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Capacity Maximization in Wireless BroadBand OFDMA Networks Using Joint Weighted-Fair Queuing Token Leaky Bucket Algorithms

Mohamed Khedr and Ahmad Abderrassoul
Arab Academy for Science, Technology and Maritime Transport,
Department of Electronics and Communications Engineering, Alexandria, Egypt

Abstratct: Resources Allocation (RA) in Orthogonal Frequency Division Multiple Access (OFDMA) Systems has been widely studied in recent literature with the aim of finding an acceptable tradeoff between maximizing system utilization (capacity maximization, power minimization, efficient subcarrier utilization, etc.) while maintaining a degree of fairness between users. Weighted Fair Queuing (WFQ) and Token Leaky Bucket (TLB) algorithms are jointly used in packet switched computer networks for traffic shaping and policing of data transmission while guaranteeing a Quality of Service (QoS) level. In this study, researchers propose a new resources allocation scheme based on WFQ and TLB algorithms for OFDMA Systems by allocating power and subcarrier resources for users based on weighted queuing and keeping in mind LTE as a future wireless communication network comparison example. Simulation results show the achievable capacity peaks with the corresponding fairness measure for soft and hard admission cases on different fading channel models: Random, Rayleigh and Rician Channel.

Key words: OFDMA, resources allocation, scheduling, weighted fair queuing, token leaky bucket, capacity maximization

INTRODUCTION

Mobile communications has significantly advanced in the last two decades and became a reliable means for providing voice and data services to over 4.6 billion subscribers worldwide. With the introduction of smart phones along with the growth of social networks, the need for mobile data connectivity has grown as well. Mobile operators and equipment vendors forecast an annual growth of data traffic by over 30% this puts more pressure on mobile operators and equipment vendors to decrease the cost per bit in order to maintain an acceptable profit margin for business profitability.

In order to accommodate with the high data traffic demand, taking into account the need for enhancing the end user experience by providing higher data rates, Long Term Evolution (LTE) was selected by the 3GPP as a universal evolution path from legacy Second Generation (2G) and Third Generation (3G) networks. LTE is expected to become the first universal mobile phone standard due to the available upgrades and available inter-system handovers from LTE to other mobile networks.

LTE utilizes Orthogonal Frequency Division Multiple Access (OFDMA) as a radio access technique due to its higher spectral efficiency, ability to combat severe channel conditions like multipath and channel delay and elimination of inter-symbol-interference and inter-carrier-interference by using Cyclic Prefix. In addition, OFDMA provides the ability to have a scalable implementation according to the available frequency band.

In an OFDMA radio network, the wideband signal is divided into several orthogonal narrowband streams; orthogonality is achieved by using signals with periodic properties subcarriers where each subcarrier's peak is at the other subcarriers' zeros. Every user is allocated radio resources sufficient to carry out his data session with the requested data rate and quality. These resources depend on the wireless channel conditions in which the user is located. Resources are primarily the number of subcarriers and amount of power sufficient to fulfill the user data rate requirements.

Mobile radio networks face a challenge when allocating radio resources this challenge is how to find an acceptable tradeoff between maximizing system utilization thus maximize users' data rates while maintaining a degree of fairness between users. Fairness can have several different forms, i.e., fairness in users' data rate, fairness in allocation durations between users, fairness in allocated power, etc.

Corresponding Author: Mohamed Khedr, Arab Academy for Science, Technology and Maritime Transport, Department of Electronics and Communications Engineering, Alexandria, Egypt

Radio Resource Management (RRM) is the system level control of co-channel interference and other radio transmission characteristics in wireless communication systems. RRM involves strategies and algorithms for controlling parameters such as transmit power, channel allocation, data rates, handover criteria, modulation scheme, error coding scheme, etc. The objective is to utilize the limited radio spectrum resources and radio network infrastructure as efficiently as possible.

RRM concerns multi-user and multi-cell network capacity issues rather than point-to-point channel capacity. Traditional telecommunications research and education often dwell upon channel coding and source coding with a single user in mind although, it may not be possible to achieve the maximum channel capacity when several users and adjacent base stations share the same frequency channel. Efficient dynamic RRM schemes may increase the system capacity in an order of magnitude which often is considerably more than what is possible by introducing advanced channel coding and source coding schemes. RRM is especially important in systems limited by co-channel interference rather than by noise for example cellular systems and broadcast networks homogeneously covering large areas and wireless networks consisting of many adjacent access points that may reuse the same channel frequencies.

The cost for deploying a wireless network is normally dominated by base station sites (real estate costs, planning, maintenance, distribution network, energy, etc.) and sometimes also by frequency license fees. The objective of radio resource management is therefore typically to maximize the system spectral efficiency in bit/s/Hz/base station site or Erlang/MHz/site, under constraint that the grade of service should be above a certain level. The latter involves covering a certain area and avoiding outage due to co-channel interference, noise, attenuation caused by long distances, fading caused by shadowing and multipath, Doppler shift and other forms of distortion. The grade of service is also affected by blocking due to admission control, scheduling starvation or inability to guarantee quality of service that is requested by the users.

Several allocation techniques have been extensively studied in literature based on the commonly used algorithms in wireless channels where OFDMA is used however some algorithms used in packet switched computer networks have not been explored with OFDMA systems extensively and these algorithms can provide fairness, QoS control and traffic shaping to enhance the end user experience. Among these algorithms used in packet switched computer networks are Weighted Fair Queuing (WFQ) and Token Leaky Bucket (TLB) algorithms that have been selected for study as a relatively new allocation algorithm for OFDMA Systems with the general target of maximizing system capacity.

This study aims at proposing an allocation technique for radio resources in OFDMA networks with the target of maximizing system capacity without sacrificing fairness between users. LTE is the target technology this research was benchmarked against as it is considered the future of mobile networks. Researchers Propose a Radio Resources Allocation technique based on Weighted Fair Queuing (WFQ) and Token Leaky Bucket algorithms (TLB) that are commonly used in Packet Switched Computer Networks.

Detailed performance evaluation of the proposed technique will show how the capacity of the OFDMA System can be maximized while maintaining a degree of fairness between users in different radio channel cases.

LITERATURE REVIEW

Several studies have been conducted in the field of Resources Allocation (RA) for OFDMA Systems. Broadly, two major approaches can be considered for RA problem; Margin Adaptive approach and Rate Adaptive approach. The main resources to be allocated are transmit power and OFDMA subcarriers with constraints on user data rate (throughput), Bit Error Rate (BER) and total transmit power.

In margin adaptive approach, the RA algorithm has the target of minimizing total transmit power with constraints on data rate and BER (Joung and Sun, 2012).

In rate adaptive approach, the RA algorithm has the target of maximizing system throughput with constraints on total transmit power (Schmidt *et al*., 2011).

Other techniques were studied as well including random allocation technique (Ren *et al*., 2011) or proportional fair allocation technique with constraints on revenue, QoS (Ergen *et al*., 2003) or channel response (Khedr *et al*., 2008). Some studies suggest moving some intelligence from the network down to the handsets (Haddad *et al*., 2011) while other studies propose allocation based on the maximum Euclidean distance between adjacent points while maintaining the same spectral efficiency (Salem *et al*., 2006). Some studies target capacity maximization using low-complexity suboptimal algorithm (Shen *et al*., 2005).

Joung and Sun (2012) introduce an Orthogonal Frequency and Time Transmission (OFTT) protocol in which orthogonal frequency and time resources are allocated to different communication modes and phases, respectively and propose a simple algorithm for resource allocation. Schmidt *et al*. (2011) present a prediction-based resource llocation algorithm for OFDMA downlink where inaccuracies in the wireless channel predictions are accounted for in the problem formulation. As the prediction quality significantly degrades with the prediction horizon researchers propose a solution based on the histogram of the prediction error. This characterization also enables different mobile stations to use different channel predictors as it does not rely on a specific prediction scheme. Ren *et al.* (2011) studies self-optimization of resource allocation for multipoint-to-multipoint OFDMA interference channels with Multiple-Input Multiple-Output (MIMO) user terminals. A Wireless Broadband Networks (WBN) Call Admission Control (CAC) framework is proposed that effectively meets the operational requirements of WBNs' service providers as well as requirements of the subscribers. Ergen *et al.* (2003) a system based on OFDMA has been developed to deliver mobile broadband data service at data rates comparable to those of wired services such as DSL and cable modems. Khedr *et al.* (2008) propose a Simple subcarrier Opportunistic Proportional Fair (SOPF) scheduling scheme specifically suited to OFDMA. Haddad *et al.* (2011) propose that RRM decision making can be delegated to mobiles by incorporating cognitive capabilities into mobile handsets resulting in the reduction of signaling and processing burden. Salem *et al.* (2006) carry an optimization of the OFDM System waveform for highly time and frequency dispersive channels and hexagonal underlying time-frequency lattices. Shen *et al.* (2005) a set of proportional fairness constraints is imposed to assure that each user can achieve a required data rate as in a system with quality of service guarantees.

WEIGHTED FAIR QUEUING AND TOKEN LEAKY BUCKET ALGORITHMS

Weighted fair queuing: Weighted Fair Queuing (WFQ) is a data packet scheduling technique allowing different scheduling priorities to statistically multiplexed data flows enabling guaranteed bandwidth services. The purpose of WFQ is to let several sessions share the same link.

WFQ is a generalization of Fair Queuing (FQ). Both in WFQ and FQ each data flow has a separate First in First Out (FIFO) queue. In FQ with a link data rate of k at any given time the N active data flows (the ones with non-empty queues) are serviced simultaneously each at an average data rate of R/N. Since, each data flow has its own queue an ill-behaved flow (who has sent larger packets or more packets per sec than the others since, it became active) will only punish itself and not other sessions. As oppose to FQ, WFQ allows different session to have different services shares. If N data flows currently are active with weights $w_1, w_2, ..., w_N$:

$$R_i = \frac{w_i R}{(w_1 + w_2 + ... + w_N)} \tag{1}$$

When using a network with WFQ switches and a data flow that is leaky bucket constrained an end-to-end delay bound can be guaranteed. By regulating the WFQ weights dynamically WFQ can be utilized for controlling the quality of service to achieve guaranteed data rate. Proportional fairness can be achieved by setting the weights to $w_i = 1/c_i$, where c_i is the cost per data bit of data flow i.

WFQ is an automated scheduling method that provides fair bandwidth allocation to all network traffic. WFQ applies priority or weights to identified traffic to classify traffic into conversations and determine how much bandwidth each conversation is allowed relative to other conversations. WFQ is a flow-based algorithm that simultaneously schedules interactive traffic to the front of a queue to reduce response time and fairly shares the remaining bandwidth among high-bandwidth flows. In other words WFQ allows network controllers to give low-volume traffic such as Telnet sessions, priority over high-volume traffic such as FTP sessions. WFQ gives concurrent file transfers balanced use of link capacity that is when multiple file transfers occur the transfers are given comparable bandwidth.

Token leaky bucket: In packet computer networks, admission control and reservation is not sufficient to provide QoS guarantees. Traffic shaping is needed at the entry to network and within the network to provide QoS guarantees. The role of traffic shaping is to decide how packets will be sent into the network, hence regulates traffic and decides whether to accept a flow's data, finally traffic shaping polices flows. Based on traffic shape, network controllers can determine if flow should be admitted into the network and periodically monitor flow's traffic. Two of the main traffic shaping algorithms are the leaky bucket and token bucket traffic shapers. Traffic policing drops out-of-profile traffic and is more resource efficient as it supports incoming and outgoing interfaces while traffic shaping reduces bursts by queuing out-of-profile traffic using Delay instead of Drop approach which minimizes retransmits but is only used for outbound interfaces. The Isochronous Traffic Shaping Model or simple leaky bucket traffic shaper was developed by Jon Turner in 1986 from Washington University, St. Louis.

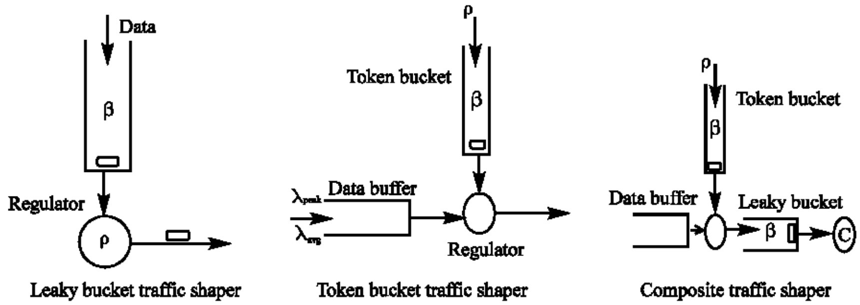

Fig. 1: Different traffic shapers

Leaky Bucket algorithm assumes a bucket full of water with hole in the bottom through which water leaks at a constant rate until the bucket is empty. Water can be added in bursts or at a constant rate. If too much water is added the bucket will overflow.

Figure 1 shows a simple Leaky Bucket Traffic Shaper where β is the size of the bucket, ρ is the rate at which the cells drain out the bottom of the bucket to be sent and regulator enforces the rate at the bottom. Token Bucket Traffic Shaper is shown where β is the capacity of the bucket ρ is the rate at which tokens are placed in the bucket, λ_{peak} is the peak data rate and λ_{avg} is the average data rate such that:

$$\lambda_{peak} > \rho > \lambda_{avg} \tag{2}$$

Token bucket algorithm assumes a fixed capacity bucket into which tokens are added at a fixed rate. Tokens normally represent the packets of a predetermined size. When a packet is set for transmission the bucket is inspected to see if it contains enough tokens to be removed from the bucket accordingly, tokens are removed from the bucket and the packet is transmitted. If tokens in the bucket are not enough for the packet to be transmitted the packet can either be discarded or buffered for latter transmission based on the traffic control setup used traffic policing will discard the packet and traffic shaping will buffer it for future transmission.

Token Leaky Bucket algorithm is a merge of the previous two algorithms with the analogy of a bucket leaking at a constant rate with water being added in the form of tokens at a constant rate. In this analogy the bucket is a queue in the flow of traffic and is directly used to control that flow. TLB characteristics provides good policing but remains hard although, confirming that the flow's data rate does not exceed channel data rate C is easy. More complexity for implementation is faced because each flow requires two counters and two timers (one timer and one ounter for each bucket).

PROPOSED ALGORITHM

Based on this introduction and after a review of literature the proposed research target for this study was developed to be proposing an allocation algorithm for radio resources allocation that maximizes system capacity without sacrificing fairness among users. Since, fairness is a broad definition and can mean fairness in allocated power, fairness in user data rate, fairness in subcarriers allocated, etc. In this study, fairness is measured as by Khedr *et al.* (2008) using Fairness Measure parameter, defined as:

$$F = \frac{\left(\sum_{k=1}^{N} r_k\right)^2}{N\sum_{k=1}^{N} r_k^2} \tag{3}$$

where, r_k is the total rate achieved by user k in a system with N users. Fairness Measure has a positive number with a maximum value of 1 corresponding to equal throughput among the k users.

Introduction: One of the main challenges in transmission of broadband data in a wireless channel is known as Inter-Symbol Interference (ISI) caused by multipath propagation. Orthogonal Frequency Division Multiplexing (OFDM) is an efficient multiplexing technique that has the capability to combat ISI by dividing a wideband channel into many orthogonal narrowband channels each facing different channel fading thus overcoming the severe channel conditions. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple access technique based on OFDM which allows multiple users to share an OFDM symbol (Shen *et al.*, 2005). OFDMA been widely selected as a multiple access scheme for high speed wireless networks in frequency selective fading environments with hostile multipath conditions due to advances in Digital Signal Processing (DSP) field providing fast processors with the ability to process the large amount of data for OFDMA allocation (Khedr *et al*., 2008).

Long Term Evolution (LTE) cellular networks are known as the future fourth generation mobile networks and are developed primarily for providing high speed Internet access to the mobile users OFDMA was selected as the radio multiple access technique for LTE mobile networks due to the aforementioned advantages. With the increasing demand of users for data traffic on one hand and the scarcity of radio resources on the other hand, Resource Allocation RA and scheduling are important topics when efficient exploitation of network resources is required (Li *et al*., 2011).

Many advantages are marked for OFDMA compared to other multi-user access schemes and the most important one is multi-user diversity enabled by adaptive resource allocation. OFDMA also inherits all other advantages of the Orthogonal Frequency Division Multiplexing (OFDM) modulation technique such as low-cost transceiver processing by Fast Fourier Transform (FFT) and Inverse FFT (IFFT) and high spectrum efficiency. Addition of a Cyclic Prefix (CP) in each OFDM symbol converts a frequency-selective fading channel into multiple flat-fading channels in the frequency domain, eliminating the need for complicated time-domain equalizers in the receivers (Li *et al*., 2011).

Several studies have focused on various resources allocation method for OFDMA Systems, these studies can be generalized in two types of problems, referred as margin adaptive (Wong *et al*., 1999) and rate adaptive (Jang and Lee, 2003; Rhee and Cioffi, 2000; Kivanc and Liu, 2000; Shen *et al*., 2005; Hajipour and Leung, 2010). The margin adaptive objective is to minimize the total transmit power with constraints on the users data rate and Bit Error Rate (BER). The rate adaptive aims at maximizing the overall system throughput with a total power constraint.

Research has been performed on Weighted Fair Queuing (WFQ) algorithms for achieving the desired bandwidth allocation on and wireless links (Hajipour and Leung, 2010). With WFQ, the bandwidth received by a flow in a shared link is in proportion to the flow’s weight. In wireless communications, the air interface is considered the shared link under investigation by assigning user weights proportional to the channel quality of each user. WFQ prevents data flow of poor channel quality users from overwhelming the resources of the network in transmissions that are not likely to be received, free of errors by the corresponding users.

Token Leaky Bucket (TLB) is an algorithm commonly used in packet switched computer networks to check that data transmissions conform to specific limits on burstiness and bandwidth. TLB can be used in either traffic policing or traffic shaping to protect the network against excessive traffic bursts (policing) or shape the data traffic according to network setup by preventing transmissions from being discarded by traffic management functions in the network (shaping).

The above introduction summarizes the details explained in the earlier studies, based on which the research target was developed to be proposing a radio resources allocation technique for OFDMA Systems using WFQ and TLB algorithms with the target of maximizing system capacity while maintaining an acceptable degree of fairness between users.

Problem formulation: The problem of resource allocation is finding an acceptable tradeoff between maximizing system resources’ utilization and maintaining a degree of fairness between different users trying to access and use the system. The main resources to allocate in OFDMA Systems are number of subcarriers to allocate per user distribution of subcarriers along the available bandwidth of transmission, transmission power required for successful transmission and modulation technique used for transmission. These resources are allocated based on the user’s requested data rate, channel condition and QoS constraints.

The multiple resources to allocate make the resources allocation problem a sophisticated problem, especially if an optimum solution is required. Most research targets maximizing one or two resources with constraints on other resources. In this study, the proposed resource allocation algorithm targets maximization of system capacity (in bps/Hz) with constraints on fairness between users in order to achieve a minimum QoS level.

The proposed algorithm divides the allocation problem into three phases; phase 1 is the WFQ phase where subcarriers are allocated to users based on their channel characteristics they feed the network with. In phase 2, a TLB for every user determines the data rates each user can achieve according to bucket status and finally, power is allocated in phase 3 for users with higher weight first until all power is depleted.

Algorithm details: The proposed algorithm assumes a single cell network in an OFDMA System, different channel models are supported namely; Random Channel, Rayleigh Channel and Rician Channel. Rayleigh Channel represents the wireless channel in dense urban areas with no Line-of-Sight (LOS) and several multipath components, while Rician Channel represents the channel in suburban areas with clear LOS condition.

Admission is toggled between soft admission where users who request higher data rates than can be allocated will be served in a best effort manner and hard admission: where users will be allocated resources only when the scheduler can provide the requested data rate.

Session durations are also considered to be either equal session durations with similar on-off periods for every user and different start time or unequal session durations with different on-off periods for each user with different start time.

Modulation Schemes were considered to be Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation 16-QAM and 64-QAM according to channel quality. Since, QPSK is the most robust modulation scheme it was considered for channels with poor quality. Higher order modulation schemes 16-QAM and 64-QAM provide higher data rate but require better channel quality.

Allocation is done on TTI basis every 1 msec with weights increasing and decreasing according to channel quality, weights are reset every 100 consecutive similar channel quality as a limiting parameter to ensure users are not stuck in a poor channel condition.

At the beginning all parameters are initialized to the default values. Admission type, number of users, channel model, session duration and allocation duration will all be set before starting the algorithm phases.

Phase 1: Based on channel characteristics, different weights are given to each user and subcarriers are reserved for users proportional to their weights. WFQ will be used for all users to allocate the subcarriers based on the channel characteristics this allocation is governed by Eq. 1.

Phase 2: Each user has his/her own TLB where tokens are added to the bucket every TTI equivalent to the maximum data rate any user can achieve and when power is allocated to the user tokens are removed from the bucket and a flag is raised. If no tokens are removed from the bucket, overflow occurs and a flag is raised. To guarantee a minimum QoS if a user is not allocated any resources in the current TTI his weight is increased in the following TTI and so forth until he is allocated resources. And the weights of users with good channel characteristics are decreased each TTI after resources are allocated to guarantee a degree of fairness.

Phase 3: Users are sorted based on their weights and power is allocated on first-come-first-serve basis until all power is depleted. This process is repeated every Transmit Time Interval (TTI).

The following pseudo code describes the proposed algorithm showing the 3 phases of allocation for subcarriers and power and modulation scheme accordingly.

Pseudo code for proposed algorithm:

```
Initialize all variables
Select Admission type (Hard or Soft)
Determine channel type (Random, Rayleigh or Rician)
Determine user session duration (Equal or Unequal
    durations)
loop for TTI = 1 to MaxTTI
        Acquire user specific data (channel quality,
        Requested rate..., etc.)
        phase 1: Determine user weights from WFQ
        Add Token to leaky bucket
        Reserve subcarriers based on user weights
        phase 2: From TLB determine modulation method
        satisfying user data rate
        phase 3: Allocate power until depleted
        Allocate subcarriers to users with allocated
        power only
        Modify TLB flags according to last TTI assignment
end for
```

Flow chart in Fig. 2 shows details of the proposed allocation algorithm. First four blocks show the initialization of the allocation process where all resources are calculated, user channel information, session duration and requested rate are acquired. The following four blocks describe the WFQ algorithm where user weights are assigned based on requested rates and channel quality. The remaining blocks describe the TLB algorithm and power allocation based on user weights from the earlier stage.

Summary: The proposed resources allocation algorithm proposes a technique for allocating OFDMA radio resources based on WFQ and TLB algorithms that are widely used in packet computer networks for traffic shaping and policing. Allocation problem is divided into 3 phases where subcarriers are allocated according to WFQ algorithm, data rate is determined by TLB algorithm and power is allocated in a water-filling method until depletion. Different channel models are supported as well as different admission types, session durations and modulation schemes.

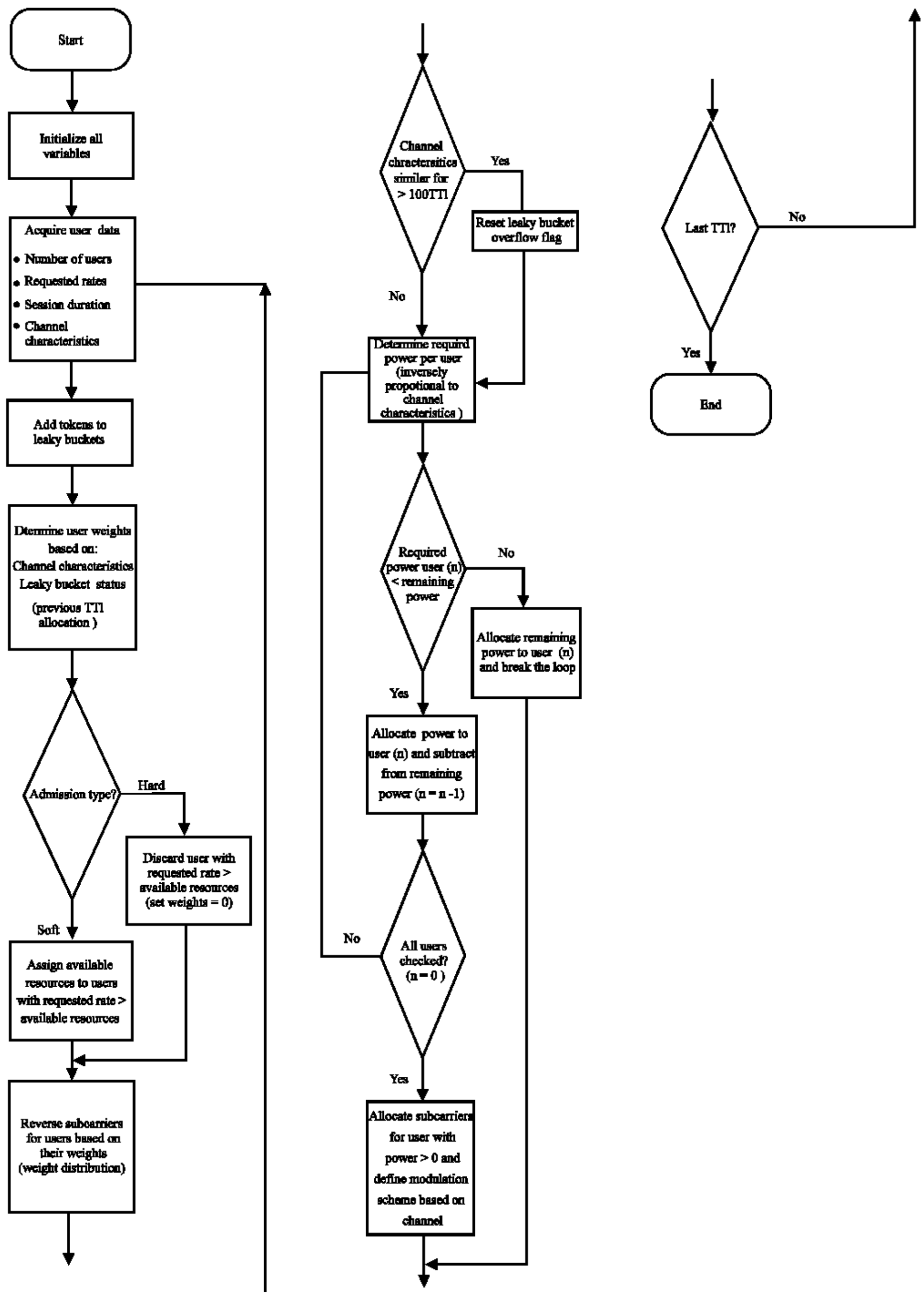

Fig. 2: Flow chart of the proposed resources allocation algorithm

SIMULATION RESULTS

Simulation platform: DFDMA Scheduler simulator was coded on Matlab® 2010 Software on an Intel ®Core™ i5 CPU, 2.4 GHz with 4 GB RAM running in Windows® 7 Operating System. Having LTE as a reference technology for comparison, the following simulation parameters were assumed:

- About 20 MHz Bandwidth, 1200 subcarrier with 15 kHz subcarrier distance
- About 20 Watt power amplifier
- Time varying channel model with 3 fading channel models Random, Rayleigh and Rician
- TTI duration of 1 msec
- 10000 TTIs simulation duration per run
- Frequency band is assumed to be 2.6 GHz

- Doppler shift of 240.75 Hz corresponding to users moving at 100 km h^{-1}
- Variable number of users per cell, starting from 1 user up to 200 users
- Downlink resources allocation only is being considered for a single cell scenario

Performance evaluation parameters: Since, the target of research is capacity maximization without sacrificing fairness between users the main evaluation parameters in the study are system Capacity C and Fairness Measure F defined in Table 1.

Where r_k is the total rate (in bps) achieved by user k in a system with N users. B_k is the allocated bandwidth for user k according to the number of subcarriers allocated.

Table 1: Performance evaluation parameters

Parameters	Units	Formula
Capacity	bps/Hz	$C=\sum_{k=1}^{N}\frac{r_k}{B_k}$
Fairness measure	Unit-less	$F=\frac{\left(\sum_{k=1}^{N}r_k\right)^2}{N\sum_{k=1}^{N}r_k^2}$

Fairness easure has a positive number with a maximum value of 1 corresponding to equal throughput among the k users and minimum value of 0.

Simulation output: Simulations were run on three different channel models random fading channel, rayleigh fading channel and rician fading channel (Table 2).

Random channel

Capacity versus number of users: Capacity is nearly maximized for soft admission case. For hard admission however, capacity drops significantly for allocation of >100 users. No major differences are noted between equal and unequal admission types (Fig. 3).

Fairness measure versus number of users: Fairness measure for soft admission case is significantly higher than Hard Admission case. Maximum fairness measure zone is between 30-55 users (Fig. 4). No major differences are noted between equal and unequal admission types.

Capacity versus fairness measure: Based on the previous results a best-performance widow can be determined for random channel as the window between 30 and 55 users on soft admission with unequal session durations. In this window, capacity is maximized and

Table 2: Simulation results summary

	Random channel		Rayleigh channel		Rician channel	
Parameters	Hard admission	Soft admission	Soft admission	Hard admission	Hard admission	Soft admission
Capacity limit	100 users	200 users	+100 users	+120 users	+60 users	+130 users
Fairness measurement limit	25 users	55 users	40 users	90 users	40 users	100 users
Typical environment	-	-	Dense urban	-	Suburban	

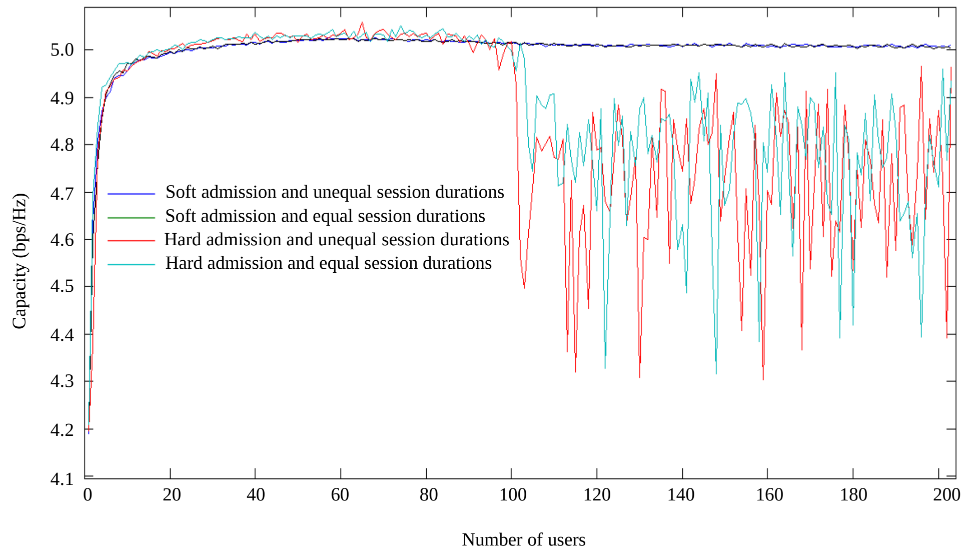

Fig. 3: Capacity vs. number of users for random channel

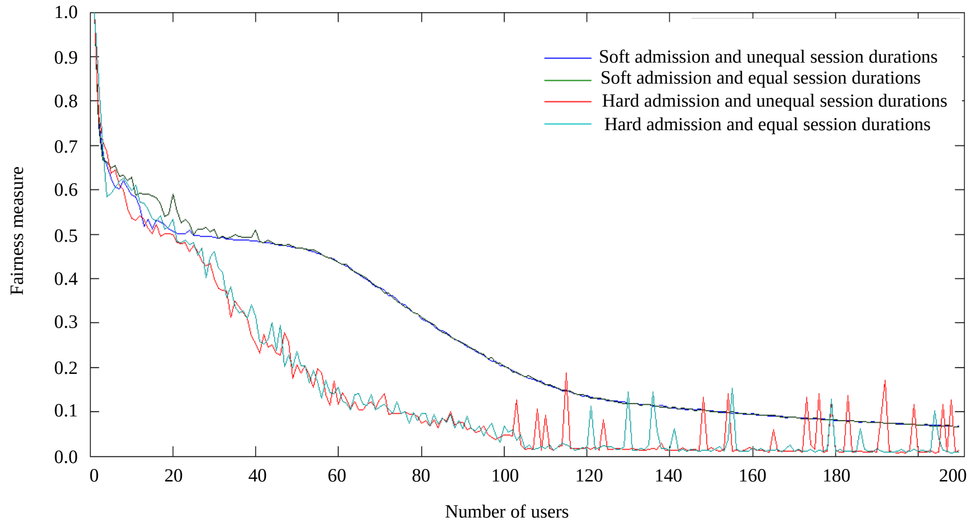

Fig. 4: Fairness measure vs. number of users for random channel

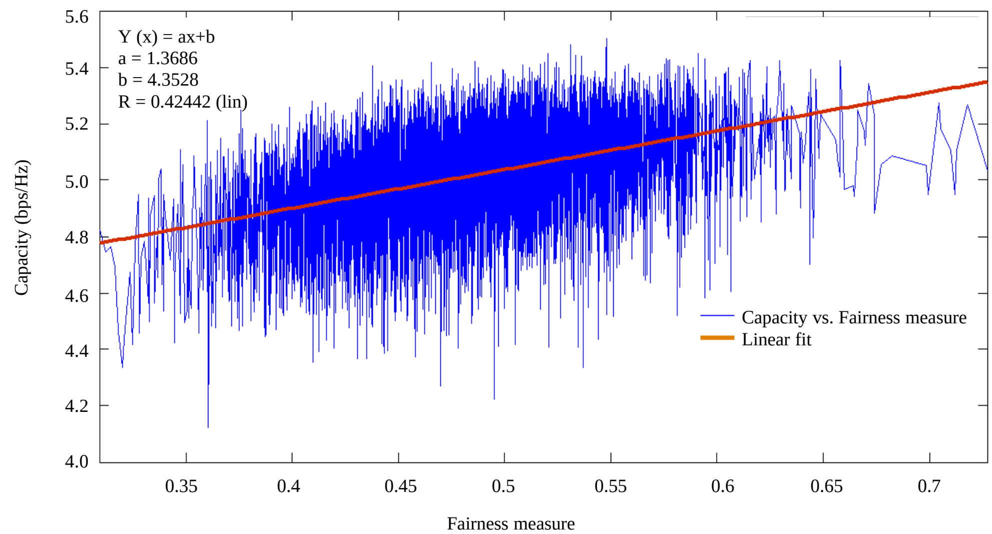

Fig. 5: Capacity vs. fairness measure for random channel, 50 users, soft admission unequal session durations

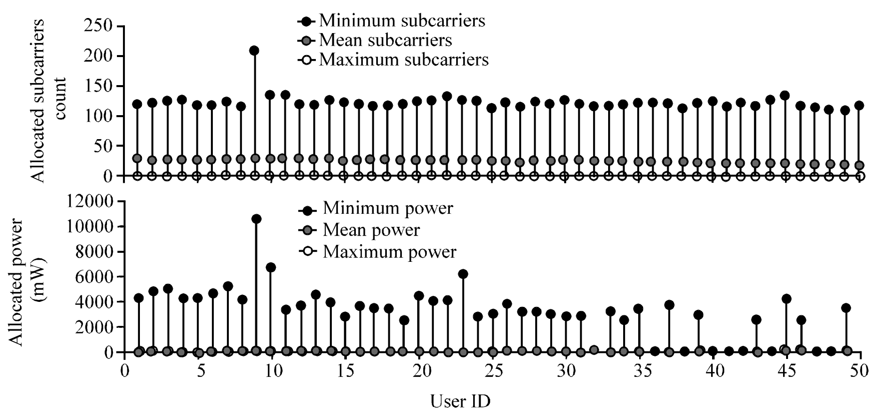

Fig. 6: Sample allocation for 50 users on random channel, soft admission, unequal session durations, 10000 TTIs

fairness measure does not begin decreasing. Running a simulation run on 50 users case shows a slight increase of capacity with the increase in fairness measure indicating better truncking and efficient utilization of resources (Fig. 5).

Sample allocation of resources: Sample allocation graphs show maximum, mean and minimum allocated values for power and subcarrier resources (Fig. 6).

Rayleigh channel

Capacity versus number of users: Capacity is maximized for Soft Admission case above 120 users while for hard admission; capacity is maximized for >90 users (Fig. 7). No major differences are noted between equal and unequal admission types.

Fairness measure versus number of users: Fairness measure for soft admission case is significantly higher than Hard Admission case. Maximum fairness measure zone is between 20-90 users (Fig. 8). No major differences are noted between equal and unequal admission types.

Capacity versus fairness measure: Based on the earlier results a best-performance widow can be determined for

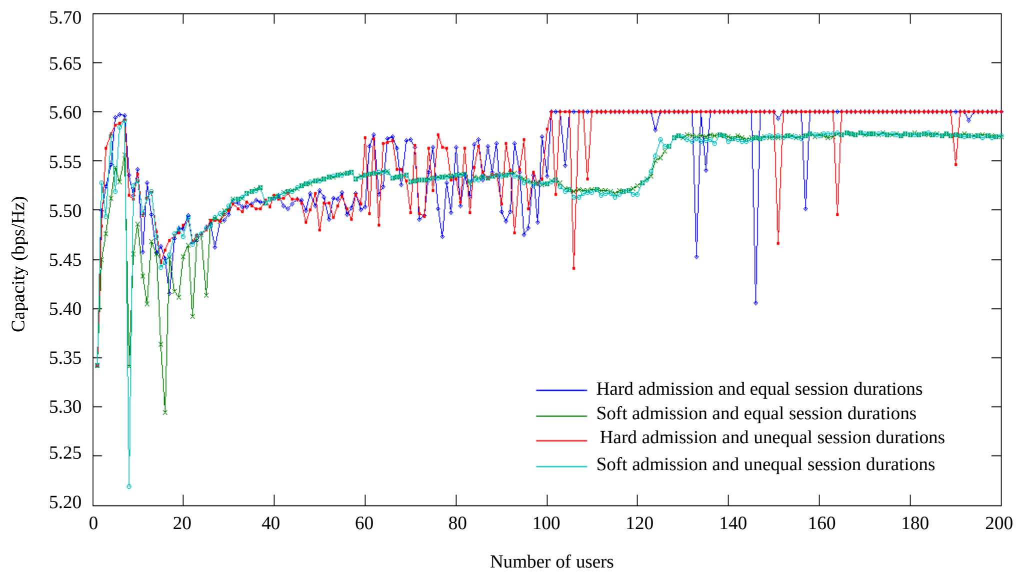

Fig. 7: Capacity vs. number of users for rayleigh channel

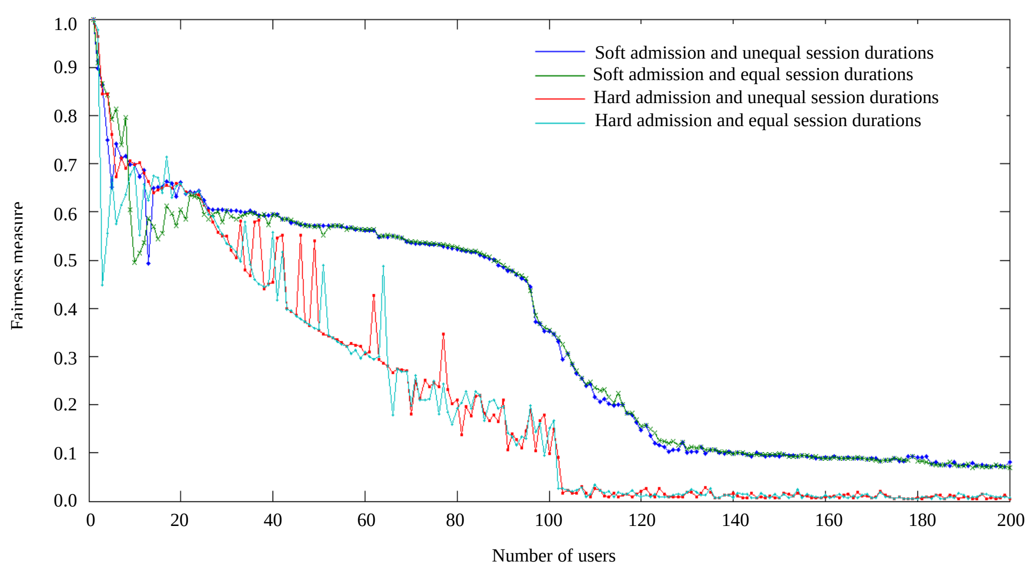

Fig. 8: Fairness measure vs. number of users for rayleigh channel

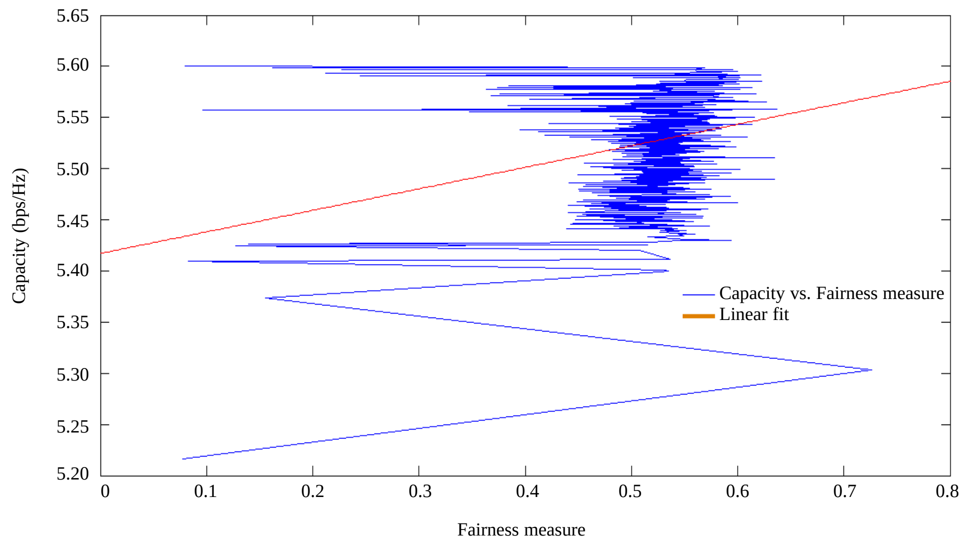

Fig. 9: Capacity vs. fairness measure for rayleigh channel, 80 users, soft admission unequal session durations

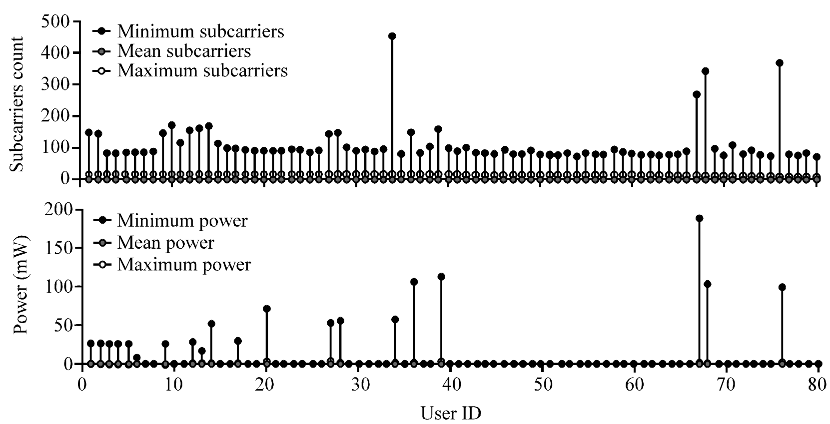

Fig. 10: Sample allocation for 80 users on rayleigh channel, soft admission, unequal session durations, 10000 TTIs

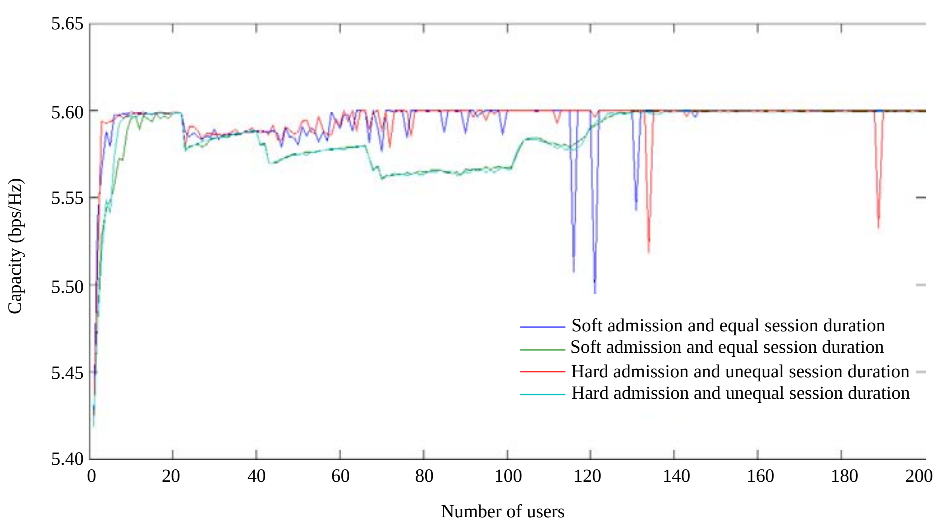

Fig. 11: Capacity vs. number of users for rician channel

rayleigh channel as the window between 20 and 90 users on soft admission with unequal session durations although, hard admission has higher capacity but fairness measure is severely impacted. In this window, capacity is maximized and fairness measure does not begin decreasing (Fig. 9). Running a simulation run on 80 users case shows a slight increase of capacity with the increase in fairness measure indicating better truncking and efficient utilization of resources.

Sample allocation of resources: Sample allocation graphs show maximum, mean and minimum allocated values for power and subcarrier resources (Fig. 10).

Rician channel

Capacity versus number of users: Capacity is maximized for soft admission case above 130 users while for hard admission, Capacity is maximized for >60 users. No major differences are noted between equal and unequal admission types (Fig. 11).

Fairness measure versus number of users: Fairness measure for soft admission case is significantly higher than hard admission case and soft admission shows nearly constant fairness measure up to 100 users. Maximum fairness measure zone is between 20-100 users (Fig. 12). No major differences are noted between equal and unequal admission types.

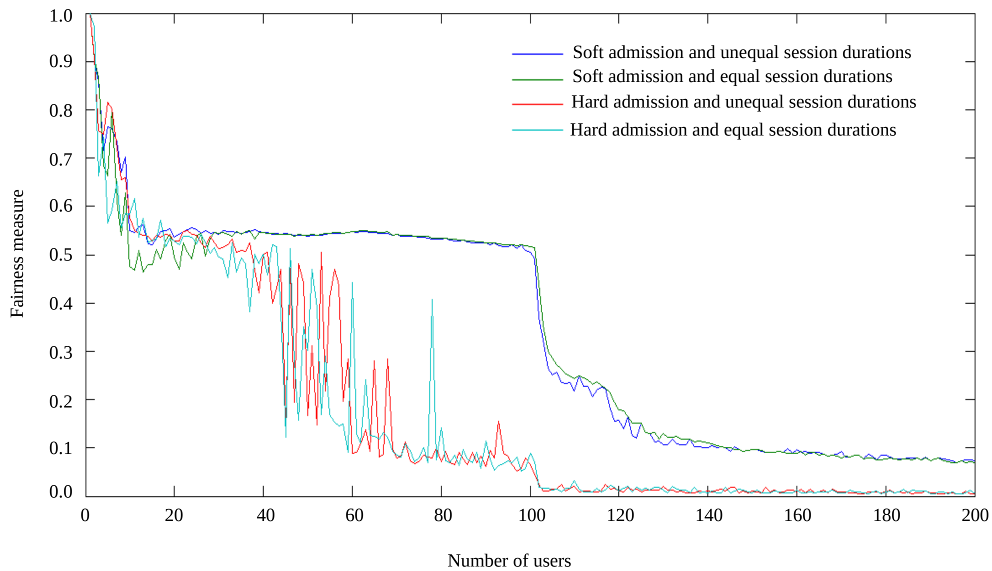

Fig. 12: Fairness measure vs. number of users for rician channel

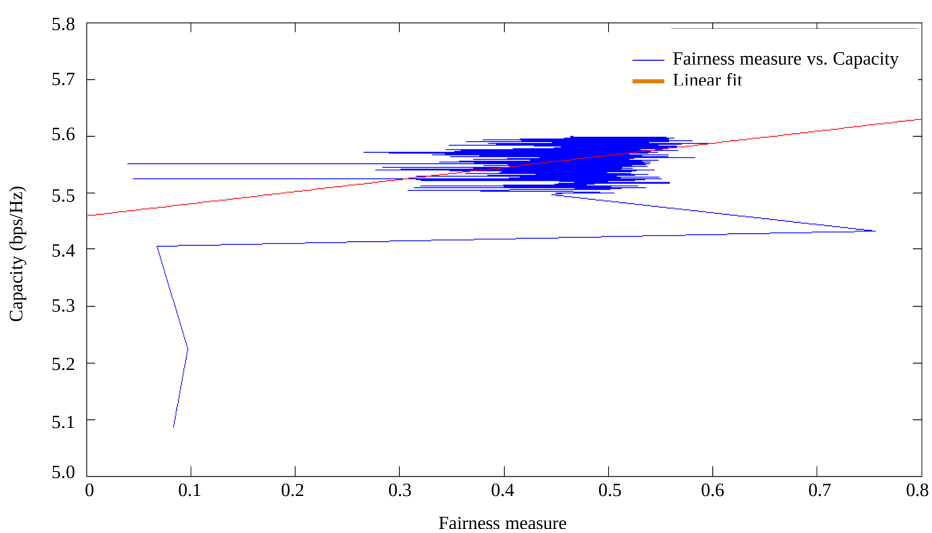

Fig. 13: Capacity vs. fairness measure for rician channel, 100 users, soft admission unequal session durations

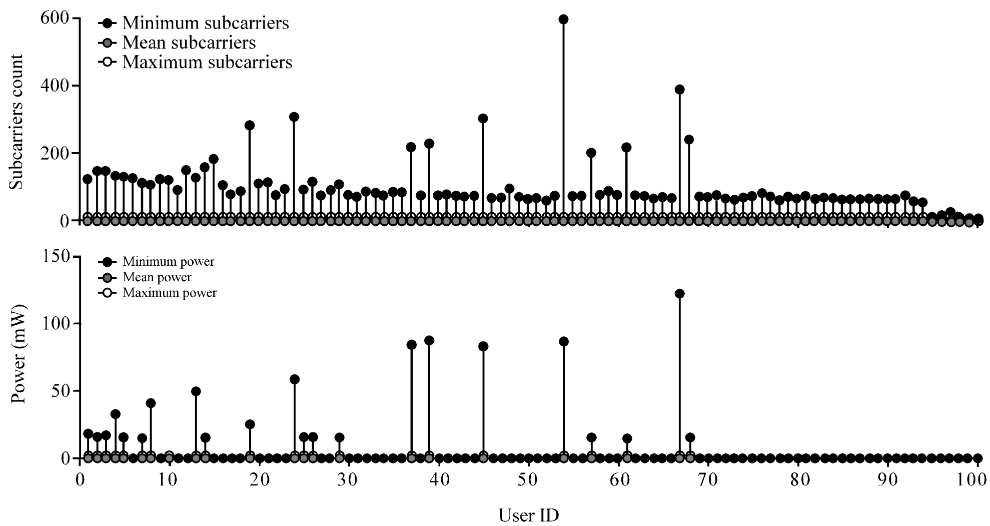

Fig. 14: Sample allocation for 80 users on rician channel, soft admission, unequal session durations, 10000 TTIs

Capacity versus fairness measure: Based on the previous results, a best-performance widow can be determined for rayleigh channel as the window between 20 and 100 users on soft admission with unequal session durations although, hard admission has higher capacity but fairness measure is severely impacted. In this window, capacity is close to maximum and fairness measure does not begin decreasing.

Running a simulation run on 100 users case shows a slight increase of capacity with the increase in fairness measure, indicating better truncking and efficient utilization of resources (Fig. 13).

Sample allocation of resources: Sample allocation graphs show maximum, mean and minimum allocated values for power and subcarrier resources (Fig. 14).

CONCLUSION

In this study, an OFDMA resources allocation algorithm has been proposed this resources allocation algorithm uses WFQ and TLB algorithms as new technique for allocating radio resources, namely power and subcarriers by queuing data while maintaining a minimum QoS level. WFQ and TLB algorithms are widely used in packet switched computer networks and wired links. Investigating performance of WFQ and TLB algorithms on a wireless link for OFDMA resources allocation can be considered as a new approach to allocate radio resources in OFDMA Systems as a replacement to the commonly used proportional fair allocation method or other allocation algorithms that have been researched recently.

Different admission and session types have been investigated aiming at providing maximal fairness and capacity from the OFDMA System on different channel models representing dense urban and suburban environments. From simulation results, the best-performance window is determined at which maximum capacity can be achieved for the system with the highest corresponding fairness. Different types of admission where investigated as well and soft admission was found superior to hard admission in fairness and user experience.

In random fading channel conditions, system performance was tested with different number of active users to determine the system performance limits and a realistic limit of 40 concurrent active users was found to be the performance peak point of the system after which when the number of users increases the system performance deteriorates in terms of fairness and capacity.

In rayleigh fading channel conditions system performance was tested with different number of active users to determine the system performance limits and a realistic limit of 80 concurrent active users was found to be the performance peak point of the system after which when the number of users increases the system performance deteriorates in terms of fairness and capacity. Rayleigh channel represents the channel in dense urban area where a larger number of users is expected and simulation results conform to expected results.

In rician fading channel conditions, system performance was tested with different number of active users to determine the system performance limits and a realistic limit of 100 concurrent active users was found to be the performance peak point of the system after which when the number of users increases the system performance deteriorates in terms of fairness. Rician channel represents the channel in suburban areas where a larger coverage area is expected and simulation results conform to expected results.

RECOMMENDATIONS

Several enhancements can be considered as a future road map for enhancing the proposed resources allocation algorithm or can be implemented as independent research topics these suggested enhancements include:

- Creating a graphical user interface to facilitate manipulation with simulations
- Comparing Weighted Fair Queuing and Token Leaky Bucket scheduling to Proportional Fair scheduling
- Determining system complexity and optimization of simulation algorithm
- Using Monte Carlo Simulation Method to mimic real life performance
- Considering the effect of different types of noise and interference on the performance

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