULTS and DISCUSSION:

The design parameters for the whole proposed system Cooperative Transmission Using Hierarchical Modulation Utilizing Coded OFDM is shown in the following table 1. The parameters were selected based on the IEEE802.11a standard and the simulation results have been performed by MATLAB.results would be presented along with BER analysis for Rayleigh fading channel and modulation 16QAM are used.

In this section comparison of simulation results for performance in terms of BER versus SNR between the cooperative communication with coded OFDM utilizing HM as the proposed system and 3 different reference systems.

In Figure 4 the performance of a coded OFDM communication system over a Rayleigh fading channel with 16-QAM modulation (without cooperative system) along with a coded cooperative system over the same channel utilizing OFDM with two different combining techniques are shown.

Table 3.1 System Parameter

Parameter	Value
Modulation	**4 ,16-QAM**
Channel	**Rayleigh Fading**
Noise model	**AWGN**
FFT and IFFT size	**64**
Number of subcarriers	**52**
Cyclic prefix length	**16**
Number of bits	**10^4**
Convolutional code	**Rate 1/2**
Relay protocols	**(DF) and (AF)**
Combining methods	**(EGC) and (MRC)**

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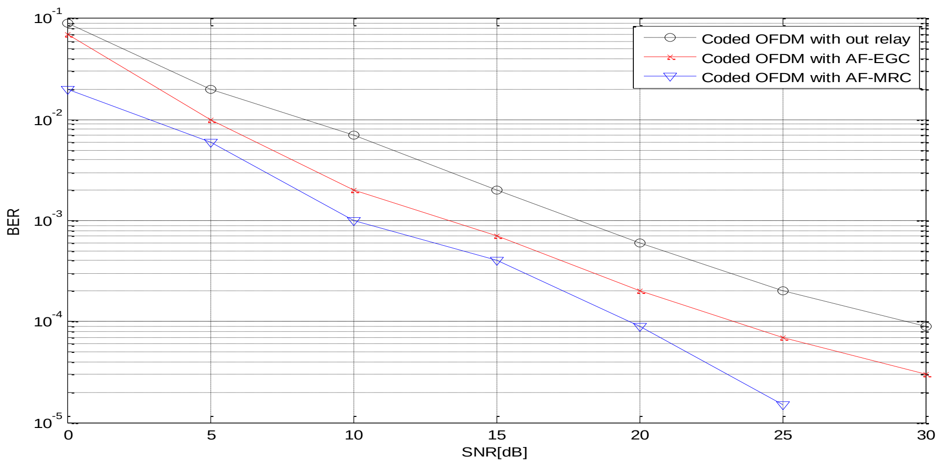

Figure 4. Coded 16 QAM OFDM Amplify and forward cooperative relay with MRC and EGC.

As shown in Figure 4, coded OFDM cooperative AF system with MRC combining technique and 16 QAM modulation have a better performance than the same system but with EGC combining technique by 3 dB, and system without relay by 8dB at 10^{-4} BER.

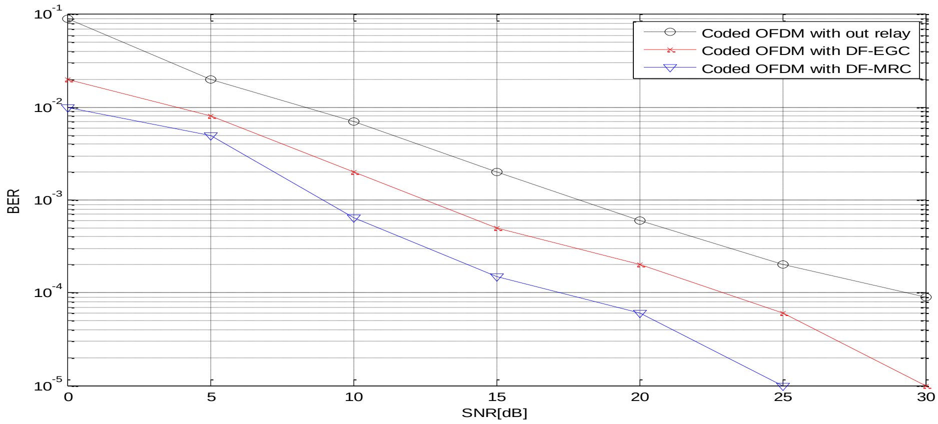

Figure 5. Coded 16 QAM OFDM Decode and forward cooperative relay with MRC and EGC.

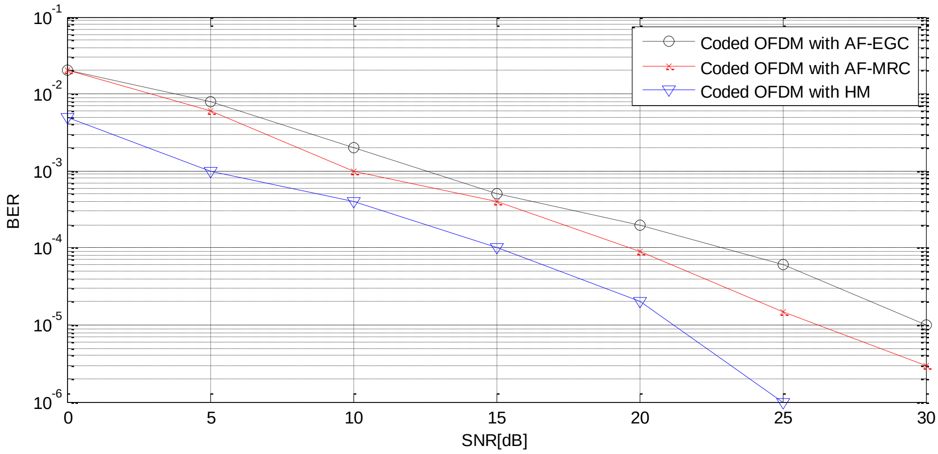

Figure 6. Comparison between Conventional 16-QAM AF relay and coded OFDM cooperative DF system utilizing HM over Rayleigh fading channel

In Figure 6. The proposed system with coded OFDM cooperative system utilizing HM outperforms, traditional coded OFDM cooperative AF/16-QAM system using MRC combing scheme by 5dB and coded OFDM system with AF using EGC combining by 8 dB at 10^{-4} BER

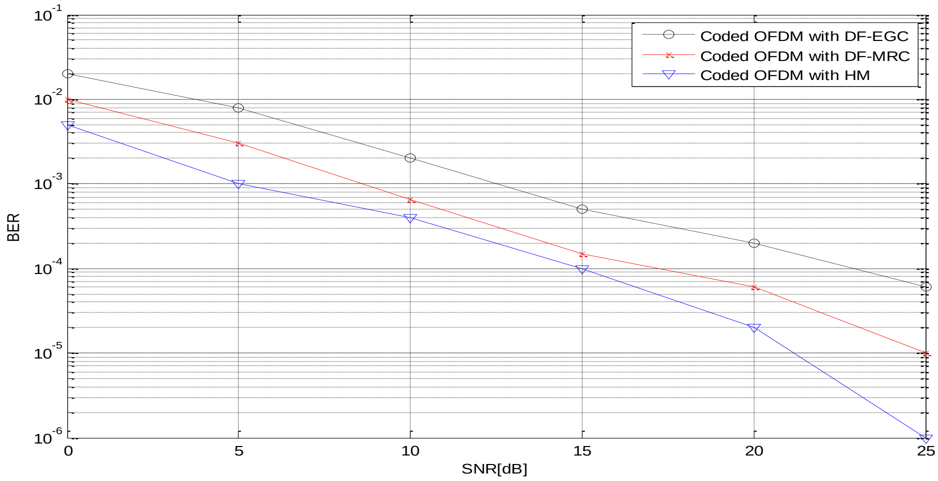

Figure 7. Comparison between Conventional 16-QAM DF relay and coded OFDM cooperative DF system utilizing HM over Rayleigh fading channel.

In Figure 7. The proposed system with coded OFDM cooperative DF system utilizing HM outperforms, traditional coded OFDM cooperative DF/16-QAM system using MRC is combing scheme by 3dB and coded OFDM system without relay by 11dB at 10^{-4} BER.

4. CONCLUSION

Cooperative Transmission using Hierarchical Modulation Utilizing coded OFDM scheme was proposed. The merging between cooperative communication, distributed convolutional code, OFDM, and HM scheme to attain further performance gain was achieved in an accepted way. Using cooperative communication improved the system transmission due to the existence of a relay at the middle between source and destination. A further improvement was achieved by merging HM with OFDM to tackle the deep fading effect through the channel and to enhance the data rate using the multi-carrier system. A wide comparison between different relaying protocols such as DF and AF and Different combining techniques used in the cooperative system was investigated and compared to the proposed system. The proposed cooperative Coded OFDM system with Hierarchical modulation is outperforming the reference system (Cooperative DF coded OFDM with MRC) with 3dB at 10^{-4}. Also, the proposed system outperforms (Cooperative coded OFDM with EGC) with 5 dB at 10^{-4} BER. Moreover, simulation results show that the proposed system outperforms (Cooperative AF coded OFDM with MRC) with about 4dB at 10^{-4} BER.

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