Complexity and Fairness Analysis of a new Scheduling Scheme for VoIP in 3G LTE

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Abstract— **3G Long Term Evolution is an emerging and promising technology that aims at providing broadband ubiquitous internet access and improving multimedia services. This is achieved through streamlining the system for packet services since long term evolution is an all Internet protocol based network. The fact that 3G long term evolution is a packet based network brings along some improvements in the form of higher bit rates, lower latencies, and a variety of service offerings. However, some technical challenges are expected to arise when voice traffic is transmitted over a long term evolution network. This has become an interesting area of research and different types of resource management schemes have been developed which are quite challenging and complex. In this paper, we analyze the complexity and fairness of our proposed scheduling scheme for voice over internet protocol in 3G long term evolution called voice over internet protocol optimization scheduling algorithm. We compare it with other algorithms in literature. There is second order complexity in the number of users based on quality feedback, queue length metrics, and there is linear complexity in resource blocks using voice over internet protocol optimization scheduling algorithm. Simulation results also showed approximately 10 – 20 percent improvement in fairness and performance based on the fairness index and throughput.**

Keywords-LTE; Scheduling Schemes; VoIP; Complexity; Fairness.

I. INTRODUCTION

3G Long Term Evolution (LTE) was identified by the third generation partnership project (3GPP) as the preliminary version of next generation wireless communication systems because of its high data rates [1]. This mobile cellular communications technology provides a maximum 100Mbps downlink and 50Mbps uplink when using 20 MHz bandwidth [2]. In the downlink physical layer, LTE uses Orthogonal Frequency-Division Multiple Access (OFDMA) radio technology to meet the LTE requirements for spectrum flexibility and enables cost-efficient solutions for wide carriers with high peak rates. In the uplink, LTE uses a pre-coded version of OFDMA which is Single-Carrier Frequency-Division Multiple Access (SCFDMA) in order to compensate for a drawback with normal OFDMA which has a high Peak-to-Average-Power Ratio (PAPR) [3].

Wireless technology has expanded from voice only to high-speed data, multimedia applications, and wireless internet [4]. LTE requirements for high data rates are achieved by the fact that this technology is only designed for packet switched networks (PSN); hence, there is no need for the circuit switched mode. However, this design brings with it more technical challenges especially for voice services. Voice over internet protocol **(**VoIP) services are both delay and packet loss sensitive. The biggest challenge of VoIP over LTE is the delivered Quality of Service (QoS). Normally, users would expect voice with the same quality as that provided by circuit switched networks. However, traffic delivered over PSNs is subject to delay and packet loss [5]. A major issue with VoIP over LTE is that 3G LTE adopts a different method of resource transmission from other cellular systems like Code Division Multiple Access (CDMA). It uses Physical Resource Blocks (PRB) as its transmission unit. PRBs can be defined as the basic unit with both frequency and time aspects [6]. Basically, the base station of 3G LTE, known as eNodeB has a fixed number of available PRBs according to their allocated bandwidth and it is supposed to assign PRBs repeatedly at every Transmission Time Interval (TTI) [2].

Different techniques have been introduced in the literature to over come the challenges faced when real time traffic is trasmitted over an LTE network. In [7], Yaacoub, Al-Asadi, and Dawy proposed two low complexity heuristic algorithms. The complexity of both algorithms was analysed. The first algorithm had a linear complexity in the number of users and a quandratic complexity in the number of resource blocks. The second algorithm had a linear complexity in both the number of user and resource blocks. It was shown that good results could be achieved by the proposed linear complexity algorithm (second algorithm). It was also shown through simulations that the maximization of sum throughput leads to a higher cell throughput, although considering the logarithm of throughput as a utility function ensures proportional fairness, and thus constitutes a tradeoff between throughput and fairness.

In [8], Zhao et al. investigated two fairness criterias with regards to adaptive resource allocation for uplink OFDMA systems. These two criteria were Nash bargaining solution (NBS) fairness and proportional fairness (PF). These two criterias can provide attractive tradeoffs between total throughput and each user's capacity. Using Karush-Kuhn-Tucker (KKT) condition and iterative method, two effective algorithms were designed to achieve NBS fairness and proportional fairness respectively. Through simulation results, NBS fairness criteria shows better performance in total capacity but the BS cannot control the rate ratio because it only depends on the channel state of the users. PF Criteria can provide a controllable rate ratio regardless of the channel condition for each user. However, to achieve the hard fairness, the system capacity degrades sharply.

In [9], Piro et al. proposed a new open-source framework to simulate LTE networks. In this simulator, different scheduling algorithms were developed, these include; proportional fair (PF), exponential proportional fair(EXP-PF), and modified largest weighted delay first (M-LWDF). We will consider the first two algorithms since their fairness and complexity context constitues an extension to algorithms described in [7][8]. We will also compare the performance of these two algorithms to our proposed scheduling algorithm VOSA. we will refer to these two algorithms in the simulations as PF and EXP-PF. Our involvement in [7] is that we only compared the complexity and fairness of our algorithm to algorithm 1 in [7]. Since algorithms in [7] are extension to the algorithms proposed in [9], we also compared the performance of our algorithm to those proposed in [9].

PF: This scheduler was developed in [9] and its main aim is to maximize the total network throughput and to guarantee fairness among flows. It assigns radio resources taking into account both the experienced channel quality and the past user throughput [10]. This scheduler uses the metric which is defined as the ratio between the instantaneous available data rate and the average past rate with reference to the i-th flow in the j-th flow subchannel. This can be depicted in equation 1 obtained from [9].

$$W_{i,j} = \frac{r_{i,j}}{R_{i,j}} \tag{1}$$

where $W_{i,j}$ is the scheduler metric, $R_{i,j}$ is the estimated average data rate, and $r_{i,j}$ is the instantaneous available data rate which is computed by the AMC module, considering the channel quality indicator (CQI) feedback that the UE hosting the i-th flow have sent for the j-th subchannel. It should be also noted that i and j are sub channel flows.

EXP-PF: This scheduler was also developed in [9] and it basically aimed at increasing the priority of real-time flows with respect to non-real-time flows, where their head-of-line packet delay is very close to the delay threshold [11]. Its metrics were computed in [9] using the following equations.

$$W_{i,j} = \exp\left(\frac{\alpha_i D_{HOL,i} - X}{1+\sqrt{X}}\right)\frac{r_{i,j}}{R_{i,j}} \tag{2}$$

and

$$X = \frac{1}{N_{r,t}}\sum_{i=1}^{N_{r,t}} \alpha_i D_{HOL,i} \tag{3}$$

with N_{rt} being the number of active downlink real-time flow. Considering a packet delay threshold T_i, the probability σ_i is defined as the maximum probability that the delay $D_{HOL,I}$ of the head-of-line packet delay exceeds the delay threshold.

Therefore, α_i is given by;

$$\alpha_i = -\frac{\log \alpha_i}{T_i} \tag{4}$$

Equations 3 and 4 proposed in [9], calculates the average summation of the entire down link real time flows based on the probability that the first packet to be transmitted in the queue exceeds the delay threshold. This helps to prioritize down link real time flows.

With all these techniques introduced in the literature, there are still some challenges when real-time traffic like voice is transmitted over an LTE network. This is mostly due to the fading channels of wireless links and the delay and packet loss sensitive voice characteristic. Another issue is that, most of the proposed solutions in the literature are found to be more complex and do not grant fairness between VoIP users. Users which are very close to the base station are assigned more PRBs than those far from the base station.

So, in this work, we analyze the complexity and fairness of our proposed scheduling scheme for VoIP in 3G LTE called VoIP Optimization Scheduling Algorithm (VOSA) [12]. Then compare it with other scheduling algorithms in [8], which are PF and EXP-PF, in order to analyze its performance based on user throughput. The main contribution in this paper that was not discussed in our previous publication is that we analyzed the complexity, fairness, and throughput of our model presented in [12].

The simulation results were generated using the open source LTE system simulator called LTE-SIM [9]. It models different uplink and downlink scheduling strategies in multicell/multiuser environments; taking into account user mobility, radio resource optimization, frequency reuse techniques, the adaptive modulation, and coding (AMC) module. It also includes other aspects that are relevant to the industrial and scientific communities.

Our contributions in this paper are:

- Complexity and fairness analysis of our proposed scheduling algorithm VOSA and compared it with algorithm 1 in [7].
- Performance analysis of VOSA and compared it with algorithms in [9].

The rest of the paper is organised as follows: Section II discusses the VOSA Scheduling algorithm, metric maximization, and describes in summary VOSA algorithm. Section III describes the simulation. Section IV presents complexity and fairness analysis, as well as performance simulation results. Section V reviews the main conclusions.

II. VOSA SCHEDULING ALGORITHM

Our proposed scheduling algorithm and its details can be found in [12]. The main aim of this proposed scheduling algorithm is to improve the QoS of voice traffic when transmitted over an LTE network. At the same time it reduces the negative impact, which may be caused by the introduction of the new algorithm on the entire system's performance. This algorithm is activated at every TTI by considering if there is a VoIP call and if the duration period of the new algorithm has not exceeded the limit. To determine the duration of our new algorithm, we use the adaptive method proposed in [2]. This method provides limits to the *VOSA* which is adaptively changed between a pre-specific minimum and maximum value according to the ratio of dropped packets. Higher drop ratio means that there are many ongoing VoIP calls, and hence, it is necessary to increase the limits to allow more consecutive TTIs to be dedicated to VoIP calls. On the other hand, a low drop ratio implies that QoS of VoIP calls are satisfied at decent levels, and thus, it is safe to reduce the duration of the algorithm and serve other service in the network.

Our scheduling scheme is designed by making modification to the algorithm in [2]. *VOSA* allocates PRBs to VoIP calls based on the arrival time metric. Once the PRBs allocation is done, the scheduling order of the calls is determined by the size of the following factors: Quality feedback (QF) and Queue length (QL) of each call. The better the factor values are, the earlier the corresponding call is scheduled.

A. Metric Maximization

Let $N_{RB,K}$ be the number of resource blocks allocated to the number of users K, T_k be the arrival time associated to k user and $QL_{(k)}$ be the length of k's queue. Every user k sends back the quality feedback value $QF_{(k)} \in \{1,\ldots\ldots, QF^{(max)}\}^{k*1}$ containing supported values for the user k. The maximization of user utility metrics can be formulated as follows:

$$MAX \sum_{n=1}^{K} U\left(\frac{QF_k QL_k}{N_{RB,k}}\right) \tag{5}$$

where $QL_{(k)} \geq 1$

U ($QF_{(k)}$ $QL_{(k)}$) is the user utility as a function of two main metrics (QF and QL), given the allocation of resource block $H_{RB,N}$ to user k.

1. Quality Feedback:

In order to obtain quality feedback metric, we used the Time-domain proportional fair method [TD-PF] [13] and it is obtained from the equation below.

$$QF_{k,j}[t] = \frac{R_{k,j}[t]}{Th_{k,j}[t]} \tag{6}$$

where:

$QF_{k,j}[t]$ - Quality feedback Metric for user 'k' in the channel 'j' in the instant't'

$R_{k,j}[t]$ - Shannon Channel Quality Indicator (CQI) of user 'k' in the channel 'j' in the instant 't'

$Th_k[t]$ - Average delivered user throughput, it is calculated based on the transmitted signal's SINR

2. Queue Length**:**

In order to obtain Queue length metric, we adopted the queuing method in the LTE-SIM simulator. Different traffic generators were developed, these generated packets that are transported by a dedicated radio bearer at the application layer. Using the application class, we were able to generate the packets and deliver them to the network. Once the packets reach the network, they are forwarded to the user-plane protocol stack to add protocol headers.

Then, the packets are placed in the queue by the MAC queue class at the MAC layer before being sent to the destination. The MAC queue object have got a counter which increases or decreases when the packet is inserted or removed from the queue respectively. Based on the counter in the MAC queue object, the queue length metric is determined. It should be noted that different MAC queue objects can be created in order to facilitate different traffic types.

$$QL_k = m\_queuesize + N\_datapackets * 8 \tag{7}$$

where 8 is the packet overhead due to, Radio Link Control (RLC) (2bytes), MAC headers (3 bytes) and Cyclic Redundancy Check (CRC) (3 bytes).

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B. *Summary of VOSA Algorithm*

This algorithm performs the scheduling operation based on the user utility metrics and the better the metrics are, the earlier the call is scheduled. Its operation includes the following steps:

- Indentify the traffic type whether voice or any other traffic
- Determine the user utility metrics (QF,QL)
- Find the user with the highest user utility metric as defined in equation 5
- Consider the set of available resource blocks RBs N_{avail_RB}, at every start of the algorithm , N_{avail_RB} = {1,2,…….., N_{RB}}
- Assign the resource block N* to the user k* with the highest user utility metrics value such that $N_{RB,}k^*$ = $N_{RB,}k^*$ U {N*}
- Schedule the user k* first
- Delete the user k* and resource block N* from their respective lists
- Repeat all the steps until all users are scheduled and if more resource block exists then allocate them to other traffic types

III. SIMULATION SETUP

A. *PRB Characteristics*

In this sub-section, we introduce the characteristics of PRBs, which are the transmission resources. LTE systems consists of both a time and a frequecy planes. The time plane is divided into 1 ms TTI, which consists of two slots of 0.5 ms to form 1 ms sub frames, where each sub frame contains 7 OFDMA symbols.

In each TTI, there are 14 OFDMA symbols, where 2 symbols out of 14 are reserved for uplink pilot transmission, while the other 12 symbols are used for data and control information transimission. TTI can be defined as the minimum allocation unit in the time domain [12]. If we consider the frequency plane, the minimum allocation unit is the PRB, where each PRB contains 12 subcarriers of 15 Khz bandwidth each.

The number of OFDMA symbols in a resource block depends on a cyclic prefix being used. All these can be depicted in Fig. 1. It must be noted that VoIP packets must be transmitted per TTI and they can occupy one or more PRBs [5]. The amount of data bits that can be transmitted by one PRB depends on the link between the eNodeB and the user mobile terminal. This is due to the fact that 3G LTE uses adaptive modulation and coding (AMC), which changes modulation and coding schemes depending on the wireless link conditions.

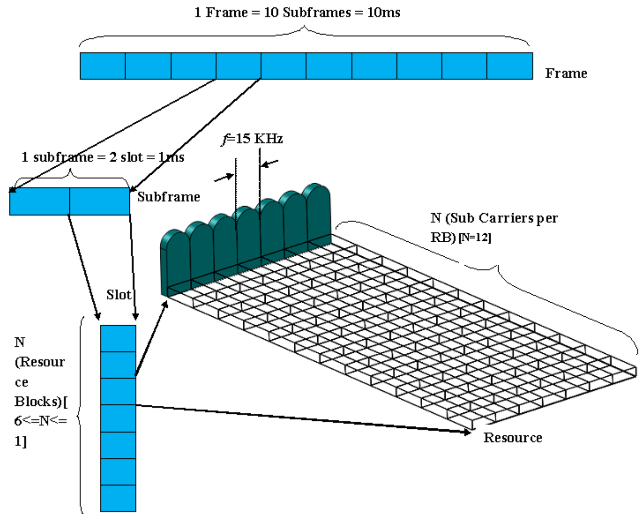

Figure 1. The structure and allocation of the eNodeB transmission resources symbols.

B. *Scenario Setup*

Our network topology is made up of a set of cells and different network nodes which include; the EnodeB, mobility management/gateway (MME/GW), and user equipements (UEs). All the simulations were run in a three tier diamond-pattern macro scenario with 19-3-sector sites which totaled to about 57 cells. Most of the simulation parameters are presented in the table 1 below. VoIP flows are generated by the traffic generator in LTE-SIM called VoIP application which generates G.729 voice flows. The voice flow has been modelled with an ON/OFF Markov chain. The ON period is exponentially distributed with a mean value of 3s and the OFF period has a truncated exponential probability density function with an upper limit of 6.9s as well as an average value of 3s [9].

During the ON period, the source sends 20bytes sized packets every 20 ms which implies that the source data rate is 8 kb/s, on the other hand during the OFF period the rate is zero because the presence of voice activity detector is assumed. Three different scheduling algorithms were used in all simulation scenarios, these are: our proposed VOSA as well as EXP-PF and PF developed in [9].

IV. DISCUSSION AND PERFORMANCE ANALYSIS

A. *Complexity Analysis*

Our proposed algorithm performs the scheduling operation after searching the user with highest utility metrics based on QF and QL. Therefore, the complexity to schedule the first user is O(KN), this will be the complexity for the first iteration. The complexity to schedule the second user is O((K-1)N) and so on.

In our algorithm, the number of iterations depends on the number of users K. As there are K iterations, the overall algorithm complexity can approximately be expressed as

$O(K^2N)$. This implies that there is a second order complexity in the number of users based on QF, QL metrics and there is also linear complexity in resource blocks N. This is due to the fact that there is no search done on the resource blocks, any available resource block is assigned to the user with highest metric.

If we compare our algorithm to algorithm 1 in [7] that has a linear complexity in the number of user and quadratic complexity in the number of resource block, i.e., '$O(N^2K)$', it is clear that our algorithm will only outperform it when the number of users are few since it will perform less iterations however when the number of users increases, algorithm 1 in [7] performs better.

TABLE 1. SIMULATION PARAMETERS

Simulation Parameters	Values
Bandwidth	5MHZ
PRB Structure	12subcarriers,2subframes
TTI	1msec
Number of available PRBs	25
Modulations for AMC	QPSK
Number of sectors	3
Simulation time	1000 TTIs
Cyclic prefix	Normal
Scheduling algorithms	VOSA,EXP-PF, and PF
Cell radius	1 km

B. Fairness Analysis

The fairness aspect is introduced mainly to solve the resource starvation problem, where users close to the base station are allocated more resources and edge users generally suffer from resource starvation [7]. Fairness can be describes as a loose concept which implies that all users are allocated equal amount of resources in order to meet the QoS requirements. From the fairness point of view, we compared our algorithm with PF and EXP-PF developed in [9]. Their fairness and complexity context constitues an extension to algorithms described in [7][8] and they are also the bench mark schedulers in the simulator that we used. We measured the fairness index of all the scheduling schemes. As seen in Fig. 2, fairness index decreases as the number of users increases. The fairness index of VOSA is higher than that of PF but lower than EXP-PF.

It should be noted that the main advantage of VOSA scheduling algorithm is to improve the QoS of voice traffic when transmitted over an LTE network. At the same time it reduces the negative impact which may be caused by the introduction of the new algorithm on the entire system's performance. However, when we consider fairness and performance analysis, EXP-PF out performs VOSA due to the following reasons;

EXP-PF employs the fairness concept in [7], which uses the algorithmic utility function that is associated with proportional fairness of the utility based optimization. This helps in achieving a better fairness factor. Also, during the allocation scheme, EXP-PF erases all the packets belonging to the real time flow from the MAC queue if they are not transmitted before their deadline expiration. This helps to improve its performance by avoiding the waste of resources such as bandwidth.

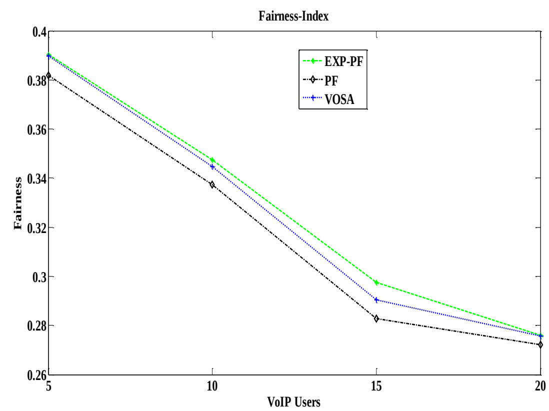

Figure 2. Fairness Index Comparison

C. Performance Analysis

Performance analysis was made by measuring user throughput for all three schedulers. As it can be seen in Fig.3, throughput decreased as the number of VoIP users increased in all algorithms.This is mainly due to the fact that some VoIP packets were being dropped as the number of users were being increased which resulted in the less utilisation of all assigned PRBs.

It is well known that VoIP packets are small packets; hence, many packets are needed to fully utilize the available PRBs. However, as congestion increased in the network, it led to VoIP packets to be dropped which led to less utilization of the available PRBs.

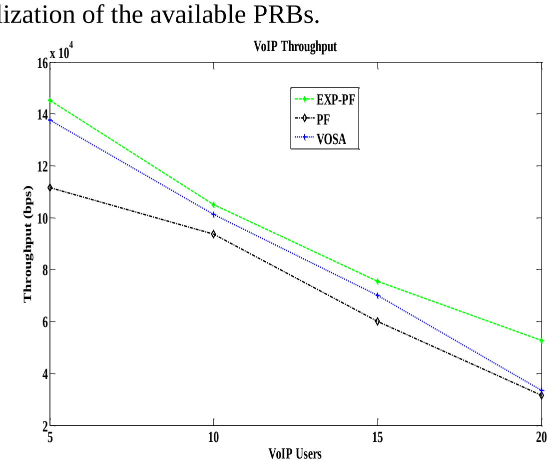

Figure 3. Throughput Comparison

V. CONCLUSION AND FUTURE WORK

In this paper, we analyzed the complexity and fairness factor of our proposed scheduling algorithm VOSA. Through simulations, we were able to compare it with other scheduling algorithms in literature. It was analyzed that VOSA performs better when the number of users is small since it schedules users after searching the user with highest utility metrics based on QF and QL and the search goes on for all available users. So the small the number of users, the few search iterations done and hence the better performance. However, VOSA performed better than PF but slightly lower than EXP-PF.

In future work, we will try to employ different tests such as real life scenarios in order to analyze the practicability of our results and to make them more reasonable. We are also working on the way of optimizing our scheduling algorithm such that we lower its complexity by just performing one main search throughout all the available users and store the data for each user separately. This would make it more scalable since a single iteration is performed.

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