

Cross-layer Optimization Resource Allocation in Wireless Networks

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Abstract
The rapid increase of the Internet and wireless communication in the past few years has made personal communication easier and less. The use of potable wireless devices for example smart phones and PDAs is on the increase. Video conferencing, and Multimedia streaming are expected to attract an increasing number of users in the nearest possible future. The requirement for such applications to run efficiently and effectively would be availability of higher resources, such as processing power, high battery life and data rate capabilities, just to mention a few. The TCP/IP protocol suite provides the protocols which is the standard for communications in the Internet today. However, they are not suitable for the next generation wireless devices and the mobile systems; this performance degradation is due to the limitations of wireless medium in terms of bandwidth, information loss, and latency which will be looked at in this paper. This paper compares the delay time of real time and non-real time traffic using two algorithms. Maximum Weighted Capacity uses a cross-layer optimization to share resources, while Maximum Capacity allocates resources based only on the users channel capacity.
Keywords: Cross-layer optimization, TCP/IP, Maximum Capacity, Maximum Weighted Capacity, channel capacity

1.0 Introduction
The visible trend in the current communication market is the rise of wireless technology (W.Stallings, 2002). A number of hand held devices now come with one or more forms of wireless technology such as Wireless Local Area Network, Bluetooth or connections to cellular mobile networks. As a result of the continuous growth of the internet and its applications, a lot of emphasis is being placed on satisfying the needs of consumers at anytime and anywhere.
Orthogonal Frequency Division Multiplexing (OFDM) increases the efficiency of limited spectral resources available when compared with other multiplexing schemes such as Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM) (P. Nicopolitidis, 2003). OFDM has gained a lot of interest to combat wireless link impairments (Herrman Rohling, Thomas May, Karsten Bruninghaus, and Rainer Grunheid; *Proceedings of the IEEE*, vol. 87, no. 10, pp. 1778–1789, October 1999) and simultaneously offering flexibility at the link layer. OFDM promises higher user data rate and great resilience to severe signal fading effects of the wireless channel at a reasonable level of implementation complexity. It has been taken as the primary physical layer technology in high data rate Wireless LAN/MAN standards.
Current wireless networks are said to be all IP based (A. Jamalipour, S. Tekinay, 2001) and using the standard protocol stack for example TCP/IP stack to ensure interoperability. The standard protocol stacks are architected and implemented in a layered manner and function inefficiently in mobile wireless environments (G. Xylomenos, G.C. Polyzos, 1999 pg 55–63). This is due to the highly variable nature of wireless links and the resource-poor nature of mobile devices.

2.0 Resource Allocation
The current trend in wireless communication networks is the provisioning of multimedia services. There are different QoS requirements for these multimedia applications over the wireless channel. The high data rate needed by the applications make the use of one single channel for each user inadequate. Use of multicarrier systems has generated a lot of interests because it is seen as the solution to the problem.
OFDM is the multicarrier system of choice because it divides an entire channel into many orthogonal narrowband subcarriers to deal with frequency-selective fading and to support a high data rate. Furthermore, in an OFDM-based wireless network, different subcarriers can be allocated to different users to provide a flexible multiuser access scheme and exploit multiuser diversity. OFDM offers a high degree of flexibility of radio resources management which can significantly improve the performance of OFDM networks. Using data rate adaption, the transmitter can send higher transmission rate over the subcarriers with better conditions so as to improve throughput and simultaneously ensure an acceptable bit-error rate (BER) at each subcarrier (S. Nanda, K. Balachandran, S. Kumar, January 2000).
Dynamic resource allocation is used. This paper uses a rate adaptive multiuser optimization technique to

maximize each user's error free capacity under given total power constraint. The resource allocation is done at the physical layer, while the MAC layer controller schedules data to be transmitted.

3.0 Maximum Capacity (MC) Based Resource Allocation

The Maximum Capacity algorithm is the first resource allocation algorithm to be discussed. It is based on (*J. Jang, K. Lee*, *2003*). The transmit power adaptation method solves the maximization problem in two step; assigning subcarriers to users first, then allocating power to each of this subcarriers. Subcarriers are assigned to only the user with the best cannel gain for the subcarrier. Transmit power is distributed over the subcarriers using the water-filling policy.

3.1 Subcarrier Allocation

In order to maximise the total data rate of the system, Jang and Lee set the BER to a fixed value, thereby imposing an upper limit to the system. The modulation constellation is modified by changing the number of bits in each transmitted symbol depending on the channel gain for each subcarrier. Setting the BER imposes an upper bound on the system, such that by continually adapting the constellation size, this BER would be the maximum for any channel condition.

For an OFDM system with bandwidth B, total transmit power $\bar{S}$ and N subcarriers, the problem is formulated as:

$$R = \frac{B}{N}\sum_{n=1}^{N} log_2\left(1 + s_{k_n^*}|\alpha_{k_n^*}|^2 \frac{N}{N_0 B\Gamma}\right)$$

$$k_n^* = arg_k \max\left\{|\alpha_{1,n}|^2, |\alpha_{2,n}|^2, \dots, |\alpha_{K,n}|^2\right\} \text{ for } n = 1, 2, \dots, N. \qquad (1)$$

Subject to

$$\sum_{n=1}^{N} s_{k_n^*} = \bar{S} \qquad (2)$$

Where $\alpha_{k_n^*}$ and $s_{k_n^*}$ are the channel gain and power assigned to user k with the best channel gain for subcarrier. Γ Is a function of the required BER and is defined as $\Gamma = -\ln(5BER)/1.5$ (G. Song, 2005).

The algorithm selects the user with the best channel gain for a subcarrier and assigns the subcarrier to the user in order to maximise the total data rate in Equation (1). Since there is no constraint on the user data rate, a user may not be assigned any subcarrier if the user has no best subcarrier.

3.2 Power Allocation

The transmit power adaptation method used for the maximum capacity algorithm is water-filling over the subcarriers with the best channel gains among multiple users. The method takes the inverse of the channel gains of all users as a container in which when power is poured in, it is distributed over all users so that the power level all of them is uniform. In essence, more power is allocated to a user with a high channel gain and less or no power is allotted to a user with lower channel gain. The aim of the process is to maximize the sum of data rate for each sub-channel. From Equation (1), we can see that capacity is a logarithmic function of power, hence, so there is a significant difference in the increase in capacity when a given power value is assigned to a subcarrier with high gain vis-à-vis one with low gain.

Thus, the water-filling algorithm adapts power allocation for subcarriers to the channel condition for a given total power in order to achieve maximum data rates. The optimum water level changes when the channel condition changes, so it has to be updated accordingly each time these changes occur.

To maximize the total data rate of the multiuser wireless system, the transmit power should be allocated as

$$\begin{cases} s_{k_n^*} = \dfrac{N_0 B\Gamma}{N}\left[\dfrac{1}{\lambda_0} - \dfrac{1}{|\alpha_{k_n^*}|^2}\right]^+, & for\ n = 1, 2, \dots, N \\ s_{k_n^*} = 0, & for\ k \neq k_n^* \end{cases} \qquad (3)$$

$[.]^+$ represents the outcome of the water-filling algorithm. λ_0 is a threshold to be determine from the total transit power constraint in Equation (2) and is given as

$$\lambda_0 = (\bar{S} + \sum_{n=1}^{N} \frac{1}{\alpha_{k_n^*}})/N \qquad (4)$$

4.0 Maximum Weighted Capacity (MWC) Based Resource Allocation

The maximum weighted capacity (MWC) algorithm as proposed by Zhou in (N. Zhou, 2008) is a resource allocation algorithm which can improve the QoS at the physical layer for multimedia data while maintaining high capacity in a multiuser OFDM network. This resource allocation algorithm is optimized with information about the channel state that is shared between the physical layer and the MAC layer. It uses a batch dependent scheduling scheme for the downlink system. The scheduling scheme, called the Delay Satisfaction (DS) scheduling, is combined with adaptive resource allocation based on the maximum weighted capacity (MWC) criterion. This maximises the weighted capacities using weights determined by scheduling as a function of a delay satisfaction indicator, the data amount and the traffic coefficient. Traffic data is classified broadly into 3 types based on their QoS requirements (i.e. Real Time, non Real Time and Best Effort). There are multiple queues per user; one for each traffic type.

4.1 Optimal Subcarrier Allocation

A total bandwidth of B is shared by N subcarriers and the OFDM signalling is time slotted where the duration of each slot is T_{slot}. QoS information from the traffic controller is received at the physical layer in as weights, W. The weight for each user is denoted as W_k. Assuming perfect CSI, the achievable instantaneous data rate of user k on subcarrier n is expressed as:

$$R_{k,n} = \frac{B}{N} log_2\left(1 + s_{k,n}|\alpha_{k,n}|^2 \frac{N}{N_0 B\Gamma}\right) \tag{5}$$

Thus, the total instantaneous data rate of user k is given by:

$$R_k = \sum_{n\in\Omega_k} R_{k,n} \tag{6}$$

Ω_k is the set of all subcarriers allocated to user k.

So the MWC resource allocation strategy uses cross-layer optimization to maximise the sum of weighted capacities given as:

$$J = \sum_{k=1}^{K} W_k R_k \tag{7}$$

subject to $s_{k,n} \geq 0$, $\sum_{k=1}^{K}\sum_{n\in\Omega_k} s_{k,n} \leq \bar{S}$, $\Omega_i \cap \Omega_j = \emptyset\ (i \neq j)$,
$\Omega_1 \cup \Omega_2 \cup \dots \Omega_k \subseteq \{1, 2, \dots, N\}$ and $R_k T_{slot} \leq Q_k$

Q_k denotes the total amount of data awaiting transmission for user k. The constraint $R_k T_{slot} \leq Q_k$ guarantees that no more resource is allocated to user k if the user has already obtained sufficient resources, to allow as much data as possible to be transmitted in the current slot.

4.2 Optimal Power Allocation

Power allocation in for MWC uses the water filling strategy to assign power to users on the system. However, the water filling algorithm has to be modified to put the weights calculated at the MAC layer for each user into consideration. The proportion of power allocated to a user is a function of the total weight for the user relative to the sum total of the weight of all users. The optimal power allocation solution is given as

$$s_{k,n} = \left[\frac{W_k}{\sum_{m=1}^{K}(W_m|\Omega_m|)}\left(\bar{S} + \sum_{m=1}^{K}\sum_{q\in\Omega_i}\frac{1}{\alpha_{m,q}}\right) - \frac{1}{\alpha_{k,n}}\right]^+ \tag{8}$$

Where $[x]^+ = \begin{cases} x, & x > 0 \\ 0, & x \leq 0 \end{cases}$, and $|\Omega_m|$ denotes the number of subcarriers in set Ω_m.

5.0 Simulation and Result

The simulation result for the MWC and MC schemes are presented in this section. The results are used to compare the performance of the MC scheme, which is a wholly physical layer scheme, and the MWC scheme. The MWC uses cross-layer optimization between the physical layer and the MAC layer to improve the performance system-centric quantities of QoS traffic. In order for the comparison to be fair, a modified version of the DS based scheduling algorithm used for MWC is applied to MC.

The maximum delay tolerance for RT, nRT traffic are set at 100msec and 400msec. Using voice traffic as a model for RT traffic, incoming data stream is fixed at 64Kbits. nRT traffic (using video traffic as a model), has an arrival rate that is Poisson distributed with a minimum data rate of 120Kbits and a maximum of 420Kbps. It is assumed that perfect CSI of the downlink channel is available at the base station. SNR is defined as the average received signal power to noise power for each user. These values are standard values used in all simulation unless otherwise stated.

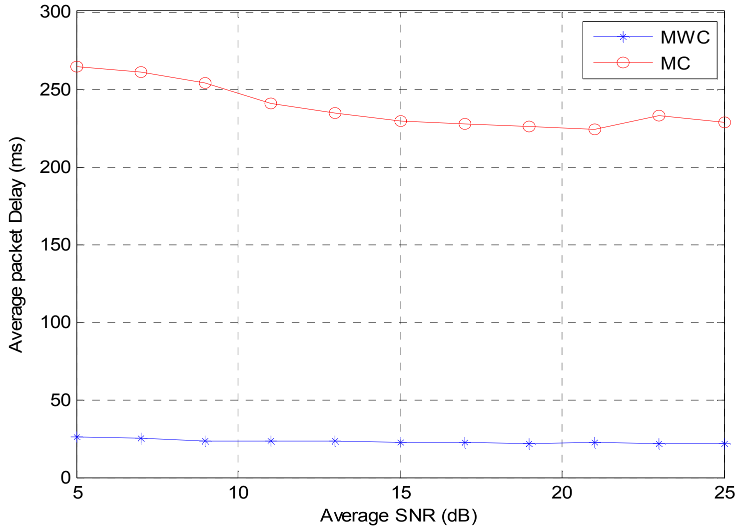

Figure 5: Average Real Time packet delay versus average SNR

Figure 5 shows the average delay of RT traffic. We can see that the delay experienced by traffic in this QoS class is significantly lower for MWC compared with MC. There is a difference of about 240msec to 200msec in the average packet delay at various SNR values. With the maximum delay tolerance expected for RT set at 100msec, we can see that RT traffic would perform badly with MC scheme.

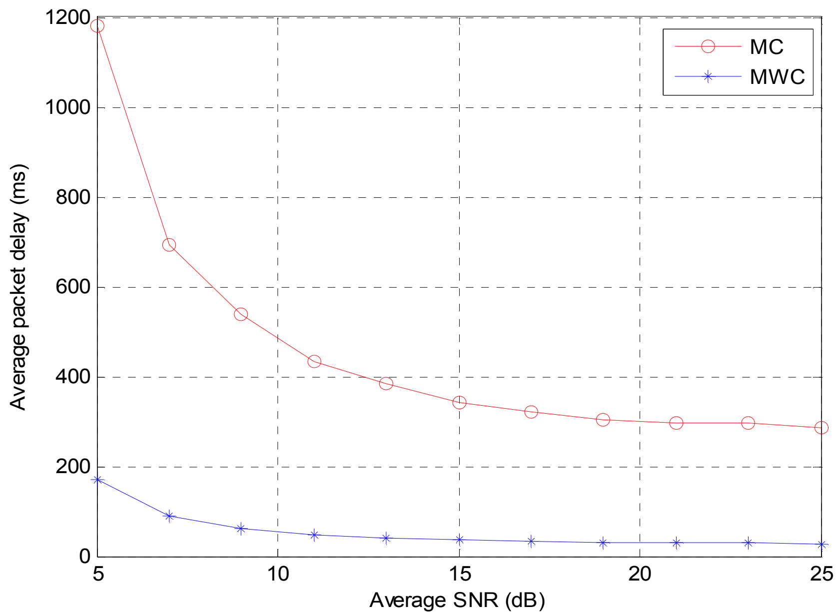

Figure 6: Average non Real Time packet delay versus average SNR

Figure 6 shows that nRT traffic performs well under the MWC scheme in terms of delay. Traffic in this QoS class transmitted using this scheme is able to meet the delay time requirements at all SNR values. However, for MC traffic in this class had to endure an average delay time of over 400msec at SNR values below 13dB. The differences in the delays experienced nRT traffic for MWC and MC varies between about 1sec at 5dB and 300msec at 25dB.

6.0 Conclusion

This paper is a comparative framework of two algorithms for resource allocation in a wireless system by comparing how they fair when passing real time traffic and non-real time traffic, with multiple users vying for wireless network resources. The main objective of this paper is to improve system performance by using cross-layer optimization techniques.

The first algorithm is maximum capacity (MC) algorithm described by Jang and Lee in [7]. The algorithm operates by allocating resources without using any information from layers apart from that of the physical layer. Subcarriers are allocated to uses with the maximum channel gain and power is allocated to these subcarriers by the water filling algorithm.

The second algorithm (MWC) is concerned with how wireless network handles QoS traffic in a multiuser environment. It makes use of information about the QoS requirements of the data stream being transmitted to determine which slots gets priority over others for transmission to users. That is, the algorithm combines the knowledge gotten from the state of the traffic packet at the MAC layer to assign the needed resources and schedule traffic to users.

The results show that MWC reliably transmits Real time and non Real Time traffic within the requirements. This is unlike the MC algorithm.

Further work on this paper in future should investigate other cross-layer designs to improve other parameters of data traffic such as jitters and dropped packets.

References

A. Jamalipour, S. Tekinay (Eds.), Fourth Generation Wireless Networks and Interconnecting Standards, Vol. 8 of IEEE Personal Communications, 2001.

G. Song; "Cross-layer Resource Allocation and Scheduling in Wireless Multicarrier Networks"; Georgia Institute of Technology; 2005

G. Xylomenos, G.C. Polyzos, "Internet protocol performance over networks with wireless links", IEEE Network 13 (4) (1999) 55–63.

Herrman Rohling, Thomas May, Karsten Bruninghaus, and Rainer Grunheid, "Broad-Band OFDM Radio Transmission for Multimedia Applications," *Proceedings of the IEEE*, vol. 87, no. 10, pp. 1778–1789, October 1999.

J. Jang, K. Lee; "Transmit Power Adaptation for OFDM Systems"; IEEE Journal on selected Areas in Communication; FEB 2003

N. Zhou, Et al, "Novel Batch Dependant Cross-Layer Scheduling for Multiuser OFDM Systems", 2008

P. Nicopolitidis, et-al; "Wireless Networks"; West Sussex, England, Wiley, 2003

S. Nanda, K. Balachandran, S. Kumar; "Adaptation techniques in wireless packet data services"; IEEE communication Magazine; January 2000

W.Stallings; "Wireless communications and networking", Upper Saddle River, N.J., Prentice Hall, 2002