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Performance Analysis of Adaptive Multi User OFDM

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Abstract: *The demand for high-speed mobile wireless communications is rapidly growing. OFDM technology promises to be a key technique for achieving the high data capacity and spectral efficiency requirements for wireless communication systems of the near future. In our proposed method Adaptive modulation techniques is used for maximizing the data throughput of subcarriers allocated to a user. It measures the SNR of each subcarrier in the transmission, then selecting a modulation scheme that will maximize the spectral efficiency, while maintaining an acceptable BER. This technique has been used in Asymmetric Digital Subscriber Line (ADSL) to maximize the system throughput.In addition Adaptive user allocation improves signal power of 3-5 dB. Also in the first techniques Crest Factor (CF)is reduced by using OFDM pilot symbols ,in the second techniques reduces the CF of data carrying symbols, by including additional subcarriers*
Keywords: *OFDM ,SNR, Spectral efficiency, throughput, BER,CF*

I. Introduction:

This paper presents an investigation into methods for maximizing the spectral efficiency of Orthogonal Frequency Division Multiplexing (OFDM) systems. As part of this, an investigation of detrimental effects on OFDM is presented, showing the effect of: band pass filtering, the use of a raised cosine guard period, clipping distortion, Additive White Gaussian Noise (AWGN) on modulation BER rate, time synchronization error, and frequency offset errors. An investigation of two adaptive techniques is also presented. These techniques utilize knowledge obtained by dynamically tracking the radio channel response, to optimize the user frequency, and subcarrier modulation. Adaptive modulation independently optimizes the modulation scheme applied to each subcarrier so that the spectral efficiency is maximized, while maintaining a target Bit Error Rate (BER).For a fading channel, adaptive modulation results in an improvement of 12 - 16 dB in the Signal to Noise Ratio (SNR) required to maintain a given BER, as compared with fixed modulation. Adaptive user allocation exploits the difference in frequency selective fading between users, to optimise user subcarrier allocation. In a multipath environment the fading experienced on each subcarrier varies from user to user, thus by utilizing user/subcarrier combinations that suffer the least fading, the overall performance is maximized. Adaptive user allocation results in an additional average signal power improvement of 3 - 5 dB.

In addition, two techniques are presented for reducing the Crest Factor (peak to average power ratio of the RF signal envelope) of OFDM signals. The first technique is a phasing scheme for OFDM pilot symbols, which uses genetic algorithms to optimize the phase angle of each subcarrier. This technique achieves a lower CF than any previously published techniques, obtaining a CF as low as 0.65 dB, which is 2 dB lower than commonly used techniques. The second technique reduces the CF of data carrying symbols, by including additional subcarriers that are optimized in amplitude and phase to cancel out the peaks in the overall OFDM symbol. This was found to produce a net improvement of 4 dB to the worst-case symbol CF.

II. System Model:

Adaptive modulation is a powerful technique for maximizing the data throughput of subcarriers allocated to a user. Adaptive modulation involves measuring the SNR of each subcarrier in the transmission, then selecting a modulation scheme that will maximize the spectral efficiency, while maintaining an acceptable BER. This technique has been used in Asymmetric Digital Subscriber Line (ADSL) to maximize the system throughput. ADSL uses OFDM transmission over copper telephone cables. The channel frequency response of copper cables is relatively constant and so reallocation of the modulation scheme does not need to be performed very often, as a result the benefit greatly out ways the overhead required for measuring of the channel response. Using adaptive modulation in a wireless environment is much more difficult as the channel response and SNR can change very rapidly, requiring frequent updates to track these changes

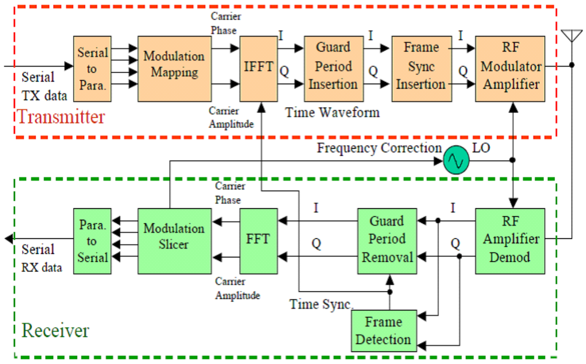

Fig1: block diagram of basic OFDM transceiver

Sets of functions are orthogonal to each other if they match the conditions in equation 1. If any two different functions within the set are multiplied, and integrated over a symbol period, the result is zero, for orthogonal functions. Another way of thinking of this is that if we look at a matched receiver for one of the Orthogonal functions, a subcarrier in the case of OFDM, and then the receiver will only see the result for that function. The results from all other functions in the set integrate to zero, and thus have no effect.

These subcarriers are orthogonal to each other because when we multiply the waveforms of any two subcarriers and integrate over the symbol period the result is zero. Multiplying the two sine waves together is the same as mixing these subcarriers. This results in sum and difference frequency components, which will always be integer subcarrier frequencies, as the frequency of the two mixing subcarriers has integer number of cycles. Since the system is linear we can integrate the result by taking the integral of each frequency component separately then combining the results by adding the two sub-integrals. The two frequency components after the mixing have an integer number of cycles over the period and so the sub-integral of each component will be zero, as the integral of a sinusoid over an entire period is zero. Both the sub-integrals are zeros and so the resulting addition of the two will also be zero, thus we have established that the frequency components are orthogonal to each other.

III. Subcarrier Modulation:

Once each subcarrier has been allocated bits for transmission, they are mapped using a modulation scheme to a subcarrier amplitude and phase, which is represented by a complex In-phase and Quadrature-phase (IQ) vector. Figure2 shows an example of subcarrier modulation mapping. This example shows 16-QAM, which maps 4 bits for each symbol. Each combination of the 4 bits of data corresponds to a unique IQ vector, shown as a dot on the figure. A large number of modulation schemes are available allowing the number of bits transmitted per carrier per symbol to be varied In the receiver, mapping the received IQ vector back to the data word performs subcarrier demodulation.

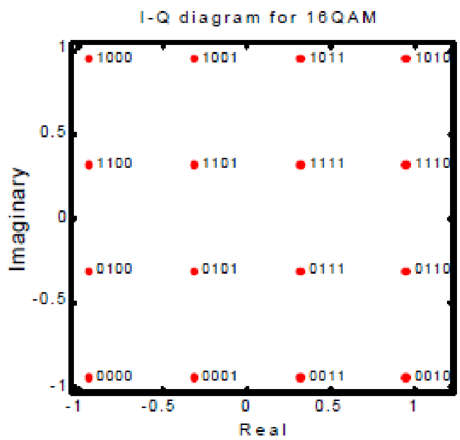

Fig2: Example Of Id Modulation Constellation

During transmission, noise and distortion becomes added to the signal due to thermal noise, signal power reduction and imperfect channel equalization. Each of the IQ points is blurred in location due to the channel noise. For each received IQ vector the receiver has to estimate the most likely original transmission vector. This is achieved by finding the transmission vector that is closest to the received vector. Errors occur when the noise exceeds half the spacing between the transmission IQ points, making it cross over a decision boundary.

3.1 Frequency To Time Domain Conversion

After the subcarrier modulation stage each of the data subcarriers is set to an amplitude and phase based on the data being sent and the modulation scheme; all unused subcarriers are set to zero. This sets up the OFDM signal in the frequency domain. An IFFT is then used to convert this signal to the time domain, allowing it to be transmitted. In the

frequency domain, before applying the IFFT, each of the discrete samples of the IFFT corresponds to an individual subcarrier. Most of the subcarriers are modulated with data. The outer subcarriers are unmodulated and set to zero amplitude. These zero subcarriers provide a frequency guard band before the nyquist frequency and effectively act as an interpolation of the signal and allows for a realistic roll off in the analog anti-aliasing reconstruction filters.

IV. Proposed Methodology:

OFDM has been used successfully in several broadcast systems, namely DAB and DVB, and for point-to-point communications. However, its application in multiuser two-way communication systems has been limited. Only recently has it been applied to Wireless LAN applications, with the development of HiperLAN2 and IEEE 802.11a .OFDM is a good contender for the RF interface in 4th generation mobile systems, however not much work has been done to date in addressing the issues of applying.

OFDM in large scale multiuser applications. Multiuser OFDM provides a very Flexible RF interface allowing users to be allocated using Frequency Division Multiplexing (FDM), by Time Division Multiplexing (TDM) or a hybrid of FDM/TDM. In addition to this, the multicarrier nature of OFDM allows the radio channel to be characterized and monitored quickly and easily, presenting numerous opportunities for optimising the overall system performance, such as:

- Allocating user subcarriers so as to minimize Signal to Interference Ratio
- (SIR) in cellular systems.
- Allocate subcarriers to minimize the effects of frequency selective fading.
- Dynamically allocate the modulation scheme on an individual subcarrier
- basis to match the current channel conditions.
- Dynamically change the bandwidth of each user based on the link quality.

This allows the bandwidth of weak users to be reduced so that their energy spectral density remains sufficiently high to maintain communications

4.1 Peer-To-Peer Networking

Most current WLAN systems, such as networks using the IEEE 802.11b standard (11Mbps DSSS), use peer-to-peer networking. This allows computers to communicate directly to each other. Computers on this type of network, typically connect to the rest of the world via a single computer connected via a wired Internet connection.

This computer effectively acts as a virtual base station, as all external data traffic is

routed through it. This type of networking is simple to set up and doesn't require any special hardware for the virtual base station. One problem with peer-to-peer networking is that some of the stations can become hidden from each other due to shadowing or distance, preventing communication. This problem can be overcome with various methods of multiple hopping of data packets, but this can cause system complexity to be greatly increased, especially if stations are mobile.

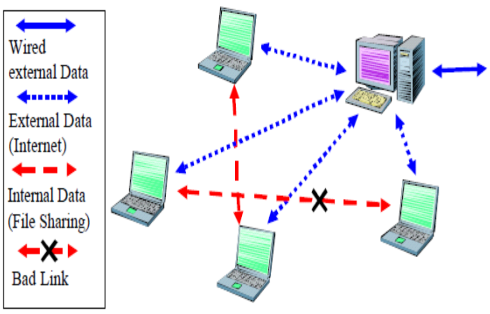

Fig3: Peer-To-Peer Networking

Peer-to-peer networking requires that all stations can communicate with each other. As a result most systems use half duplex communications and transmit and receive at the same frequency.

4. 1 Adaptive Modulation

Adaptive modulation is a powerful technique for maximizing the data throughput of subcarriers allocated to a user. Adaptive modulation involves measuring the SNR of each subcarrier in the transmission, then selecting a modulation scheme that will maximize the spectral efficiency, while maintaining an acceptable BER. This technique has been used in Asymmetric Digital Subscriber Line (ADSL) [86], [87],[88], to maximize the system throughput. ADSL uses OFDM transmission over copper telephone cables. The channel frequency response of copper cables is relatively constant and so reallocation of the modulation scheme does not need to be performed very often, as a result the benefit greatly out ways the overhead required for measuring of the channel response. Using adaptive modulation in a wireless environment is much more difficult as the channel response and SNR can change very rapidly, requiring frequent updates to track these changes. Most OFDM systems use a fixed modulation scheme over all subcarriers for simplicity. However each subcarrier in a multiuser OFDM system can potentially have a different modulation scheme depending on the channel conditions. Any coherent or differential, phase or amplitude modulation scheme can be used including BPSK, QPSK, 8-PSK, 16-QAM, 64-QAM, etc, each providing a trade off between spectral efficiency and the bit error rate. The spectral efficiency can be maximized by choosing the highest modulation scheme that will give an acceptable Bit Error Rate (BER). In a multipath radio channel, frequency selective fading can result in large variations in the received power of each subcarrier. For a channel with no direct signal path this variation can be as much as 30 dB in the received power resulting in a similar variation in the SNR. In addition to this, interference from neighboring cells can cause the SNR to vary significantly over the system bandwidth. To cope with this large variation in SNR over the system subcarriers, it is possible to adaptively allocate the subcarrier modulation scheme, so that the spectral efficiency is maximized while maintaining an acceptable BER.

4.2 Limitations Of Adaptive Modulation:

There are several limitations with adaptive modulation. Overhead information needs to be transferred, as both the transmitter and receiver must know what modulation is currently being used. Also as the mobility of the remote station is increased, the adaptive modulation process requires regular updates, further increasing the overhead. There is a trade off between power control and adaptive modulation. If a remote station has a good channel path the transmitted power can be maintained and a high modulation scheme used (i.e. 64-QAM), or the power can be reduced and the modulation scheme reduced accordingly (i.e. QPSK). Distortion, frequency error and the maximum allowable power variation between users limit the maximum modulation scheme that can be used. The received power for neighboring subcarriers must have no more than 20 - 30 dB variation at the base station, as large variations can result in strong signals swamping weaker subcarriers. Inter-modulation distortion results from any non-linear components in the transmission, and causes a higher noise floor in the transmission band, limiting the maximum SNR to typically 30 - 60 dB. Frequency errors in the transmission due to synchronization errors and Doppler shift result in a loss of orthogonality between the subcarriers. A frequency offset of only 1 - 2 % of the subcarrier spacing results in the effective SNR being limited to 20 dB . The limited SNR restricts the maximum spectral efficiency to approximately 5 - 10 b/s/Hz.

V. Simulation Results:

5.1 Simulated Results Each User Having Fixed Transmision Power

Results shown in **(a)** and **(c)** are for each user having a fixed transmission power. The transmitter power in **(b)** and **(d)** were set so that the average received power would result in an average SNR of 20 dB

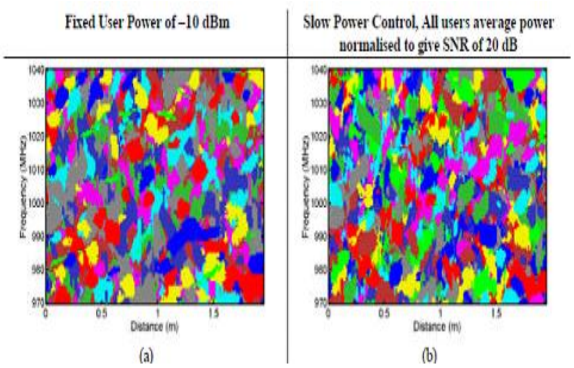

Fig 5.1 (a) and (b) show the frequency allocations for each of the users. Each user is shown as a different colour

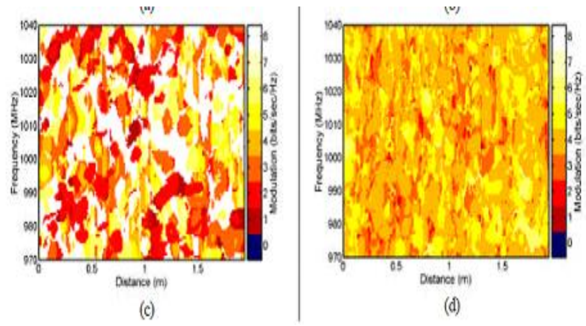

Fig 5.2 (c) and (d) show the modulation scheme used at each frequency. This simulation assumed perfect channel knowledge for each user.

5.2 Simulated Adaptive User Allocation

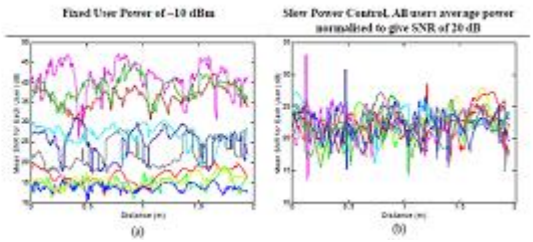

Fig 5.3 (a) and (b) show the SNR for each user

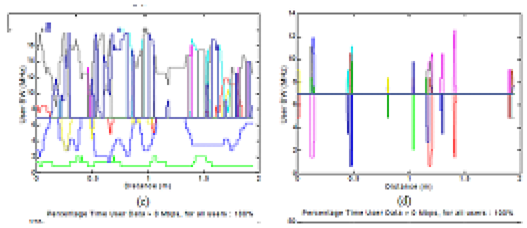

Fig 5.4 (c) and (d) shows the bandwidth allocated to each user

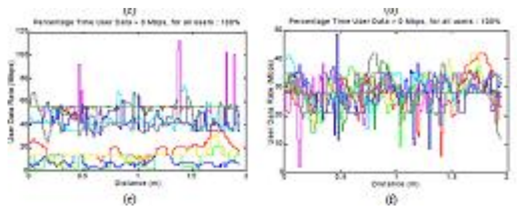

Fig 5.5 (e) and (f) shows the resulting data rate for each user

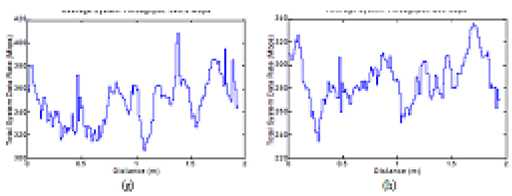

Fig 5.6 (g) and (h**)** showing the overall system data rate.

VI. Conclusion

This thesis has presented an investigation into the application of OFDM in multiuser systems, and has focused on techniques for improving the system spectral efficiency.

Most current communication systems operate at a very low spectral efficiency,resulting in under utilisation of the radio spectrum. Future systems will have to improve the spectral efficiency to achieve the capacities required. This thesis has investigated techniques that exploit the flexibility of OFDM to maintain a maximum spectral efficiency, by matching the system parameters, such as subcarrier modulation and frequency, based on current conditions of the radio channel. The aim of this work is for the communication system to approach the maximum theoretical channel capacity given the constraints of the radio channel, transmitter power and quality of service.

The application of adaptive modulation was investigated and found to provide an effective means to mitigate the effects of fading. Adaptive modulation greatly decreases the BER, with it requiring 12 - 16 dB less SNR to achieve the same BER as compared with a fixed modulation system. In addition to this, it allows the data rate of the system to improve when the channel SNR is high. When using coherent QAM, every 3 dB improvement in SNR allows the spectral efficiency of the system to improve by 1 b/s/Hz.

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