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Adaptive Resource Allocation For Wireless MIMO-OFDMA Systems

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Abstract: *For multimedia transmissions over wireless networks multicasting is emerging as an enabling technology to support several groups of users with flexible quality of service (QoS) requirements. Despite multicast has huge potential to push the limits of next generation communication systems it is yet one of the most challenging issues currently being addressed. In this paper, presented diferent multicast scheduling techniques in MIMO-OFDMA (Multiple Input and Multiple Output-Orthogonal Frequency Division Multiple Access) system and dynamic resource allocation based on physical layer. Physical layer on OFDMA is dedicated to handle the details of data transmission and reception between two or more stations. This paper provides information about various optimal and suboptimal multicast scheduling techniques used in adaptive resource allocation. We discuss existing standards employing adaptive resourse allocation in multicasting and further gives satisfactory information for the researcher to work on physical layer based multicast scheduling in OFDMA for adptive resource allocation.*

Index Terms: *Orthogonally Frequency Division Multiple Access (OFDMA), Adaptive Resource Allocation, Multicast scheduling Resource Allocation (MSRA), Multiple Input Multiple Output (MIMO), physical layer, Quality of service (QoS), Channel State Information (CSI)*

I. Introduction

The method of encoding digital data on multiple carrier frequencies is called 'Orthogonal Frequency Division Multiplexing (OFDM)'. OFDM is advantageous over single-carrier schemes because of its ability to cope with extreme channel conditions without any complex equalization filters. It uses multiple subcarriers for data transmission making it an efficient system. OFDM technique offers optimal settings for higher data rate transmissions over frequency selective channels in single-carrier schemes. IPTV, mobile TV, video conferencing and other multimedia services account for one-third of mobile internet market. These multimedia entertainments are some of the disruptive innovations that can be deployed using multicast technology [1]-[7]. Multicast technology further maximized spectral efficiency and minimizes transmission power consumption at the base station while also maximally utilizing the limited system resources [4]. The challenges are of multimedia broadcast are mainly because of wireless channel variations, user's high mobility and limited system resources. These challenges can be resolved and spectrum utilization can be maximized at the base station and better Quality of Experience (QoE) can be provided for users within the network by combining multicasting together with orthogonal frequency division multiple access (OFDMA), multiple-input-multiple-output (MIMO) antenna scheme and resource allocation through physical layer. These are identified as spectrum efficient techniques.

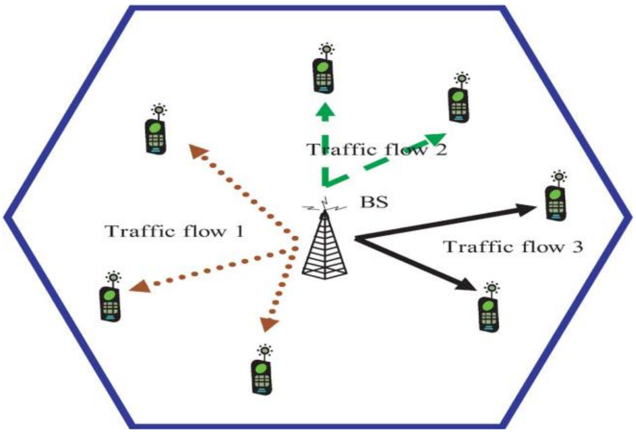


Fig.1: cellular structure of multicast transmission system

In wireles multimedia communications, the traffic is carried by two methods namely, unicating and multicasting. The above figure 1 shows multicasting method , in which users are divided into number of groups and each group is associated with a paticular data rate.

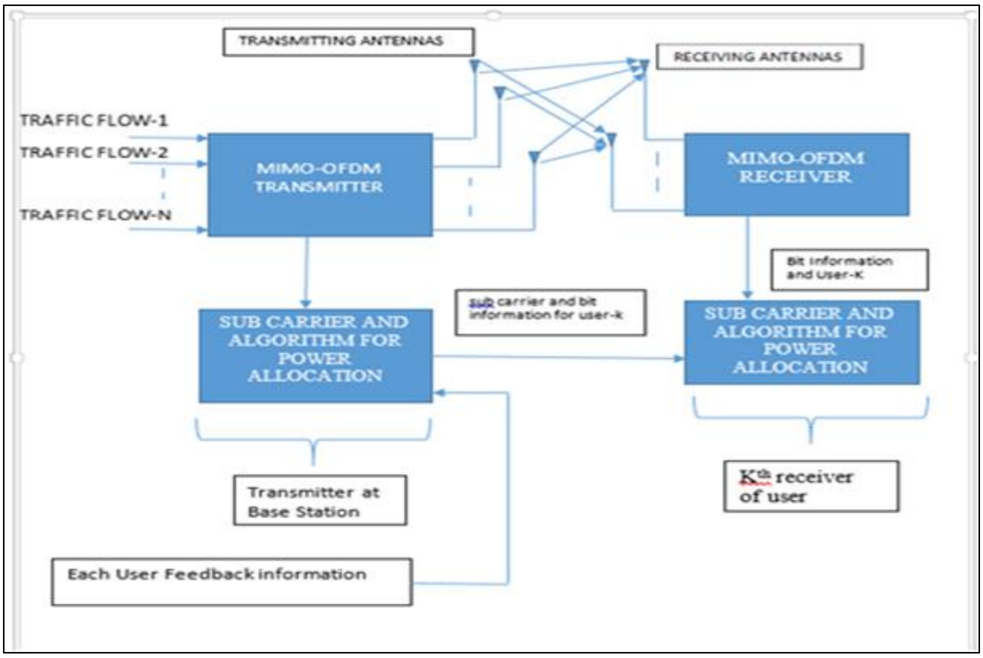


Fig.2: Block diagram of MIMO-OFDM system

The above figure represents a block diagram of MIMO-OFDM model. Through the feedback channels, the base station channel states information of each set of transmitting and receiving antennas which are sent to the block of subcarrier and power algorithms. The MIMO-OFDM transmitter get the forwarded information of the resource allocation. The system then converts the allocated number of bits selected by the transmitter from different users to form OFDM symbols and then transmits them through multiple transmit antennas. Here the spatial multiplexing mode of MIMO is considered. As soon as the channel information is collected and also the subcarrier and bit allocation information are sent to the end user for further detection.

II. Multicast Scheduling and Resource Allocation in MIMO-OFDM system

Multicast scheduling and resource allocation (MSRA) is based on two types of multicast transmissions: Single-rate and multi-rate transmissions. The BS transmits to all the users in each multicast group at the same speeds irrespective of their already non-uniform achievable capacities in a single-rate systems whereas in multi-rate systems the BS transmits to each user in each multicast group at different rates based on handling capacities of the end users. Due to its implementation simplicity, Single-rate systems were widely popular and also were known for less complexity. Due to the recent necessities of user throughput differentiation, Multi-rate systems are being sought after such that an improved spectral efficiency is attained. MSRA is still facing many technical challenges. In the presence of a bad channel the system has to detect the capacity of every single user which gives a high throughput potentials without being insensitive to the other users so as to determine the single most efficient single transmission rate is the single major problem of MSRA. Single-rate multicasting translates to trade-off between the transmission rate and system coverage. In multi rate transmission, the problem is how to reduce the computational complexities, coding, and synchronization difficulties associated with transmission to multiple subgroups or individual group members.

By determining the two types of multicast group rate determinations, scheduling, resource allocation and optimization can then be performed. Authors of [17] and [18] examined single-rate multiple multicast groups within a single cell while [19] and [20] investigated multiple multicasts with multi rate transmissions. All the above algorithms have considered different situations, performance metrics and also possible restrictions. There is a challenge in optimization problem of multiple antenna complexities at both the Base Station (BS). Specifically, [21] and [22] are among the few works investigating MIMO techniques in multicast. Hence, MSRA in wireless networks is currently a research area with many open issues. A major goal of this examination article is to present concise and understanding view of the current knowledge in several aspect of channel-aware MSRA algorithms.

3.1 Single-Rate Multicast Transmissions & Group Formation

There is no requirement of special group formation for single rate transmission except determining a compromising transmission rate for all users in the group. Three simple schemes have been adopted widely in the literature to permit researchers to design and propose practical MSRA algorithms. First is a predefined fixed default rate [23], [24]. Second one is adaptive selection and transmission at worst user's rate [25] and the third is dynamic transmission using group average throughput [26].

3.2 Multi-Rate Multicast Transmissions & Group Formation

Considering the intrinsic heterogeneous channel characteristics, to address the sub-optimality that exists in single rate transmission, multi-rate multi cast transmission emerges. To provide multi rate multicast transmissions, currently there are two techniques. One is information decomposition techniques (IDT) [27], [28]-[31] which splits high rate multimedia contents into multiple streams of data where users subscribe to amount of data each can reliably receive. The other is multicast subgroup formation [32], [33], [34] and in this method it involves splitting and classifying multicast group into smaller subgroups which is based on intra-group user's channel qualities

In multiuser OFDM or MIMO-OFDM systems, dynamic resource allocation always exploits multiuser diversity gain to improve the system performance. It is divided into two types of optimization problems:
1) To minimize the overall transmit power with constraints on data rates or Bit Error Rates (BER)
2) To maximize the system throughput with the total transmission power constraint.

III. Multicast Resource Allocation Block In Ofdma System

The below diagram illustrates the structural block diagram of a multicast system model in an OFDMA system. It also determines number of bits to form an OFDM symbol, modulation scheme and amount of power to transmit on each subcarrier. Subcarrier bits and transmit power allocation are decided by resident MSRA algorithm.

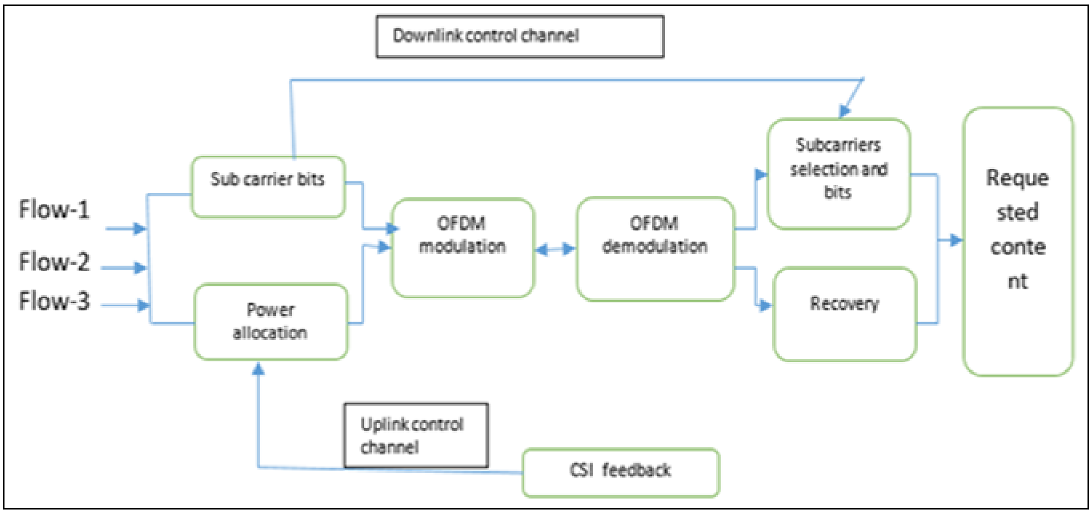


Fig.3: Block Diagram of multicast system model in OFDMA system.

In implementing channel aware MSRA, channel state information of users is assumed to be known at the base station. At each node of user channel state information is estimated and transmitted to the resource allocation block in the base station through the feedback. This reveals that channel state information can be estimated time division duplexing system. As shown in Fig. 2, the base station makes use of the channel sate information to allocate a set of subcarriers to each user. When each OFDM symbol is transmitted, through the control channel, bit allocation and subcarrier information also sent to the receivers. From this information, the receivers can make decision about decoding and extraction from the sets of subcarriers assigned to multicast groups.

Assume an OFDMA-based system with k users on Subcarriers receiving multicast downlink traffic flows from central's having G multicast groups. Sets of user's receiving the traffic flow can be represented as Kg, whereas number of users in a multicast group is $|k_g|$. We denote total number of users in the system as $\kappa = \sum_{g=1}^{G} |k_g|$. Each group has fixed or variable number of users with different channel characteristics who may be co-located or differently located. The wireless channel is a frequency selective Rayleigh fading channel and the noise power of every subcarrier is assumed to be unity for simplicity. Each subcarrier has equal bandwidth size

ofB_w=W/N, where W is the total bandwidth of the system. For simplicity, we consider an MSRA LCG-based single-rate multi-multicast system where each multicast group rate is limited by the least-capable user. If min|h_(k,n)| is the channel coefficient of minimum k∈kg
User kin group g on subcarrier n,N_0 is the white noise single-sided power spectral density on each subcarrier, then the frequency channel-to-noise-ratio (CNR) group of subcarrier n is $\frac{\hbar_{g,n}=k\in k_g|h_{k,n}|^2}{N_o B_w}$ Note that ħ_(g,n)captures the path-loss, fading, and noise of all the multicast users. Fundamentally, throughput experienced by each user depends on the number of users in each group and the differences in channel quality of each user. Therefore, multicast group transmission rate R_(g,n)on subcarrier n is then given as:

$$R_{g,n} = \frac{1}{N} log_2(1 + p_n \hbar_{g,n}) \quad (1)$$

Wherep_n denotes the amount of transmit power allocation on subcarrier n. Moreover, since more than one user can be allocated to a single subcarrier, we define a subcarrier allocation index, δ_(g,n)showing if a flow received by certain group occupies the n-th subcarrier or not. Note that here,

$$\delta_{g,n} = \begin{cases} 1, & if\ subcarrier\ n\ is\ allocated\ to\ group\ g \\ 0, & otherwise \end{cases} \quad (2)$$

The total data rate of a particular group g on all N subcarriers is then given as R_g in eqn (3)

$$R_{g,n} = \sum_{n=1}^{N} \frac{|Kg|}{N} \delta_{g,n}\ log_2{(1+p_n \hbar_{g,n})}, \forall_g \quad (3)$$

The underlying MSRA problem is basically to determine the most efficient way to allocate system resources, the optimal rate the BS should transmit to groups, which subcarrier should be assigned to which group, and the required power for transmission on each subcarrier of each group. Then, the resulting optimization problem to improve total system capacity CT becomes a non-convex, mixed-integer, non-linear maximization problems which is NP-Hard as shown in eqn. (4)-(7). NP-hard (Non-deterministic Polynomial-Time) problems are classes of problems for which no efficient solution exist [38], [39]. Results of the optimization problems give set of optimal subcarriers and power allocations

$$max\ C_T = \sum_{g=1}^{G} R_g \quad \forall_n =1, 2……N \quad (4)$$

Subject to

$$\sum_{n=1}^{N} p_n \le p_{total,} \& p_n \ge 0 \quad (5)$$

$$\sum_{g=1}^{G} \delta_{g,n} =1 \quad \forall_n, \quad (6)$$

$$\delta_{g,n} \in [0,1] \forall_g, \forall_n \quad (7)$$

Equations (5) & (6) show that the total transmit power on all subcarriers cannot be greater than the system transmit powerp_total available at the BS, where eqn. (7) is the integer constraint defined in eqn. (2). Note that the complexity and hardness of this global optimization problem is due to the integer constraint and it becomes more difficult with increase in number of users and subcarriers. Since computation complexities increase with number of individual subcarriers to be allocated, it may be potentially helpful to allocate the subcarriers in chunks or blocks to reduce complexity. In [40], [41] and references therein, it was shown that chunk-based contiguous subcarrier allocation method based on SNR or overheads. However, as expected, one common major drawback of this approach is how to reduce frequency selective fading on subcarriers which are in the chunk that may hamper the possible benefits of chunk allocation. In general, the cross-layer resource allocation and optimization problems [42] to meet the QoS requirements for all services requested by multicast users, maximize system throughput, maintain user fairness, minimize user and base station transmit power while considering channel characteristics of each user in multi-antenna OFDMA system is extremely challenging and sophisticated techniques with low complexities are required.

IV. Suboptimal Subcarrier Allocation And Power Distribution

The block diagram of multiuser MIMO-OFDM downlink system model is shown in Fig. 2. It shows that in the base station channel state information of each couple of transmit and receive antennas are sent to the block of subcarrier and power algorithm through the feedback channels. The resource allocation information is forwarded to the MIMO-OFDM transmitter.The transmitter then selects the allocated number of bitsfrom different users to form OFDMA symbols and transmits via the multiple transmit antennas. The spatial multiplexing mode of MIMO is considered. The resource allocation scheme is updated as soon as the channel information is collected and also the subcarrier and bit allocation information are sent to each user for detection.

The following assumptions are used in this paper. The transmitted signals experience slowly time-varying fading channel, therefore the channel coefficients can be regarded as constants during the subcarrier allocation and power loading period.

Throughout this paper, let the number of transmit antennas be T and the number of receive antennas R be for all users. Denote the number of traffic flows as M , the number of user as K and the number of subcarriers as N . Thus in this model downlink traffic flows are transmitted to users over subcarriers. Assume that the base station has total transmit power constraint . The objective is to maximize the system sum capacity with the total power constraint. We use the equally weighted sum capacity as the objective function. The system capacity optimization problem for muticast MIMO-OFDM system can be formulated to determine the optimal subcarrier allocation and power distribution:

$$\max C = \frac{1}{N}\sum_{k=1}^{K}\sum_{n=1}^{N}\rho_{k,n}\left(\sum_{i=1}^{M_{k,n}}\log\left(1+\frac{\lambda_{k,n}^{(i)}q_{k,n}}{N_0}\right)\right) \quad (1)$$

$$\text{subject to}: \quad \sum_{n=1}^{N}\max_{k}(q_{k,n}) \le Q$$

$$q_{k,n} \ge 0 \; for \; all \; k,n$$

$$\rho_{k,n} = \{0,1\} \; for \; all \; k,n$$

Where C is the system sum capacity which can be derived based on [16] and the above assumptions;Q is the total available power; $q_{k,n}$ is the power assigned to user in the subcarrier n ;$P_{k,n}$ can only be the value of 1 or 0 indicating whether subcarrier n is used by user or not. is the rank of
$H_{k,n}$ which denotes the MIMO channel gain matrix (R*T)
on subcarrier n for user and are the eigenvalues of $H_{k,n} H^{!}_{k,n}$;
Kn is the allocated user index on subcarrier n ; N o is the noise power in the frequency band of one subcarrier.

The different point of muticast optimization problem in (1) compared to the general unicast system is that there is no constraint of $\sum_{k=1}^{K}\rho_{k,n} = 1$ for all , which means that many users can share the same subcarrier in multicast system because they may need the same multimedia contents.
The capacity for user K , denoted as R_K, is defined as

$$R_k = \frac{1}{N}\sum_{n=1}^{N}\rho_{k,n}\left(\sum_{i=1}^{M_{k,n}}\log\left(1+\frac{\lambda_{k,n}^{(i)}q_{k,n}}{N_0}\right)\right) \quad (2)$$

The optimization problem in (1) is generally very hard to solve. It involves both continuous variables and binary variables. Such an optimization problem is called a mixed binary integer programming problem. Furthermore, since the feasible set is not convex the nonlinear constraints in (1) increase the difficulty in finding the optimal solution. Ideally, subcarriers and power should be allocated jointly to achieve the optimal solution in (1). However, this poses a prohibitive computational burden at the base station in order to reach the optimal allocation. Furthermore, the base station has to rapidly allocate the optimal subcarrier and power in the time varying wireless channel. Hence, low-complexity suboptimal algorithms are preferred for practical implementations. Separating the subcarrier and power allocation is a way to reduce the complexity, because the number of variables in the objective function is almost reduced by half. In an attempt to avoid the full search algorithm in the preceding section, we devise a suboptimum two-step approach. In the first step, the subcarriers are assigned assuming the constant transmit power of each subcarrier. This assumption is used only for subcarrier allocation. Next, power is allocated to the subcarriers assigned in the first step. Although such a two-step process would cause suboptimality of the algorithm, it makes the complexity significantly low. In fact, such a concept has been already employed in OFDMA systems and also its efficacy has been verified in terms of both performance and complexity. However, the algorithm proposed in this paper is unique in dealing with MIMO-OFDM based multicast resource allocation.Before we describe the proposed suboptimal resource allocation algorithm, we firstly show mathematical simplifications for the following subcarrier allocation. It is noticed that in large SNR region, i.e., $\lambda_{k,n}^{(i)}q_n/N_0 \gg 1$, we get the following approximation:

$$\arg\min_k \sum_{i=1}^{M_{k,n}} \log\left(1+\frac{\lambda_{k,n}^{(i)} q_n}{N_0}\right) = \arg\min_k \prod_{i=1}^{M_{k,n}} \left(1+\frac{\lambda_{k,n}^{(i)} q_n}{N_0}\right)$$

$$\approx \arg\min_k \prod_{i=1}^{M_{k,n}} \frac{\lambda_{k,n}^{(i)} q_n}{N_0} = \arg\min_k \prod_{i=1}^{M} \lambda_{k,n}^{(i)} \text{ when } M_{1,n} = \cdots = M_{K,n} = M \quad (3)$$

where $\arg\min_k \prod_{i=1}^{M} \lambda_{k,n}^{(i)}$ is named as product-criterion which tends to be more accurate when the SNR is high. On the other hand, in small SNR region, i.e., $\lambda_{k,n}^{(i)} q_n / N_0 \ll 1$, using $\log(1+x) \approx x$, we get

$$\arg\min_k \sum_{i=1}^{M_{k,n}} \log\left(1+\frac{\lambda_{k,n}^{(i)} q_n}{N_0}\right) \approx \arg\min_k \sum_{i=1}^{M_{k,n}} \frac{\lambda_{k,n}^{(i)} q_n}{N_0} = \arg\min_k \left(\sum_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)}\right)\frac{q_n}{N_0} = \arg\min_k \sum_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)} \quad (4)$$

where is named as sum-criterion which is more accurate when the SNR is low. These two approximations will be used in the suboptimal algorithm for the high SNR and low SNR cases, respectively. In this way, we can reduce the complexity significantly with minimal performance degradation.

The steps of the proposed suboptimal algorithm are as follows:
• Step 1 Assign the subcarriers to the users in a way that maximizes the overall system capacity;
• Step 2 Assign the total power to the allocated subcarriers using the multi-dimension water-filling algorithm.

A. Step 1—Subcarrier Assignment

For a given power allocation vector $q = (q_1, q_2, \ldots, q_n)$ for each subcarrier, RA optimization problem of (1) is separable with respect to each subcarrier. The subcarrier problem with respect to subcarrier n is

$$\max R(n) = \sum_{k=1}^{K} \rho_{k,n} \left(\sum_{i=1}^{M_{k,n}} \log\left(1+\frac{\lambda_{k,n}^{(i)} q_{k,n}}{N_0}\right)\right)$$
$$\text{subject to:} \quad \max_k(q_{k,n}) \le q_n$$
$$\rho_{k,n} = \{0,1\} \; for \; all \; k,n \quad (5)$$

Then the multicast subcarrier allocation algorithm based on (3) for each subcarrier is given as follows.
1) For the th subcarrier, calculate the current total data rate when the th user is selected as the user who has lowest eigenvalue product

$$R(n) = N_{k,n} \sum_{i=1}^{M_{k,n}} \log\left(1+\frac{\lambda_{k,n}^{(i)} q_{k,n}}{N_0}\right) \quad (6)$$

2) For the th subcarrier, select the user index $K_{n \text{ which}}$ can Maximize

$$k_n = \arg\max_k R(n) \quad (7)$$

Then we have

$$\rho_{k,n} = \begin{cases} 1, & \prod_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)} \ge \prod_{i=1}^{M_{k_n,n}} \lambda_{k_n,n}^{(i)} \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

For the low SNR case, the product-criterion (3) is changed into the sum-criterion (4) for this step's subcarrier allocation.

B. Step 2 Power Allocation

The subcarrier algorithm in step 1 is not optimum because equal power distribution for the subcarriers is assumed. In this step, we propose an efficient power allocation algorithm based on the subcarrier allocation in step 2. Corresponding to each subcarrier, there may be several users to share it for the multicast service. In this case, the lowest user's channel gain on that subcarrier among the selected users in step 1 will be used for the power allocation. The multi-dimension water-filling method is applied to find the optimal power allocation as follows.

The power distribution over subcarriers is

$$q_n^* = \max(0, q_n)$$

Where q_n means the power assigned to each antenna of subcarrier n and it is the root of the following equation,

$$\sum_{i=1}^{M_{k_n,n}} \frac{\lambda_{k_n,n}^{(i)}}{\lambda_{k_n,n}^{(i)} q_n + N_0} + \alpha = 0, n = 1, 2, \ldots, N, \qquad (9)$$

where K_n is the allocated user index on subcarrier n ; α is the water-filling level which satisfies $\sum_{n=1}^{N} M_{k_n,n} q_n^* = Q$ where Q and N are the total power and the number of subcarriers, respectively.

In case of T=R=1 , that is, a single antenna system, the optimal power distribution for the subcarriers is transformed into the standard water-filling solution:

$$q_n^* = \left(-\frac{1}{\alpha} - \frac{N_0}{\lambda_{k_n}^{(1)}}\right)^+ = \left(-\frac{1}{\alpha} - \frac{N_0}{H_{k_n}^{(1)}}\right)^+ \qquad (10)$$

where $(x)^+ = \max(0, x)$ and $\lambda_{k_n}^{(1)}$ is the same as $H_{k_n}^{(1)}$ for a single antenna.

The multi-dimension water-filling algorithm is an iterative method, by which we can find the optimal power distribution to realize the maximum of system capacity.

V. Overall View Of A Physical Layer On Ofdma System

Afolabi et al. [63] proposed the Multicast Scheduling resource allocation for downlink multicast services in OFDMA services and also to evaluate the core characteristics. JianXu et al. [64] implemented the adaptive resource allocation for high downlink capacity in next generation wireless system and he proved that the system improves the performances of Quality of Service for users. JinZyren [65] proposed the Long Term Evolution is the next term forward in cellular services. It is designed to meet carrier needs for high speed data and media transport as well as the high capacity voice support. Farzad Manavi et al. [66] proposed a prototype design for the physical layer of IEE 802.11a Standard which is based on OFDM. It includes synchronization circuitry used for packet detection and time synchronization Juan Sanchez et al. [67] proposed the concept that has

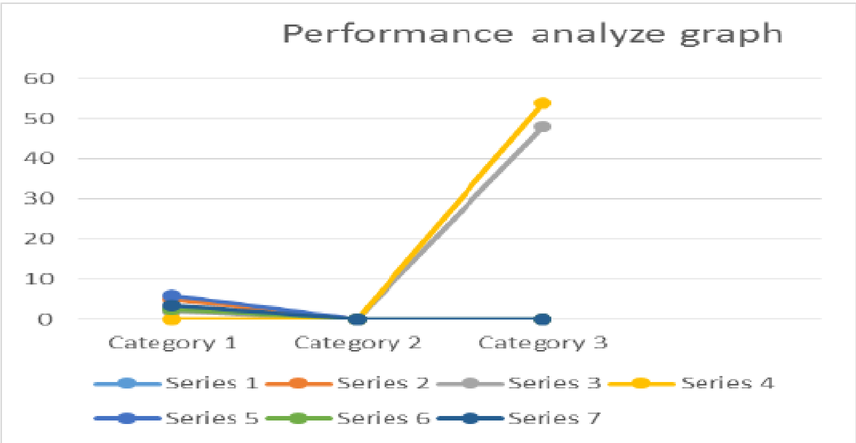
Author	Method	SNR	Bandwidth	BER
Afolabi et al[40]	Dynamic Resource Allocation	2.5 dB	-	-
JianXu et al[41]	AdaptiveResource allocation	5db	-	-
JinZyren [42]	LongTerm Evolution	2db	1.25-20 MHz	48mbps
Farzad et al[43]	XilinxVertex11 FPGA	-	>20mhz	54mbps
Sanchez et al[44]	LTE Technology	6db	1.25-20mhz	-
Xiaomin Ran et al[45]	OFDMA in non-ideal condition	2.5 dB	-	-
Timothy et al[46]	SDR	3.4db	10-30mhz	-
MarkBeach et al[47]	Space time coding	3.5db	-	-

Table 1: performance analysis

analyzed the performance of the new LTE cellular technology. The analysis has focused on the main features involved in the downlink, like the user multiplexing, adaptive modulation and coding, and support for multiple antennas to provide Quality of Service for users.

Xiamomin Ran et al. [68] constructed an algorithm about OFDMA physical resource allocation for non-ideal environment. In an algorithm initially construct an OFDMA network security model. Then, the concept of system average confidential capacity is putted forward as an index to measure the safety of system when the state of wiretap channel is unknown. Finally, the joint optimization distribution of subcarrier and power is realized by dual decomposition to maximize the average confidential interrupt capacity.

Timothy et al. [69] proposed two pertinent problem formulations minimizing transmitted power under multiple minimum received power constraints, and maximizing the minimum received power subject to a bound on the transmitted power in an OFDM system. The proposed method had shown that both Formulations are NP-hard optimization problems. Its Solution can often be well approximated using semi definite relaxation tools. Proposed method have explored the relationship between the two formulations and also insights approximate solutions Provided herein offer useful designs across a broad range of applications. MarkBeach et al… [70] Implemented that, the OFDM was proposed as the transmission technique for a future 4G network. The key link parameters were identified and initial physical layer performance results were presented for a number of channel models system provides data rates of around 1.3-12.5 Mb/s by employing different transmission modes. Hence, this system will be suitable for multimedia traffic, which is a key requirement for 4G systems. In order to achieve diversity gain and enhance performance, space-time block codes were employed



Category1-signal to noise ratio Category2-bandwidth
Category3-Biterror rate Series denotes method in the performance analyze table

VI. Conclusion

Most resource management schemes are developed without considering mobility of user and interferences in cell. Therefore to enhance capacity of a cell , more rigorous studies are required on base station cooperation and mobility effect on multicast resource allocation as no.of users in groups dynamically changes. It requires cross layer optimization study. Some of the imoprtant problems of multicast systems hindering it from achieving its full potential are, the selection of the most efficient group transmission rates and determination of the optimal MSRA strategy. OFDMA at the physical layer, in combination with multicasting provides an optimized resource allocation and Quality of Service (QoS) support for different types of services.

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