Multi-User Adaptive Resource Allocation Scheme for WLAN OFDM-MIMO Transmission

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Abstract. . Orthogonal Frequency division multiplexing (OFDM) has recently been proposed for use in high data-rate wireless systems. OFDM has an important property of spectrum utilization technique that distributes each tone, which is orthogonal with every other tone. The system capacity can be significantly improved by multiple transmit and receive antennas that are used to form Multi-input multi-output (MIMO) channel. The combination of OFDM with MIMO transmission performance can be vastly improved by properly allocating the resources amongst different users. For that this paper proposes a multi-user Adaptive resource allocation scheme for Wireless Local Area Network (WLAN) transmission. Based on the channel information and power level, resource allocation algorithm assigns a set of subcarriers to each user and loads the corresponding subcarriers with different number of bits per OFDM symbol subject to resultant BER which should not be higher than target BER. The main objective of this proposed algorithm is to maximize the overall data rate of the channel. The improved performance of this system is compared with fixed resource allocation TDMA scheme and the simulation result shows that the minimum user's capacity is appreciably improved compared to the TDMA scheme..

Keywords: OFDM, MIMO, Spectrum Utilization technique, WLAN, IEEE 802.11a Standards and Adaptive Resource Allocation.

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1 Introduction

OFDM has also been identified as a promising interface solution for broadband wireless networks and 802.11a for its excellent performance over frequency selective channels [1] [2]. In multipath environment, **MIMO** system can increase the transmission rate, system performance and it has enormous communication capacity [3]. In [4-6] it is suggested that different users are separated, by transmitting the data on different subcarriers. In [7] multiple users are allowed to transmit on the same subcarriers because they can be separated in space domain by multiple antennas. It introduces Co Channel Interference (CCI), but [8] provides the solution, by reduced complexity algorithm, where the users are classified according to their spatial separability, which is quantified by the correlation between the spatial signatures. OFDM has been selected as the basic modulation technique for several high speed wireless networks like WLAN and uses IEEE standards [9] including IEEE 802.11a, IEEE 802.11g and HYPERLAN/2. This paper proposes OFDM-MIMO system for WLAN 802.11a standard and its performance can be improved by Adaptive resource allocation technique. Basically two types of resource allocation techniques have been proposed in the multi-user OFDM-MIMO system. They are fixed resource allocation [10] and dynamic resource allocation [11] [12]. Fixed resource allocation scheme is not optimal since the scheme is fixed regardless of the present channel condition. Due to the time-varying nature of the wireless channel, dynamic resource allocation achieves higher performance. This is mainly classified into two technique as Margin Adaptive (MA) [11] and Rate Adaptive (RA) [12] [13] technique. The MA technique objective is to achieve the minimum overall transmit power for the given constraints on the users' data rate or Bit Error Rate (BER). The RA technique objective is to maximize each user's error-free capacity with a total transmit power constraint. Performance of the system can be vastly improved by properly allocating resources amongst the different users. In this paper an adaptive resource allocation scheme algorithm for maximizing the minimum user's capacity is proposed. The rest of the paper is organized as follows. In Section 2, the system model is described. The adaptive resource allocation optimization problem is formulated in Section 3. The performance of the proposed algorithm is investigated in Section 4. Finally the paper is concluded in Section 5.

2 Task Graph Model

With the rapid growth of wireless networks, there is an urgent need to develop new technologies to achieve high resource utilization efficiency. This paper considers a multi-user OFDM-MIMO system that has K users and N subcarriers as shown in Fig 1. Serial data from K users are fed into the resource allocation block, which allocates bits from different users to different subcarriers. Using the channel information, the transmitter applies the combined subcarrier, power and bit allocation algorithm to assign different subcarriers to different users and loads the corresponding subcarriers with different number of bits per OFDM symbol. We define, $r_{n,k}$ as the number of bits of k^{th} user that are assigned on the n^{th} subcarrier. Depending on the number of bits assigned to a subcarrier, the adaptive modulator will use the corresponding modulation scheme.

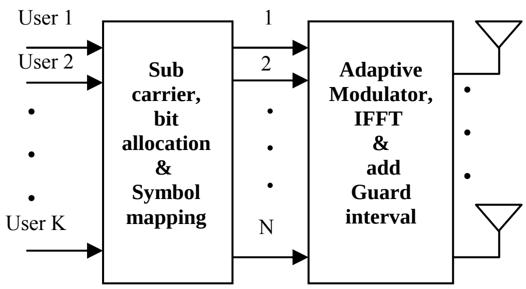

Fig 1 Multi-user OFDM-MIMO system Transmitter Block

The frequency domain complex symbols at the output of the adaptive modulators are transformed into the time domain samples by Inverse Fast Fourier Transform (IFFT). Cyclic extension of the time domain samples, known as guard interval is then added to ensure the orthogonality between the subcarriers. The transmitted signal is then passed through AWGN channel. The magnitude of the channel gain seen by the k^{th} user on the n^{th} subcarrier is denoted by $g_{n,k}$. At receiver, the guard interval is removed to eliminate Inter Symbol Interference (ISI) and the time domain samples of the k^{th} user are transformed by Fast Fourier Transform (FFT) into modulated symbol. The modulated symbols to bits according to the subcarrier and bit allocation information are mapped.

3 Adaptive Resource Allocation

In the adaptive resource allocation scheme, the number of bits of k^{th} user that are assigned on the on the n^{th} subcarrier is defined as

$$r_{n,k} = \frac{1}{2N} \sum_{n=1}^{N} \log_2 \left(1 + \frac{g^2_{n,k} \rho_{n,k}}{\Gamma \sigma^2_{n,k}} \right) \quad (1)$$

$r_{n,k}$ take values in the set D = { 0,1,2, . . . M }, where M is the maximum number of information bits/OFDM symbol that can be transmitted by n^{th} subcarrier. Let $\rho_{n,k}$ be allocation indicator. In this case $\rho_{n,k}=1$ when n^{th} subcarrier is allocated to the k^{th} user, while $\rho_{n,k} = 0$ otherwise. p_n denotes the power allocated to the n^{th} subcarrier and $\sigma^2_{n,k}$ denote the channel noise variance measured over the bandwidth B. $r_{n,k}$ denotes the number of bits allocated to the k^{th} user on the n^{th} subcarrier. $g_{n,k}$ denotes the magnitude of the channel gain $|H_{n,k}|$ of k^{th} user on the n^{th} subcarrier. The signal-to-noise gap Γ is a function of the permissible probability of symbol error P_e.
Mathematically, the optimization problem is

$$R_T^{*} = \max \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{1}{2N} \log_2 \left(1 + \frac{g^2_{n,k} \rho_{n,k}}{\Gamma \sigma^2_{n,k}} \right) \quad (2)$$

Subject to the following constraints C1 and C2

C1: For all $k \in \{1,2,\ldots K\}$ user,

$$P_k = \sum_{n=1}^{N} p_{n,k} \quad (3)$$

C2: For all $n \in \{1,2, \ldots N\}$ subcarrier,
if there exists k' with $r_{n,k'} \neq 0$

$$\text{then } r_{n,k} = 0 \ \forall\ k \neq k' \quad (4)$$

Total transmit power among the various subcarriers are maintained constant. Let us consider the bit allocation algorithm for single-user environment.

Bit Allocation Algorithm for Single user channel:

Rewrite the optimization problem in (2) for a single user case,

$$R_T^{*} = \max \sum_{n=1}^{N} \frac{1}{2N} \log_2 \left(1 + \frac{g^2_{n,k} \rho_{n,k}}{\Gamma \sigma^2_{n,k}} \right) \quad (5)$$

and the maximization under the constraint

$$P = \sum_{n=1}^{N} p_n \quad (6)$$

As the transmit power p_n is fixed and known, we can calculate r_n based on given channel gain g_n. $\{r_n\}$ for $n=\{1,2,\ldots N\}$ is the final bit allocation solution.

Multi-user Subcarrier and Bit allocation:

The problem becomes more difficult in the multi-user environment. As users cannot share the same subcarrier, allocating bits to a subcarrier essentially prevents other users from using that subcarrier. The new optimization problem is

$$R_T = \max \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{\rho_{n,k}}{2N} \log_2\left(1 + \frac{g^2_{n,k} p_{n,k}}{\Gamma \sigma^2_{n,k}}\right) \quad (7)$$

Subject to

$$P_k = \sum_{n=1}^{N} \rho_{n,k} p_{n,k} \quad \text{for all } k \in \{1,2,\ldots K\} \quad (8)$$

and

$$\rho_{n,k} = \begin{cases} 1 \text{ if } r_{n,k} \neq 0 \\ 0 \text{ if } r_{n,k} = 0 \end{cases} \quad (9)$$

Let $q_{n,k} = \rho_{n,k}\, p_{n,k}$ (10)

Reformulate the optimization problem in (7)

$$R_T = \max \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{\rho_{n,k}}{2N} \log_2\left(1 + \frac{g^2_{n,k} q_{n,k}}{\Gamma \sigma^2_{n,k} \rho_{n,k}}\right) \quad (11)$$

where $q_{n,k}$ and $\rho_{n,k}$ have to satisfy,

$$P_k = \sum_{n=1}^{N} q_{n,k} \quad \text{for all } k \in \{1,2,\ldots K\} \quad (12)$$

$$\sum_{k=1}^{K} \rho_{n,k} = 1 \text{ for all } n \in \{1,2,\ldots N\} \quad (13)$$

Optimal solution is obtained by using standard optimization technique (by Lagrangian method) and Lagrangian L is

$$L = \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{\rho_{n,k}}{2N} \log_2\left(1 + \frac{g^2_{n,k} q_{n,k}}{\Gamma \sigma^2_{n,k} \rho_{n,k}}\right) - \sum_{k=1}^{K} \lambda_k \left(\sum_{n=1}^{N} q_{n,k} - P_k\right) - \sum_{k=1}^{K} \beta_n \left(\sum_{n=1}^{N} \rho_{n,k} - 1\right) \quad (14)$$

where λ_k and β_n are the Lagrangian multipliers for the constraints (12) and (13) respectively.

$$L = \sum_{n=1}^{N} \sum_{k=1}^{K} \log_2 e \frac{\rho_{n,k}}{2N} \log_e\left(1 + \frac{g^2_{n,k} q_{n,k}}{\Gamma \sigma^2_{n,k} \rho_{n,k}}\right) - \sum_{k=1}^{K} \lambda_k \left(\sum_{n=1}^{N} q_{n,k} - P_k\right) - \sum_{k=1}^{K} \beta_n \left(\sum_{n=1}^{N} \rho_{n,k} - 1\right) \quad (15)$$

After differentiating L with respect to $q_{n,k}$ and $\rho_{n,k}$ respectively, we obtain the necessary conditions for the optimal solution, $q^*_{n,k}$ and $\rho^*_{n,k}$. If $\rho^*_{n,k} \neq 0$, then we have

$$\frac{\partial L}{\partial q_{n,k}} = \sum_{n=1}^{N} \sum_{k=1}^{K} \log_2 e \left(\frac{\rho_{n,k}}{2N}\right) \cdot \log_e\left(\frac{1}{1 + \frac{g^2_{n,k} q_{n,k}}{\Gamma \sigma^2_{n,k} \rho_{n,k}}}\right)\left(\frac{g^2_{n,k}}{\Gamma \sigma^2_{n,k} \rho_{n,k}}\right) - \lambda_k \begin{cases} > 0 \text{ if } q^*_{n,k} = 0 \\ = 0 \text{ if } q^*_{n,k} \in (0, V.\rho^*_{n,k}) \\ < 0 \text{ if } q^*_{n,k} = (0, V.\rho^*_{n,k}) \end{cases} \quad (16)$$

On the other hand, if $\rho^*_{n,k} = 0$ and $q^*_{n,k} = 0$, then we have

$$q_{n,k} \frac{\partial L}{\partial q_{n,k}} + \rho_{n,k} \frac{\partial L}{\partial \rho_{n,k}} \geq 0 \qquad (17)$$

for all $\rho_{n,k} \in (0,1)$ and $q_{n,k} \in (0, V\rho_{n,k})$.
These necessary conditions can be interpreted by the fact that if the minimum occurs within the constrained region (0,1) for $\rho_{n,k}$ and $(0,V\rho_{n,k})$ for $q_{n,k}$.

To find λ_k from (16)

$$\sum_{n=1}^{N} \sum_{k=1}^{K} \log_2 e \left(\frac{\rho_{n,k}}{2N}\right) .$$

$$\log_e \left(\frac{1}{1+ \frac{g^2_{n,k}\, q_{n,k}}{\Gamma \sigma^2_{n,k}\, \rho_{n,k}}} \right) \left(\frac{g^2_{n,k}}{\Gamma \sigma^2_{n,k}\, \rho_{n,k}} \right) = \lambda_k$$

By simplification

$$\frac{\rho_{n,k} \log_2 e}{q_{n,k} + \frac{\Gamma \sigma^2_{n,k}\, \rho_{n,k}}{g^2_{n,k}}} = \lambda_k \qquad (18)$$

This result indicates that the solution to the constraint optimization problem is

$$q_{n,k} + \frac{\Gamma \sigma^2_{n,k}\, \rho_{n,k}}{g^2_{n,k}} = \boldsymbol{T} \qquad (19)$$

where ***T*** is a prescribed constant under the designer's control. That is, the sum of the transmit power and the noise variances scaled by the ratio $\Gamma/g^2_{n,k}$ must be maintained constant.

Optimization Problem:

Maximize the overall data rate of the channel in terms of number of bits per subcarrier while simultaneously satisfying the requirements of each user's data rate, BER and the total transmit power. (i)Based on channel information $g^2_{n,k}$ the OFDM transmitter assigns different subcarriers with different number of bits. (ii) The resultant BER should not be higher than target BER and the overall transmit power should be within the power constraint.
Objective:

$$\max R = \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{n,k}\, r_{n,k} \qquad (20)$$

Subject to

$$C1: \quad P_k = \sum_{n=1}^{N} p_{n,k} \qquad (21)$$

$$C2: \quad \rho_{n,k} = \begin{cases} 1 \ ; \ r_{n,k} \neq 0 \\ 0 \ ; \ r_{n,k} = 0 \end{cases} \qquad (22)$$

$$C3: \quad \sum_{n=1}^{N} \rho_{n,k}\, r_{n,k} \geq V \qquad (23)$$

where V is the minimum rate requirement.

(i) Assume number of subcarrier is larger than number of user.
(ii) The overall data rate of OFDM MIMO System is maximized when each subcarrier is assigned to user with the best SNR for that subcarrier with power subsequently distributed.

$$C4: \ r_{n,k} = \frac{1}{2N} \sum_{n=1}^{N} \log_2 \left(1 + \frac{g^2_{n,k}\, \rho_{n,k}}{\Gamma \sigma^2_{n,k}} \right) \qquad (25)$$

where P_{tot} is the total transmit power of the system and $r_{n,k}$ is the number of bits of the k^{th} user, that are assigned to the n^{th} subcarrier.

4 Simulation Results

The performance of the proposed adaptive resource allocation scheme for OFDM-MIMO system is considered for the WLAN environment. Based on WLAN IEEE 802.11a standard, the main simulation parameters are presented in Table 1.

TABLE 1 System Parameter

Carrier Frequency	5GHz
Bandwidth	1MHz
Number of User	16
Target BER	10^{-2}
Channel Encoding	No Coding
Number of subcarrier	64
Guard Interval	16
Channel Model	AWGN
Sample Period	0.05μs

Bit Error Rate (BER) versus the average SNR (dB) for adaptive and Non-adaptive or fixed scheme is shown in Fig 2. BER obtained in the adaptive algorithm is reduced significantly compare to non adaptive scheme for the same average SNR (dB).

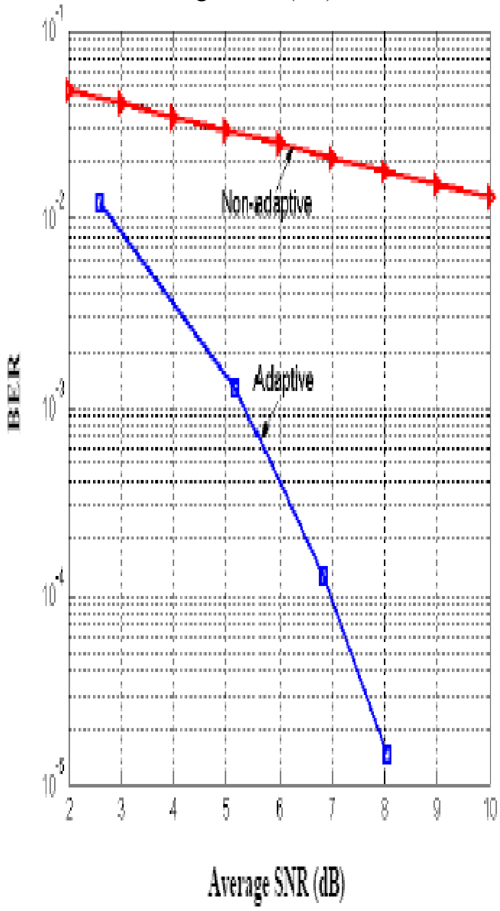

Fig 2 BER verses Average SNR (dB) for Adaptive and non-adaptive scheme.

In the proposed algorithm, based on the channel state information $H_{n,k}$, the number of subcarriers are allocated to each user is presented in Fig 3. Selects the total number of subcarrier to be 64 and it is distributed among 16 users based on the proposed algorithm.

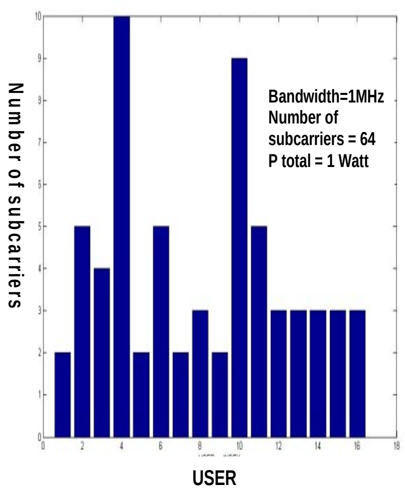

Fig 3 Subcarrier allocation for 16 users.

Once the subcarrier allocation is fixed, the optimal bit and power allocation algorithm to every user is applied. The proposed algorithm distributes the total transmit power P_{tot} of 1W, amongst the user depending on ***T***. That is, the sum of power of the each user is equal to P_{tot} is shown in Fig 4.

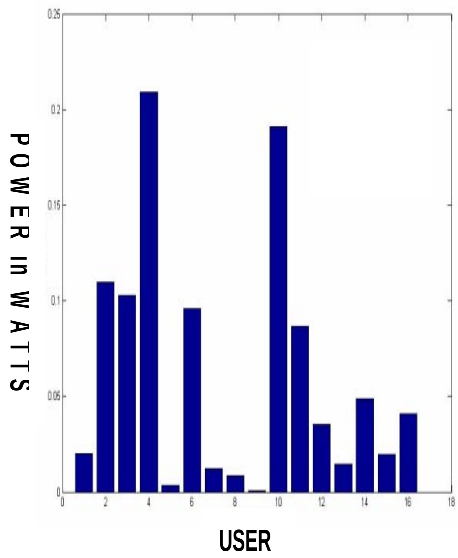

Fig 4 Power allocation for 16 users.

The throughput bits per subcarrier verses average SNR is plotted in Fig 5 for both adaptive and non-adaptive technique and it shows that proposed adaptive technique improves throughput bits per subcarrier compared to fixed technique. After the allocation of resources are completed, the minimum user's capacity (bits/sec/Hz) is calculated for P_{tot} = 1W and Bandwidth = 1MHz

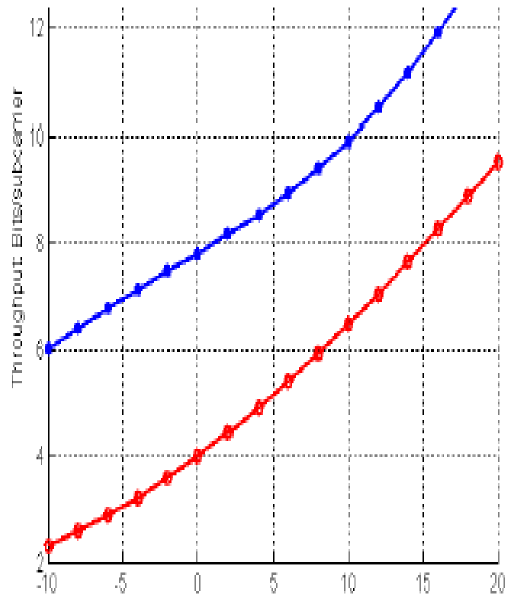

Fig 5 Throughput bits/subcarrier verses Average SNR (dB) for Adaptive and non-adaptive scheme.

The minimum user's capacity of the proposed algorithm with the non-adaptive or fixed resource allocation of TDMA is compared in Fig 6. For example, in the case of 12th user, user capacity is doubled compared to TDMA scheme. That is, 0.35 (bits/sec/Hz) for TDMA and 0.70 (bits/sec/Hz) for the proposed adaptive resource allocation scheme.

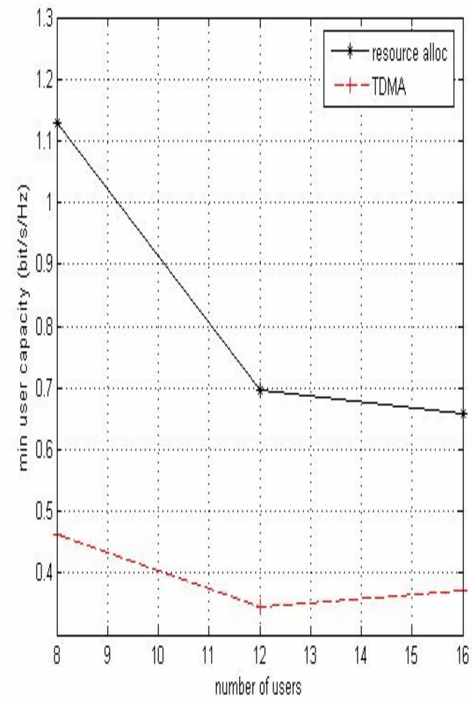

Fig 6 Minimum user's capacity for 16 users. P_{totl}= 1 watt, BW=1MHz.

The same concept of minimum user's capacity for different value of P_{tot} is evaluated for 16 users for P_{tot} values of 0.8, 1.0, 1.2 and,1.4. BW=1Mhz in Fig 7. The simulation results have shown the promising results in term of the minimum user's capacity for several values of P_{tot} and the capacity is doubled compared to TDMA scheme by appropriate allocation of the resources (bit, subcarrier and power) amongst users.

5 Conclusion

In this paper, OFDM MIMO transmission in a WLAN environment was considered and maximization of the overall data rate or throughput by adaptively assigning subcarrier to the users with number of bits to each subcarrier based on the channel information and power level constrain. The performance of the dynamic resource allocation proposed scheme is compared with fixed resource allocation TDMA scheme. The simulation results indicated that an appreciable improvement in capacity has been observed.

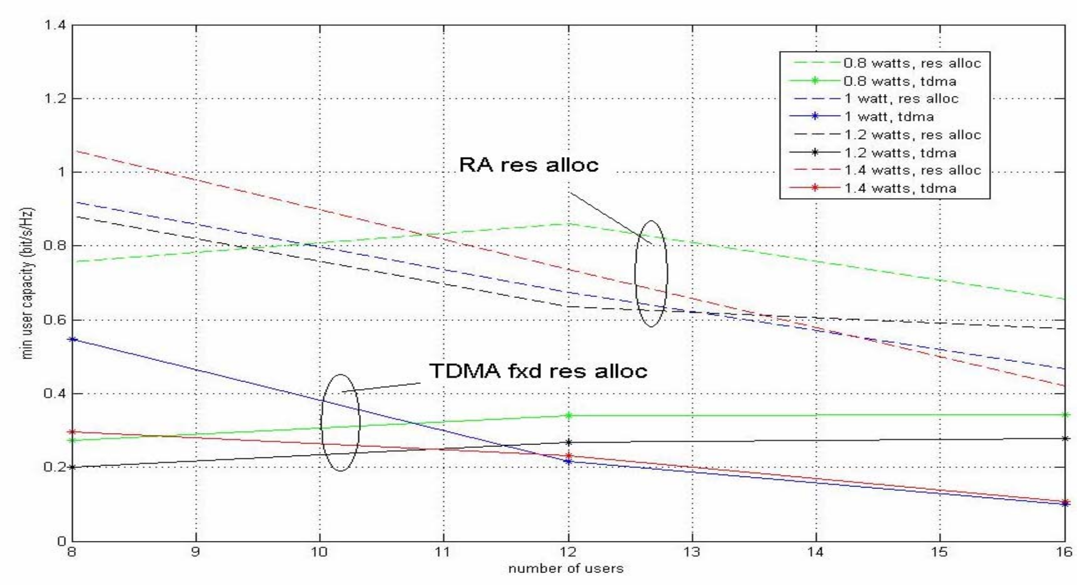

Fig 7 Minimum user's capacity for 16 users for P_{tot} values of 0.8, 1.0, 1.2 and,1.4. BW=1Mhz

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APPENDIX

According to Shannon's information capacity theorem, the capacity of an AWGN channel is defined by

$$C = B \log_2 (1+SNR) \text{ bits/sec} \quad (26)$$

Where B is the channel bandwidth, and SNR denotes the signal-to-noise ratio measured at the channel output. For a given SNR, data transmit over an AWGN channel of bandwidth B at the maximum rate of C bits per second with arbitrarily small probability of error, the capacity C in bits per transmission or channel is

$$C = 1/2 \log_2 (1+SNR) \text{ bits/transmission}$$

In practice, the system transmit data at a rate R less than the maximum possible rate C. the signal-to-noise gap Γ is a function of the permissible probability of symbol error P_e and defined by

$$\Gamma = \frac{2^{2C}-1}{2^{2R}-1} = \frac{SNR}{2^{2R}-1} \quad (27)$$

Equivalently,

$$R = \frac{1}{2}\log_2\left(1+\frac{SNR}{\Gamma}\right) \text{bits/transmission} \quad (28)$$

Let P denote the transmitted signal power and σ^2 denote the channel noise variance measured over the bandwidth B. The Signal-to-noise is SNR = P / σ^2 , where σ^2=N_oB. Therefore, the data rate is

$$R = \frac{1}{2}\log_2\left(1+\frac{P}{\Gamma\,\sigma^2}\right) \text{bits/transmission}$$

Consider multicarrier transmission system, channel frequency response is $H(f_n)$ at subchannel carrier frequency $f=f_n$ and $g_n=|H(f_n)|$, the overall SNR

$$SNR = \prod_{n=1}^{N} (P_n / \sigma_n^2)^{1/N} \quad (29)$$

and

$$R = \frac{1}{2N}\sum_{n=1}^{N}\log_2\left(1+\frac{g_n^2 P_n}{\Gamma\,\sigma_n^2}\right) \quad (30)$$

The g^2_n and Γ are fixed, maintain the total transmit power at some constant value P, the optimization problem is stated as Maximize the bit rate R for the entire multicarrier channel transmission system through an optimal sharing of the total transmit power P between the N subcarrier, subject to the constraint that P is maintained constant.