International Journal of Image Processing and Vision Science

Volume 2 | Issue 2 Article 3

October 2013

Wireless OFDM Systems and Cross-Layer Optimization

Madhusmita Panda
ECE Department, GITA, Bhubaneswar, madhusmita.panda@gmail.com

Rajiv Ku. Dash
ECE Department, GITA, Bhubaneswar, rajivkdash@gmail.com

Recommended Citation

Panda, Madhusmita and Dash, Rajiv Ku. (2013) "Wireless OFDM Systems and Cross-Layer Optimization," *International Journal of Image Processing and Vision Science*: Vol. 2 : Iss. 2 , Article 3.
DOI: 10.47893/IJIPVS.2013.1071
Available at: https://www.interscience.in/ijipvs/vol2/iss2/3

Wireless OFDM Systems and Cross-Layer Optimization

[1] Madhusmita Panda, Asst. Professor ECE Department, GITA, Bhubaneswar
[2] Rajiv Ku. Dash, Asst. Professor ECE Department, GITA, Bhubaneswar

Abstract

The increasing popularity of wireless broadband services nowadays indicates that, future wireless systems will witness a rapid growth of high-data-rate applications with very diverse quality of service requirements. To support such applications under limited radio resources and harsh wireless channel conditions, dynamic resource allocation, which achieves both higher system spectral efficiency and better QoS, has been identified as one of the most promising techniques. In particular, jointly optimizing resource allocation across adjacent and even nonadjacent layers of the protocol stack leads to dramatic improvement in overall system performance. In this article an overview of recent research on dynamic resource allocation, especially for OFDM systems is provided. Recent work and open issues on cross-layer resource allocation and adaptation are also discussed

.

***Keywords*:** cross-layer optimization, OFDM, PHY, MAC, co-channel interference (CCI)

***Introduction* :**

Recently, a lot of research effort has been spent on cross-layer system design. It has been shown that cross-layer potentially provide significant performance gains for various systems. Here several aspects of cross-layer system optimization regarding wireless OFDM systems has been reviewed [1]. The OFDM is well known for its high spectrum efficiency and robust performance over heavily impaired wireless links. OFDM has already been adopted in Hiper- LAN, 802.11a, 802.11g, and 802.16 , and is now considered one of the main air interfaces under consideration for fourth-generation (4G) wireless systems. Meanwhile, recent developments in Multiple-input multiple-output (MIMO) techniques have resulted in a significant boost in performance for OFDM systems[2]. Besides their robust performance over wireless media, OFDM and MIMO are particularly suitable for adaptive transmission and resource allocation due to the existence of parallel sub-channels in the frequency and space domains [3]. This unique feature enables flexible adaptive resource allocation to significantly enhance system capacity and resource utilization.

OFDM Systems:

The basic principle of OFDM is parallelization. In OFDM, the wideband spectrum is divided into orthogonal narrowband subcarriers as in frequency-division multiplexing and the user bit stream is split into subsets, sub-symbols. Each sub-symbol modulates a subcarrier and several sub-symbols of a user are transmitted in parallel over subcarriers. Appropriate subcarrier spacing preserves channel orthogonality and leads to high spectral efficiency. OFDM transmission reduces the effective symbol transmission rate and provides immunity to intersymbol interference (ISI)[2].

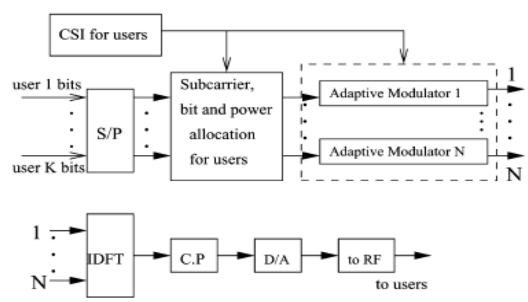

Fig.1. Single-cell multiuser OFDM transmission diagram.

Multiuser Resource Allocation Algorithm :

Zhang *et al.* proposed a multiuser resource allocation algorithm that involves both intracell and intercell optimization [5]. The system diagram is shown in Fig. 2. For the intracell level, their main contribution is to introduce a reduced complexity multiuser subcarrier bit and power allocation scheme. Specifically, the subcarriers are first allocated to maximize the total data rate without considering the individual user's data rate constraints. Afterward, subcarrier allocation is adjusted step by step to satisfy the individual data rate constraints. As to the intercell level, the major contribution is to design a cell selection scheme to exploit the intercell diversity and reduce the outage probability, which is inevitable when there is a transmit power limit at the BS. Unlike conventional cell selection schemes, the adaptive cell selection algorithm proposed in [4] is particularly designed for adaptive physical-layer transmission. It is based on the traffic density, QoS requirements and received power levels of all users. In particular, the cell is assigned based on the following factors:

• Resource availability in the candidate cells.

• Amount of resources that have already been assigned to other users.

• Amount of resources necessary to satisfy the investigated user's QoS.

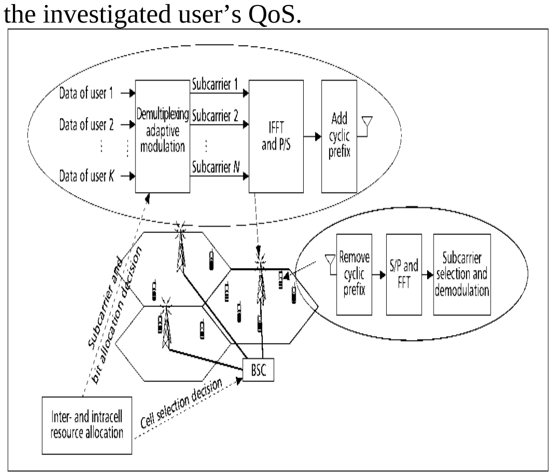

Fig2: System diagram of inter- and intracell resource allocation and optimization.

This algorithm effectively solves the outage problem and focus on studying the dynamic resource allocation problem from the view of PHY layer without considering the packet access characteristic, such as the randomness of the queuing behavior and the traffic arrival.

Although independent consideration of layers simplifies wireless system design, it constrains performance significantly because:

1) It does not take into account the effect of co-channel interference on higher layer mechanisms;

2) It does not consider the impact of local adaptation actions on overall system performance; and

3) It attempts to optimize performance at one layer while treating parameters of other layers as fixed.

The growing consensus about cross-layer design [4] refers to the need for interaction and information exchange between the physical and higher layers and accounts for the volatile and time-varying nature of the wireless medium.

Under the premise of cross-layer design, physical and higher layer control decisions reach their full potential when in synergy with each other.

Cross MAC-PHY Resource Allocation:

Adaptive cross-layer resource allocation that exploits interdependencies and interactions across the PHY, MAC, and higher layers has recently attracted extensive research interests [6]. The basic idea of cross-layer resource allocation is to jointly adapt bandwidth, power allocation and transmission strategies across the protocol stack in order to improve the resource utilization efficiency which guarantees a predetermined QoS at the receiver. Optimize system design combining both resource allocation in PHY layer and scheduling in MAC layer, but most of these algorithms are based on the following two implicit assumptions[7]:

- There is no constraint on the maximum size of every user's transmission buffer, i.e. all the users have infinite queue size and are delay-insensitive;
- Every scheduled user always has sufficient source packets in queue to transmit.

But, in practice, limit queue sizes should not be considered and users with empty transmission buffers are not scheduled despite favorable channel conditions. Moreover, most of the existing literatures about resource allocation and scheduling are based on the perfect CSI at the transmitter, which is impractical in the realistic wireless communication system. Considering the above issues, a cross-layer scheduling and dynamic resource allocation (CLSDRA) scheme for downlink multiuser MIMO Systems utilizing both information theory and queuing theory[8] is shown in fig 3.This scheme schedules users and allocates resources, such as channel, bit and power to the scheduled users to maximize the utility function. The utility function sums the product of each scheduled user's delay requirement, HOL packet waiting time , queue length and data rate with the partial CSI from PHY layer and the QSI from MAC layer and provides better performance which balances system throughput and packet drop rate compared to conventional single-layer scheduling schemes and existing single-layer resource allocation strategies.

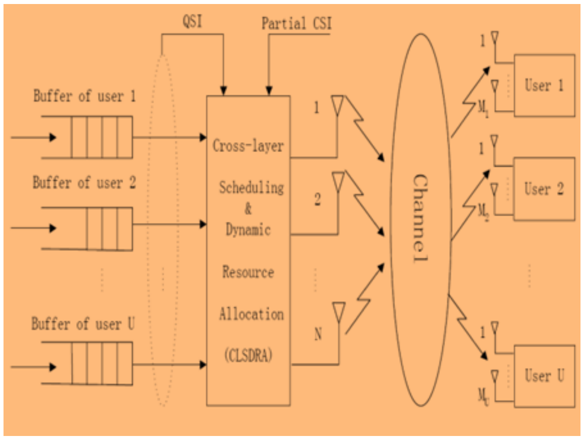

Fig.3. Simplified block diagram of a downlink multiuser MIMO system with CLSDRA

One example of the cross MAC-PHY layer resource allocation is opportunistic scheduling, such as that proposed in [9,10]. Opportunistic scheduling endeavors to maximize the system capacity by scheduling one or more users with the best instantaneous channels in each time slot. Zhang and Letaief proposed a joint MAC-PHY layer resource management algorithm for wireless OFDM networks with random packet arrivals [11]. The proposed resource allocation scheme involves the joint optimization of three parts: packet scheduling, subcarrier allocation, and power control. The idea is illustrated in Fig.4 .

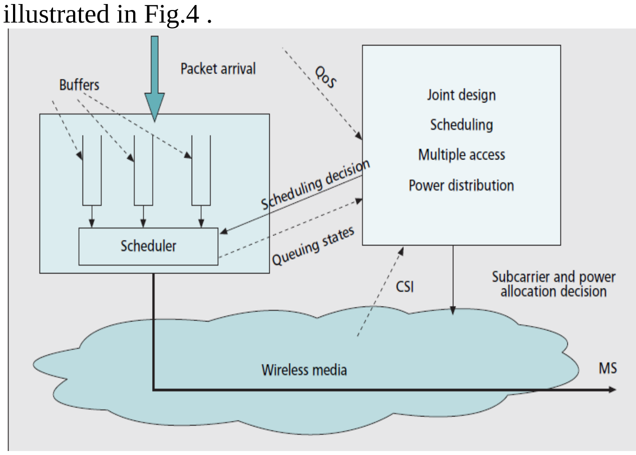

Fig 4: Cross MAC-PHY layer resource allocation.

Assume that there are K users and N subcarriers, and the time axis is divided into frames. On arriving at the BS, the packets from different users are buffered in separate queues, which are assumed to have infinite lengths. Within one queue, packets are served in a first-in first-out (FIFO) order. Across the queues, packets are served according to a proposed resource allocation discipline. The joint MAC-PHY optimization is based on the users' QoS requirements, queuing states observed in the MAC layer, and CSI observed in the PHY layer. The resource allocation decisions are fed back to the two layers to adjust the scheduling and transmission parameters. The basic idea behind this algorithm is to serve the packets in a way that approximates a fair queuing system in wired networks, which is referred to as *reference system*. Leads or lags of the flows are introduced in a controlled manner to explore the time domain diversity on top of the diversities in the frequency and multiuser domains. The authors proved through analysis that the proposed algorithm is able to guarantee QoS in terms of throughput and maximum delay as well as fairness to users over wireless media.

Cross-Layer Adaptation, Design, And Optimization

In the previous section, cross MAC-PHY adaptive resource allocation for broadband OFDM systems has been introduced. In this section, a state-of-the-art review of cross-layer adaptation and design is discussed.

To satisfy different QoS requirements in future wireless communication systems, a multitude of advanced techniques have been studied in each layer of the network protocol stack. For example, multiple antennas, coding, adaptive modulation, and power control at the PHY layer, scheduling and aggressive multiple access at the MAC layer, delay-constrained and energy-constrained routing and mobility management in the network layer, and adaptive QoS in the application layer.

These research efforts have mainly focused on isolated components of the overall network design. However, tasks would be too complex for a single layer to support the heterogeneous traffic and stringent QoS requirements. As a result, a cross-layer design that supports adaptivity and optimization across multiple layers of the protocol stack is needed. This represents a paradigm shift in the design of wireless networks where the protocols at each layer are not developed in isolation, but rather within an integrated and hierarchical framework to take advantage of the interdependencies between different layers. In particular, the available resources are dynamically optimized in response to the variation in the link quality and QoS requirements through an integrated design framework where only necessary information is exchanged between the different layers and selected parameters are jointly optimized. Being new and vibrant, the cross-layer approach, as shown in Fig. 5, has already shown various optimization opportunities through the co-design of the different protocol layers.

For example, in wireless networks, packets may be lost not only due to collisions, but also because of channel fading. Traditional MAC protocols, which are designed independent of the PHY layer, typically regard each packet loss as a collision. Whenever a mobile senses a packet loss, it starts a backoff process to avoid successive collisions. As a result, the traditional MAC protocols end up being over-conservative when packet losses can be caused by fading. As such, it is clear that there are potential benefits to be obtained by designing MAC operations with feedback from the PHY layer, which indicates loss probability due to channel fading. Addition- al performance improvement can also be obtained by leveraging the use of the latest performance enhancing tools in cross-layer design.

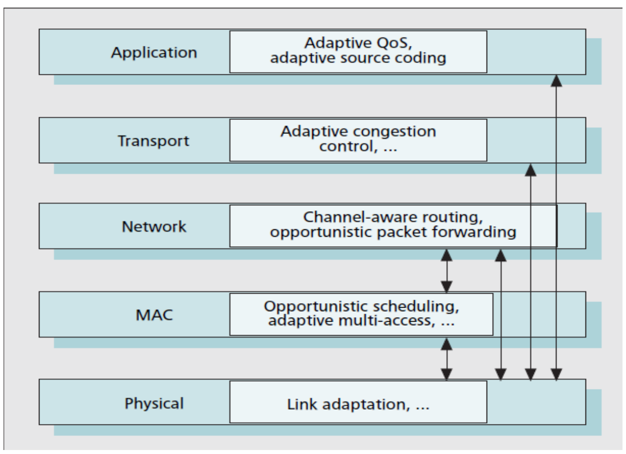

Fig 5. Cross-layer design, adaptation, and optimization

For instance, multiuser detection is a powerful PHY-layer scheme that allows a wireless receiver to decode multiple packets simultaneously. Such a scheme, if used, will have a great impact on the performance of the MAC protocol in wireless networks. This is because multiple packets can now be reliably and correctly detected at the same time, and as a result, conventional MAC protocols that endeavor to avoid simultaneous packet transmissions in order to minimize collisions may not be efficient in this scenario.

Wireless links not only affect the design of MAC protocols, but also have a large impact on the network, transport, and application layers. For example, the connectivity and topology of a network can change with the PHY-layer link adaptation and power control. So does the routing cost on each link. In [11] Chiang proposed a distributed algorithm for joint optimal end-to-end congestion control and per-link power control. The algorithm utilizes the coupling between the transport and physical layers to increase the end-to-end throughput and energy efficiency in a wireless multi-hop network. The overall communication network is modeled by a generalized network utility maximization problem, with each layer corresponding to a decomposed sub-problem. ***Issues with cross layer optimization***

Clearly, cross-layer design and adaptation represents a new and exciting methodology, but also poses significant technical challenges with numerous open problems that are broad and deep. These open problems are broadly classified into two categories: theoretical modeling and algorithm design.

As to theoretical modeling, critical issues include: how to properly take advantage of the interdependencies among the multiple layers; which set of parameters should be exchanged across the multiple protocol layers; which layers should be jointly optimized and designed; and how to deal with network complexity in terms of analysis, performance limits, and protocol design.

Algorithm design also poses many challenges. For example, one major issue is that most cross-layer schemes require centralized control and optimization. Although good for cellular systems, centralized optimization may be infeasible for distributed wireless networks such as ad hoc networks and 802.11 WLANs with a distributed coordination function (DCF) mode, due to the lack of a central coordinator. It is therefore essential to develop decentralized cross-layer design and optimization algorithms for practical implementation.

Another issue relates to the enormous overhead due to frequent control signal transmission and CSI feedback, once the PHY channel is considered in the design of higher-layer protocols. This is because the wireless links vary on a timescale that is much faster than the variation in higher-layer behaviors, such as traffic load and network topology. In particular, the shadowing effect varies in the order of seconds, and the multipath fading typically varies in the order of milliseconds to tens of milliseconds. This overhead may significantly cancel out the spectrum efficiency enhancement brought by cross-layer optimization. To solve this problem, it is necessary to develop resource allocation algorithms that require minimum CSI and control signaling.

Finally, computational complexity is yet another critical issue. Typically, the cross-layer design is formulated into an optimization problem, which is usually combinatorial and non-convex, due to the QoS constraints, the interference between different users, and the interaction between the protocol layers. Prohibitively high computational complexity is therefore typically needed to solve such problems. In particular, the optimal system design solution may need to be updated once the wireless channel changes, and this may make the complexity unaffordable to real-world systems. As a result, it is important to build up a simple model for cross-layer optimization and propose reduced-complexity algorithms.

Conclusion:

Dynamic resource allocation considerably improves resource utilization efficiency by exploiting multiuser diversity gain as well as system dynamics in various domains. As the subscriber population and service demand continue to expand, the advantages of dynamic resource allocation will be increasingly important in future broadband and ubiquitous wireless communications systems. This article has attempted to give an overview of the recent advances on dynamic multiuser resource allocation. In particular, the latest work on resource allocation for joint MAC-PHY design was introduced. The state-of-art research on cross-layer design, adaptation, and optimization is also discussed.

References:

[1] Y. J. Zhang and K. B. Letaief, "Dynamic Multiuser Resource Allocation And Adaptation For Wireless Systems," *IEEE Trans. Commun.*, vol.13 , no 4. , Aug. 2006, pp. 38-47

[2]M. Bhoge, J.Gross, M.Meyer and A.Wolisz., " Dynamic Resource Allocation in OFDM Systems: An Overview of Cross –Layer Optimization Principles and Techniques," *IEEE Networks*, draft, Jan/Feb,06

[3] Y. J. Zhang and K. B. Letaief, "An Efficient Resource Allocation Scheme for Spatial Multiuser Access in MIMO/OFDM Systems," *IEEE Trans. Commun.*, vol. 53, no. 1, Jan. 2005, pp. 107–16.

[4] C. Y. Wong *et al.*, "Multiuser OFDM with Adaptive Subcarrier,Bit and Power Allocation," *EEE JSAC*, vol. 17,no. 10, Oct. 1999, pp. 1747–58.

[5] Y. J. Zhang and K. B. Letaief, "Multiuser Adaptive Subcarrier-and-Bit Allocation with Adaptive Cell Selection for OFDM Systems," *IEEE Trans. Wireless Commun.*, vol. 3, no. 5, Sept. 2004, pp. 1566–75.

[6] A. J. Goldsmith and S. B. Wicker, "Design Challenges for Energy-Constrained Ad Hoc Wireless Networks,"*IEEE Wireless Commun. Mag.*, vol. 9,no 4, Aug. 02,pp.8–27.

[7] I. Koutsopoulos, L. Tassiulas, "Cross-layer Adaptive Techniques for Throughput Enhancement in Wireless OFDM-based Networks," IEEE/ACM Transaction on networking, Vol.14,October 2006, pp. 1056-1066

[8]C. Zhong and Lu-xi Yang "Cross-layer Scheduling and Dynamic ResourceAllocation for Downlink Multiuser MIMO Systems with Limited Feedback", *IEEE,2007*

[9] X. Liu, E. K. P. Chong, and N. B. Shroff, "Opportunistic Transmission Scheduling with Resource-Sharing Constraints in Wireless Networks,"*IEEE JSAC*, vol. 19, no. 10, 2001, pp. 2053–64.

[10] P. Viswanath, D. Tse, and R. Laroia, "Opportunistic Beamforming Using Dumb Antennas," *IEEE Trans. Info. Theory*, vol. 48, June 2002, pp. 1277–94

[11]Y. J. Zhang and K. B. Letaief, "Cross-layer Adaptive Resource Management for Wireless Packet Networks with OFDM Signal," to appear in *IEEE Trans. Wireless Commun.*; www.ie.cuhk.edu.hk/~yjzhang/Research.htm.

[12] M. Chiang, "Balancing Transport and Physical Layers In Wireless Multihop Networks: Jointly Optimal Congestion Control and Power Control," *IEEE JSAC*, vol. 23, no. 1, Jan. 2005, pp. 104–16.