

Performance of Non-Cooperative and Cooperative Subcarrier Allocation in OFDM Systems

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ABSTRACT: In this paper, the performance of non-cooperative and cooperative relaying protocols for multi-user OFDM systems are analyzed and compared. The cooperative relaying protocol consists of Amplify and Forward relaying protocol and proposed Decode and Forward relaying protocol. The two subcarrier allocation algorithms are used in non-cooperative and cooperative relaying protocols. 1. Throughput subcarrier allocation algorithm 2. Fairness subcarrier allocation algorithms are considered. Throughput subcarrier allocation algorithm to maximize the throughput of the systems and Fairness subcarrier allocation algorithm to prioritize the fairness in the multi-user OFDM systems. Proposed DF relaying protocol in terms of bit error rate and channel capacity shows the better performance compared to non-cooperative and AF relaying protocol.

KEYWORDS— OFDM, Subcarrier allocation, Throughput, Fairness, Relaying system

1. INTRODUCTION

OFDM is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, power line networks, and 4G mobile communications. OFDM is essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT), and is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. The word "coded" comes from the use of forward error correction (FEC). A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

A. Orthogonality

Conceptually, OFDM is a specialized FDM, the additional constraint being: all the carrier signals are orthogonal to each other. In OFDM, the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other, meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver; unlike conventional FDM, a separate filter for each sub-channel is not required. The orthogonality requires that the sub-carrier spacing is $\Delta f = \frac{k}{T_U}$ Hertz, where T_U seconds is the useful symbol duration (the receiver side window size), and k is a positive integer, typically equal to 1. Therefore, with N sub-carriers, the total passband bandwidth will be $B \approx N \cdot \Delta f$ (Hz). The

orthogonality also allows high spectral efficiency, with a total symbol rate near the Nyquist rate for the equivalent baseband signal (i.e. near half the Nyquist rate for the double-side band physical passband signal).

B. Efficiency Comparison Between Single Carrier and Multicarrier

The performance of any communication system can be measured in terms of its power efficiency and bandwidth efficiency. The power efficiency describes the ability of communication system to preserve bit error rate (BER) of the transmitted signal at low power levels. Bandwidth efficiency reflects how efficiently the allocated bandwidth is utilized and is defined as the throughput data rate per Hertz in a given bandwidth. If the large number of subcarriers are used, the bandwidth efficiency of multicarrier system such as OFDM with using optical fiber channel is defined as

$$\eta = 2 \cdot \frac{R_s}{B_{OFDM}}$$

Factor 2 is because of two polarization states in the fiber. Where R_s is the symbol rate in giga symbol per second (Gsp/s), and B_{OFDM} is the bandwidth of OFDM signal.

C. General OFDM-Based Relaying System Model

We consider the downlink of a single-cell OFDM-based relaying system. Fig 1 illustrates this general multi-user relaying system model used.

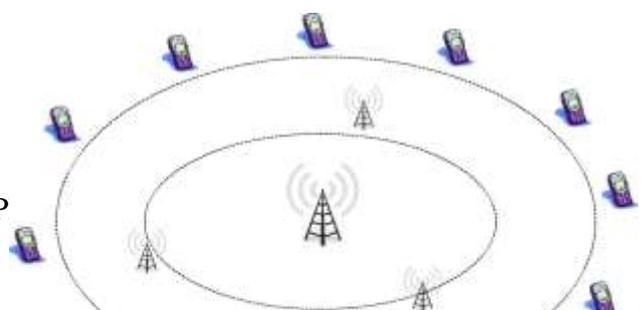


Fig 1. Multi-user relaying system model.

The major elements in this model are: Base station (BS), relaying station (RS) and mobile station (MS). Compared to the traditional multi user system, relay stations are the new system components. The major functionality of RS in the downlink is to transmit a copy of the received signal from BS to MS by following the relaying protocol. RS's are assumed to be pre-assigned to MS's. All the MS's are assumed to be experiencing similar channel statistics. All the RS's are also assumed to be experiencing similar channel statistics as well. Therefore, we have considered the homogenous MS's and RS's in the system and left the heterogenous case as the future work of this dissertation.

II. NON CO-OPERATIVE SUBCARRIER ALLOCATION TECHNIQUE

The formulated optimization problem to allocate subcarriers and power to the users is very complex to solve. Sub-optimal algorithms have been generally proposed to reduce the complexity of the subcarrier allocation algorithms. It was proved in that allocating the subcarriers to the users with the highest gain, and then allocating the total power to the subcarriers according to water-filling, maximizes the total throughput of the system. Therefore, a two-step resource allocation procedure was generally considered in the OFDM systems. The subcarriers are allocated to the users according to their subcarrier gains in the first step. In the second step, the power is allocated to the subcarriers (users).

A. User Data Rate

The subcarrier allocation matrix, $C = [c_{k,n}]_{K \times N}$, specifies which subcarrier(s) should be allocated to which user. $c_{k,n} = 1$, if and only if subcarrier n is allocated to user k ; otherwise it is zero. None of the users shares subcarrier, so in case $c_{k,n} = 1$ then $c_{l,n} = 0$ for all $l \neq k$. The total transmit power at the base station is assumed to be P over the whole bandwidth and is equally divided between all the N subcarriers. In such a system, the data rate for the k th user, R_k , is given by:

$$R_k = \frac{B}{N} \sum_{n=1}^N c_{k,n} \log_2(1 + \gamma_{k,n}),$$

Where $\gamma_{k,n}$ is the SNR of the n th subcarrier for the k th user and is given by:

$$\gamma_{k,n} = \frac{P_n |h_{k,n}|^2}{N_0 \frac{B}{N}},$$

and $h_{k,n}$ is the gain for user k and subcarrier n and P_n is the transmit power of user k on subcarrier n . provides the error-free data rate of the wireless channel however the achieved data rate in practical systems is less than what is suggested by Shannon theory. The difference between the SNR needed to achieve a data rate for a practical system and the theoretical SNR is called SNR gap. The SNR gap, Γ , was studied for MQAM. It was shown that for a target BER of P_b , the SNR gap, Γ , can be calculated as:

$$\Gamma = \frac{-\ln(5P_b)}{1.5},$$

and consequently the data rate according to this data rate is calculated as:

$$R_k = \frac{B}{N} \sum_{n=1}^N c_{k,n} \log_2 \left(1 + \frac{\gamma_{k,n}}{\Gamma} \right),$$

B. Throughput-Oriented Subcarrier Allocation

The throughput-oriented subcarrier allocation problem in a multi-user OFDM system is formulated as follows

$$\max_{c_{k,n}} \frac{B}{N} \sum_{k=1}^K \sum_{n=1}^N c_{k,n} \frac{B}{N} \log_2 \left(1 + \frac{P_t |h_{k,n}|^2}{N_0 \frac{B}{N}} \right),$$

$$C1: c_{k,n} \in \{0,1\}, \quad \forall k,n$$

$$C2: \sum_{k=1}^K c_{k,n} = 1, \quad \forall n$$

Constraints C1 and C2 guarantee that the subcarriers are not shared by the users and once a subcarrier is assigned to a user it will not be allocated to another user.

C. Fairness-oriented subcarrier allocation

The fairness-oriented subcarrier allocation problem in a multi-user OFDM system is formulated as follows

$$\max_{c_{k,n}} \min_k \sum_{n=1}^N c_{k,n} \frac{B}{N} \log_2 \left(1 + \frac{P_t |h_{k,n}|^2}{N_0 \frac{B}{N}} \right),$$

$$C1: c_{k,n} \in \{0,1\}, \quad \forall k,n$$

$$C2: \sum_{k=1}^K c_{k,n} = 1, \quad \forall n$$

D. Performance Evaluation: Throughput and Fairness

We compare the performance of the asymptotically fair algorithm with throughput-oriented and fairness-oriented algorithms in terms of average fairness

and throughput. Asymptotically fair algorithm is shown to outperform the fairness-oriented algorithm in terms of throughput. It also outperforms the throughput-oriented algorithm in terms of the average fairness.

III. COOPERATIVE AF SUBCARRIER ALLOCATION IN OFDM SYSTEMS

We assume an AF TDMA-based relaying protocol similar to what was described. One RS is assigned to every MS in the system to accommodate the relaying. BS-MS pair plus RS build up a unit that is similar to the single-relay model. We will take advantage of this similarity and apply the optimal power allocation results presented to the multi-user relaying system to increase the power efficiency of the system. Based on the capacity equations derived for the AF relaying system, a new parameter called cooperation coefficient is defined.

A. Cooperation Coefficient

The maximum error-free data rate for MSK can be written as:

$$r_{k,n} = \frac{B}{2N} \log_2 \left(1 + \frac{P_n}{N_0} |h_{k,n}|^2 + \frac{\frac{P_n}{N_0} \frac{P_{rk,n}}{N_0} |h_{rk,n}|^2 |h_{ik,n}|^2}{\frac{P_n}{N_0} \sigma_{ik,n}^2 + \frac{P_{rk,n}}{N_0} |h_{rk,n}|^2 + 1} \right)$$

Where B is the total bandwidth divided into N subcarriers. We notice that the data rate is the function of the direct paths and indirect paths. Therefore, $r_{k,n}$ can be rewritten as:

$$r_{k,n} = \frac{B}{2N} \log_2 \left(1 + \frac{P_n}{N_0} (|h_{k,n}|^2 + a_{k,n} |h_{ik,n}|^2) \right)$$

Where $a_{k,n}$ is the contribution level from RS in the data rate of MSK on the n^{th} subcarrier. We define this parameter as cooperation coefficient. Therefore, $a_{k,n}$ can be written as:

$$a_{k,n} = \frac{\frac{P_{rk,n}}{N_0} |h_{rk,n}|^2}{\frac{P_n}{N_0} \sigma_{ik,n}^2 + \frac{P_{rk,n}}{N_0} |h_{rk,n}|^2 + 1}$$

It should be noted that the cooperation coefficient cannot exceed one; i.e., the cooperation level in the capacity from the indirect path is always less than the direct path.

B. The PDF of Cooperation Coefficient

The cooperation coefficient is a random variable. We first intend to find the probability density function (pdf) of cooperation coefficient and then its mean and variance to understand and analyze its characteristics. According to the definition of cooperation coefficient, the cooperation coefficient is a function of $h_{rk,n}$, the indirect subcarrier gain.

Therefore, following the procedure for finding pdf of a function of a random variable, the pdf of cooperation coefficient, a , is as follows:

$$f_A(a) = \frac{\beta}{(1-a)^2} f_{Hr} \left(\frac{\beta a}{1-a} \right)$$

The cooperation coefficient for different relay location, d_i and equal power allocation to base station and relay station. We assume a normalized distance for BS – MS_k pair; i.e., $d = 1$. RS_j is located on the line connecting BS to MS_k and the path-loss index is three ($\alpha = 3$). This implies different values for σ_i^2 , σ_r^2 and β .

Cooperation coefficient is distributed in the interval of (0,1). A cooperation coefficient closer to zero implies that the effect of indirect link in the total data rate of mobile station is very small and, having a cooperation coefficient closer to one means that both the indirect and indirect links have almost the same impact on the total data rate.

C. Cooperative Subcarrier Allocation

The problem of subcarrier allocation in the downlink of a multi-user OFDM relaying system is considered. Performing joint subcarrier and power allocation in the system exponentially increases the complexity of the resource allocation algorithm as well as the time needed to find the optimized solution. Base station has to rapidly update the resource allocation information to benefit effectively from the dynamic nature of the environment

Here, we consider a flat power allocation and focus on the problem of subcarrier allocation in the relaying system. We assume a relaying system with K users and R relay stations with N subcarriers to be allocated to the users.

1) Throughput-Oriented Cooperative Subcarrier Allocation

The main goal of throughput-oriented cooperative subcarrier allocation in a multi-user OFDM relaying system is to maximize the total throughput and is formulated as follows:

$$\left[\sum_{k=1}^K \sum_{n=1}^N C_{k,n} \frac{B}{2N} \log_2 \left(1 + \frac{P_n}{N_0} (|h_{k,n}|^2 + a_{k,n} |h_{rk,n}|^2) \right) \right]$$

The constraints C_1 and C_2 guarantee that subcarriers are not shared in the system similar to the non-cooperative problem formulation. Total power P_t is equally divided between the base station and the relay station over N subcarriers. Therefore, the objective value in assigning the subcarriers to the mobile stations should also include the cooperation coefficient and the relay station's subcarrier gain.

We choose the objective value as $|h_{k,n}|^2 + a_{k,n} |h_{rk,n}|^2$ for user k. As stated earlier, we have chosen flat power allocation to decrease the complexity of the algorithm.

2) Fairness-Oriented Cooperative Subcarrier Allocation

The main goal of fairness-oriented cooperative subcarrier allocation in a multi-user OFDM relaying system with equal power allocation is to maximize the total throughput with maintaining the fairness among the users and is formulated as follows:

$$\left[\sum_{n=1}^N C_{k,n} \frac{B}{2N} \log_2 \left(1 + \frac{P_n}{N_0} \left(|h_{k,n}|^2 + a_{k,n} |h_{k,n}|^2 \right) \right) \right]$$

IV. COOPERATIVE DF SUBCARRIER ALLOCATION IN OFDM SYSTEMS

Assume a DF TDMA-based relaying protocol similar to what was described. One RS is assigned to every MS in the system to accommodate the relaying. BS-MS pair plus RS build up a unit that is similar to the single-relay model. It will take advantage of this similarity and apply the optimal power allocation results presented to the multi-user relaying system to increase the power efficiency of the system. Based on the capacity equations derived for the DF relaying system, a new parameter called cooperation coefficient is defined. Cooperation coefficient concept is applied to the subcarrier allocation algorithm to increase the throughput of the multi-user relaying system.

First define the cooperation coefficient and analyze its characteristics in the system. The multi-user DF relaying system model is presented next. The cooperative subcarrier allocation problem is formulated and the algorithm is proposed

DF RELAY SUBCARRIER ALLOCATION:

Also known as digital relaying, DF relaying is a technique that requires more processing time and hardware at the relay. DF relay decodes the received signal from the relay and performs error-correction on the decoded signal, if required. The relay then re-transmits the correctly decoded signal to the destination.

A. USER DATA RATE:

The maximum error-free data rate for MSK can be written as:

$$r_{k,n} = \frac{W}{2N} \log_2 \left(1 + \frac{P_n}{N_0(W/N)} |g_{k,n}|^2 + \frac{P_{r_{k,n}}}{N_0(W/N)} |g_{r_{k,n}}|^2 \right)$$

where W is the total bandwidth divided into N subcarriers. We notice that the data rate is the function of the direct paths and indirect paths.

B. COOPERATIVE SUBCARRIER ALLOCATION

Considering a flat power allocation and focus on the problem of subcarrier allocation in the relaying system. Assuming an relaying system with K users and R relay stations with N subcarriers to be allocated to the users. The power allocation to mobile stations and relays will be discussed in this section.

1. Through put-Oriented Cooperative Subcarrier Allocation

The main goal of throughput-oriented cooperative subcarrier allocation in a multi-user OFDM relaying system is to maximize the total throughput and is formulated as follows:

$$\max_{c_{k,n}} \left[\sum_{k=1}^K \sum_{n=1}^N \frac{W}{2N} \log_2 \left(1 + \frac{P_s}{N_0(W/N)} |g_{k,n}|^2 + \frac{P_{s_{k,n}}}{N_0(W/N)} |g_{r_{k,n}}|^2 \right) \right]$$

subject to:

$$C_1 : C_{k,n} \in \{0,1\}, \forall k, n$$

$$C_2 : \sum_{k=1}^K C_{k,n} = 1, \forall n$$

The constraints C₁ and C₂ guarantee that subcarriers are not shared in the system similar to the non-cooperative problem formulation.

The throughput-oriented cooperative subcarrier allocation algorithm is a fairly simple procedure. In the first step, all the variables are initialized and the objective value is calculated for all the subcarriers of all the users. In the next step, each subcarrier is assigned to the user that has the highest objective value for that subcarrier. The procedure continues until all the subcarriers are allocated. This algorithm does not consider the fairness among users in the system. In the next section, we introduce the fairness-oriented subcarrier allocation algorithm for the cooperative relaying system by modifying the objective value in subcarrier allocation.

2. Fairness-Oriented Cooperative Subcarrier Allocation

The main goal of fairness-oriented cooperative subcarrier allocation in a multi-user OFDM relaying system with equal power allocation is to maximize the total throughput with maintaining the fairness among the users and is formulated as follows:

$$\left[\sum_{n=1}^N C_{k,n} \frac{W}{2N} \log_2 \left(1 + \frac{P_s}{N_0} \left(|g_{k,n}|^2 + a_{k,n} |g_{r_{k,n}}|^2 \right) \right) \right]$$

subject to:

$$C_1 : C_{k,n} \in \{0,1\}, \forall k, n$$

$$C_2 : \sum_{k=1}^K C_{k,n} = 1, \forall n$$

By modifying the objective value for a fairness-oriented subcarrier allocation algorithm, the fairness-oriented cooperative subcarrier allocation algorithm is proposed as follows:

In the first step, all the variables are initialized and objective value is calculated for all the subcarriers of all the users. In the second step, one subcarrier is assigned to each user based on the objective value; i.e., one

subcarrier is assigned to each user (in a greedy pattern). After all the users have been assigned one subcarrier each, in the third step, the user with the lowest data rate is given the priority to choose its next subcarrier. This procedure continues until all the subcarriers are allocated.

The cooperative subcarrier allocation algorithm proposed here requires instantaneous knowledge of cooperative coefficient at the base station (besides $|g_{k,n}|$ and $|g_{r,k,n}|$), which itself implies availability of the knowledge of the relaying channel at the base station. Cooperation coefficient is a function of $|g_{r,k,n}|$ and its availability at the base station requires continuous feedback of the relaying subcarrier gain to the base station. Mean of cooperation coefficient can be found based on the distance between the relay station and the mobile station. We will show that by using the mean of cooperation coefficient instead of its instantaneous value the total throughput of the system degrades comparably. In the worst case scenario, when no information about the mean of cooperation coefficient is available, we can assume a uniform distribution for cooperation coefficient and calculate the mean. The cooperative algorithm still achieves a better performance compared to the non-cooperative one.

V. RESULTS & DISCUSSION

COMPARISON OF THROUGHPUT BETWEEN NON-COOPERATIVE, AF AND AF COOPERATIVE RELAYING PROTOCOL

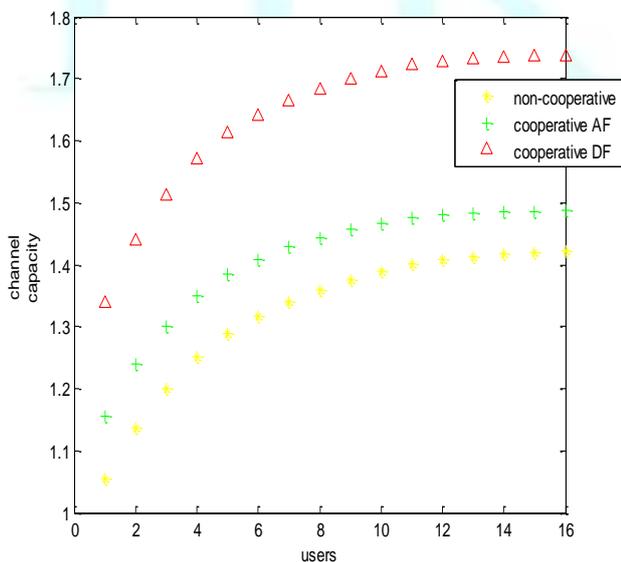


Fig 2 Total throughput versus number of users for throughput oriented algorithm

when user increases, channel capacity also increases. when comparing non-cooperative and cooperative AF relaying protocol, cooperative DF relay protocol shows better performance.

COMPARISON OF FAIRNESS BETWEEN NON-COOPERATIVE, AF AND AF COOPERATIVE RELAYING PROTOCOL

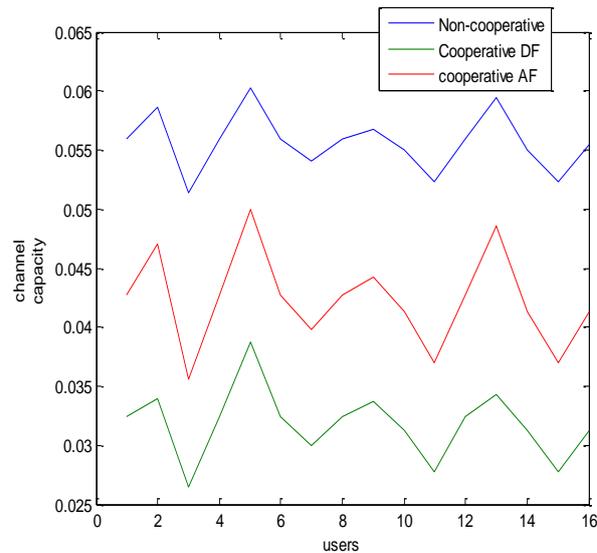


Fig 3 Total throughput versus number of users for fairness oriented algorithm

In this graph the subcarrier is fairly distributed and when comparing non-cooperative and cooperative AF relaying protocol, cooperative DF relay protocol shows better performance.

COMPARISON OF FAIRNESS INDEX BETWEEN NON-COOPERATIVE, AF AND AF COOPERATIVE RELAYING PROTOCOL

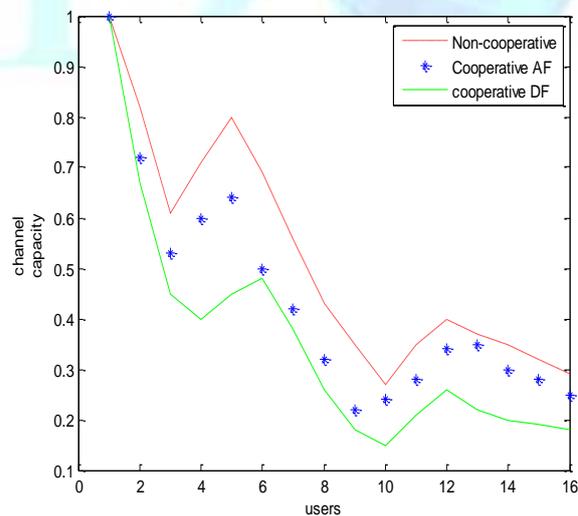


Fig 4 Fairness index comparison for non-cooperative, AF and DF cooperative relaying protocol when user increases, channel capacity also decreases. when comparing non-cooperative and cooperative AF relaying protocol, cooperative DF relay protocol shows better performance.

COMPARISON OF BIT ERROR RATE BETWEEN NON-COOPERATIVE, AF AND AF COOPERATIVE RELAYING PROTOCOL

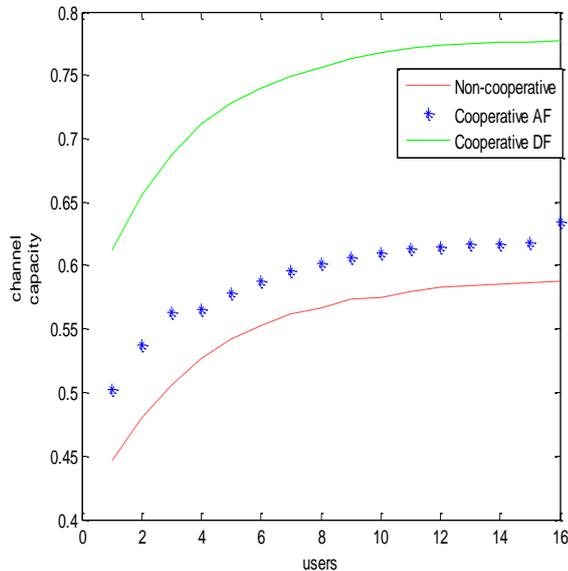


Fig 5 Bit error rate comparison for non-cooperative, AF and DF cooperative relaying protocol

when user increases, channel capacity also increases and bit error rate get reduced. when comparing non-cooperative and cooperative AF relaying protocol , cooperative DF relay protocol shows better performance.

AWGN(Additive White Gaussian Noise) presents in the cooperative AF relay protocol. It amplifies the noise, to overcome the noise, cooperative DF relaying protocol is proposed.

SPECIFICATIONS

- Channel Bandwidth B=1.25 MHz
- Channel Gain h(assume as high channel gain)(0 to 1)
- No .of sub carriers N=256
- Spectral Noise density(AWGN) No=10⁻³ m watt for 0dbm
- No. of users k=(1 to K)

VI. CONCLUSION

In this paper, the performance of non cooperative and cooperative subcarrier allocation are analyzed and compared. Results shows that proposed cooperative DF relaying protocol is reduced the BER and high channel capacity compared to the cooperative AF relaying protocol and non-cooperative system. In case of source to relay SNR value is low in the system, DF relaying protocol are not decoded the information correctly. In future, hybrid DF/AF relaying protocol will be considered, the threshold elow or above SNR value is to the select proper AF or DF relaying protocol in the relaying systems.

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