AlQalam
Alq J Med App Sci
https://journal.utripoli.edu.ly/index.php/Alqalam/index eISSN 2707-7179

Original article

Fairness-Aware Radio Resource Management in OFDMA-Based Wimax Networks with Comparison Between Three Downlink Scheduling Algorithms

Osama Shibani, Arebi Yakhlef*, Ayoub Alazzabi

Department Electrical Engineering, Higher Institute of Industrial Technology, Tripoli El Negela, Libya

ARTICLE INFO

Corresponding Email:arebi1978@gmail.com

Received: *11-05-2024*
Accepted: *13-07-2024*
Published: *29-07-2024*

Keywords. *Fairness Index, Wireless Networking, Wimax Networks, Max Rate Algorithm, System Throughput.*

ABSTRACT

This study focuses on managing equity-conscious radio resources in OFDMA-based WIMAX networks with comparison of three algorithms, Max Rate, RR and PFS. Hence WiMAX Forum has been formed, which promotes the technology and provides compatibility and teroperability for 802.16-based products. The problem in heterogeneous WiMAX, users may possess different transmit power capabilities and experience independent channel realizations. As a result, those with lower power Capabilities or poor channel conditions will starve throughput share. It is observed that users with better channel conditions always dominate usage of the spectrum, causing low throughput for users with poor channel conditions. This paper studied the performance of downlink scheduling algorithms that perform radio resource allocation in order to improve the performance of the WiMAX system. These algorithms are Max Rate, Round Robin, and Proportional Fair. In addition, scheduling algorithm was implementing in order to explain the fairness concept. The algorithms were comparing to each other in terms of system throughput and fairness index. The performance evaluations are carrying out using MATLAB software. Simultaneous results show that the most suitable scheduling algorithm in terms of fairness index and system throughput for the WiMAX network is proportional fair. Meanwhile, Max Rate provides the highest throughput, even though the number of users is increased.

Cite this article. *Shibani O, Yakhlef A, Alazzabi A. Fairness-Aware Radio Resource Management in OFDMA-Based Wimax Networks with Comparison Between Three Downlink Scheduling Algorithms. Alq J Med App Sci. 2024;7(3):606-614.* https://doi.org/10.54361/ajmas.247324

INTRODUCTION

The fairness is a crucial issue in wireless networking technologies and it is a desirable property, which offers protection between users in the wireless network [1-3]. Achieving fairness in a network can ensure no negative impact of the traffic flow of user by the traffic flow of an ill-behaving user [4]. The system might be fair or unfair based on whether or not this system meets some criteria such as delay or throughput [5-7]. For instance, if the user experiencing a delay less than t has a probability greater than p, the system is said to be unfair while fairness can be achieved if the probability is less than p [8-10]. Another example related to users who receive a throughput of more than r bits/sec, the scheduling algorithm may be said to be fair in this case and unfair otherwise. The aim behind the fairness concept is to see if a value for the fairness of a scheduling algorithm can be defined in a similar manner to how Shannon defined a value for the information of a source [11-14]. Fairness measures are based on proportions of allocated resources and it can be evaluated by two ways, equal and unequal weighted users [15-18].

METHODS

Fairness concept Fairness is a crucial issue in wireless networking technologies and it is a desirable property that offers protection between users in the wireless network. Achieving fairness in a network can ensure no negative impact of the traffic flow of user by the traffic flow of an ill-behaving user. The system might be fair or unfair based on whether or not this system meets some criteria such as delay or throughput. For instance, if the user experiencing a delay less than t has a probability greater than p, the system said to be unfair while fairness can be achieved if the probability is less than p. Another example related to users who receive a throughput of more than r bits/sec, the scheduling algorithm might be said to be fair in this case and unfair otherwise. The aim behind the fairness concept is to see if a value for the fairness of a scheduling algorithm can been define in a similar manner to how Shannon defined a value for the information of a source. Fairness measures based on proportions of allocated resources and it can be evaluated by two ways, equal and unequal weighted users.

Fairness Index

Fairness Index is a metric used to determining equality of resource sharing among users of the same application models. Jain's fairness (Jain, 1984) index is an example that be used to get a fairness among users based on the following equation [19, 20]

$$F(x_1, x_2, x_n) = \frac{(\sum_{i=1}^{n} xi)^2}{n\sum_{i=1}^{n} x_i^2} \ldots\ldots\ldots\ldots (1, 1)$$

Where n is the number of users and xi is the throughput for it link, when subscribers receive the same allocation, the fairness has a maximum value. The fairness range starts from 1/n, which is the worst case up to 1 which represents the best case.

WiMAX Scheduling Algorithms

1. Round Robin (RR) scheduling algorithm assigns an equal portion of time slots to each MS in order, handling all MSs as having the same priority. The RR algorithm allows every MS to transmit or receive at regular interval on the shared channel, which is share by many stations in wireless networks. Based on this property, RR may appear as a fair algorithm. RR algorithm hardly provides very good service to the MS due to its low efficiency compared with other scheduling algorithms such as Proportional Fair Scheduling (PFS). RR is the simplest scheduling algorithm and easy to implement, but this algorithm does not take into account the changing reception conditions at the different 25 receivers or the multiuser diversity. Consequently, when their reception conditions are worse than average, RR will schedule transmissions from/to subscriber’s half of the time.
2. Max Rate As a channel dependent scheduling, Max Rate algorithm is able to achieve maximum system throughput by taking advantages of multiuser diversity. First, the scheduler obtains data rate of an identical sub-channel for different terminals by analyzing Channel State Information (CSI) from these terminals. After that, the scheduler assigns this sub-channel based on SNR to the terminal that can achieve the highest data rate in this sub-channel. The Max Rate algorithm can be mathematically denoted as:

$$i = \arg\max Rk, n(t) \ldots\ldots\ldots\ldots (1.2)$$

Where Rk, n(t) represents the data rate of terminal k for one sub-channel n in time slot t. Max Rate is not a fair algorithm because it does not consider the terminals which have bad channel conditions. In terms of throughput, Max Rate is an efficient scheme to maxims total throughput.
3. Proportional Fair scheduling algorithm an ideal system, there are two issues that should considered implementing the idea of multiuser diversity: fairness and delay. When users’ fading statistics are the same as in the ideal case, the strategy above maximizes both the throughput of individual users and the total capacity of the system. In reality, since users have different channel conditions, the statistics are not symmetrical, some users are moving and others are stationary. Some users are facing scattering environment while others with no caterers around them, some users are closer to the BS with a good average SNR. In addition, the planning is concerned with maximizing long-term average throughputs. There are latency requirements where the average throughputs over the delay time scale is the performance

metric of interest. Addressing these issues and 26 exploiting the multiuser diversity gain inherent in a system are the main challenge as the users have different channel conditions that fluctuate independently.

To meet this challenge, a simple scheduling algorithm called Proportional Fair Scheduling (PFS) has designed for OFDMA-based system. In this system, the requested data rate Rk,n(t) represent the feedback of the channel quality of user k in time slot t to the BS, this data rate is supported by the kth user's n sub-carrier. The working principle of PFS was discussing as follows. For each user there is an average throughput $Tk,n\ (t)$ on every sub-carrier in a past window of length tc , PFS keeps track of $Tk,n\ (t)$, the scheduling algorithm transmits at each sub-carrier in time slot t to the user k* with the largest

$Rk,n(t)\ Tk,n(t)$ ………………………..……………………………. (1.3)

Among all active users in time slot t, where $Rk,\ (t)$ = log (1 + $SNRk,\ (t)$) is the applicable rate of user k in time slot t, equation (1.4) is an updating process of the average throughput $Tk,\ (t)$ by using an exponentially weighted low-pass filter

$T\ k$,n $(t + 1)$ = (1 − 1/t_c) $Tk,n\ (t)$ + 1/t_c $Rk,n\ (t)$ $k = k*$ ……………………… (1.4)

$T\ k$,n $(t + 1)$ = (1 − 1/t_c) $Tk,n\ (t)$ $k \neq k*$ ……………………………………… (1.5)

The implemented PFS algorithm in an OFDMA uses the equation (1.3) in order to calculate the largest value for the user, the calculation process performed at each sub-carrier and time slot to allocate this sub-carrier to that user. At the same time, there is an updating mechanism at each sub-carrier and time slot for the users' average throughput by equations (1.4) and (1.5), the conventional power allocation and users' rate requirements are not considering by PFS, the reason for that related to system performance degradation due to weak points when employed in heterogeneous user channel environment. In this study, an equal power value was considering among the subcarriers.

The principles working of PFS algorithm can be explain more by 27 observing figure 1 frequency channel response is plotted as a function in equal and unequal fading statistics scenarios for two users [21, 22].

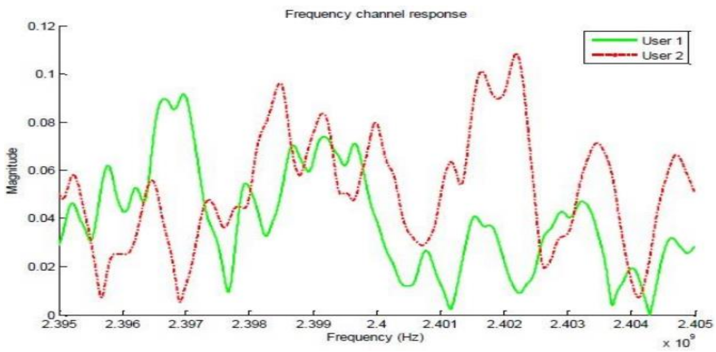

Figure 1. The frequency channel response

The fading statistics in Figure 1 are identical for two users. The throughput for each user converges to the same value when the scheduling time scale tc is much larger than the correlation time scale of the fading dynamics. Hence, the user with the highest requested rate will be pick by reducing the scheduling algorithm; PFS algorithm in the long term becomes very fair as every user is serving when his channel is good. There is a multipath fading responsible for channel fluctuation for both users in Figure 2 This fading is mainly due to different distances from the BS. It can be notice that one channel is stronger than another channel. Therefore, all the resources will be assigned to the user who has a strong channel condition while leaving the weak user out. As a result, the system will be highly unfair, the parameter tc coupled to the latency time scale of the application. Peaks are defined with respect to this time scale, the scheduler can afford to wait longer when the latency time scale is large before scheduling a user when his channel has a really high peak. The resource assignment according to PFS algorithm is decide solely by instantaneous SNR when tc value is infinity, in this case, the system will be highly unfair with maximized throughput. On the other hand, the system can be fair when the lower value of tc is one. Hence, the trade-off between throughput and fairness could be obtain by controlling the tc value.

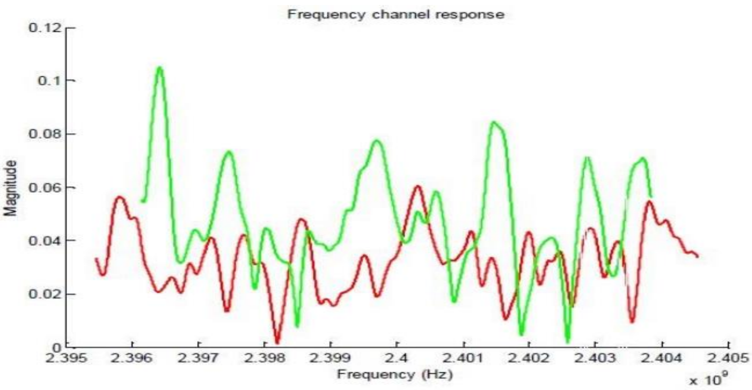

Figure 2. Frequency channel response for unequal users

The resource allocation procedures in PFS algorithm are as follows [23-26]:
1. Assign a value to the average throughput Tk, n (t).
2. Compute Rk, n (t) by using the following equation
Rk,n (t) = B/N log2(1 + SNR) ………………………………….. (1.6)
Where B represents the bandwidth while N represents the number of subcarriers.
3. Calculate (R_(k,n) (t))/(T_(k,n) (t))
4. When (R_(k,n) (t))/(T_(k,n) (t)) is maximum, then schedule the users.
5. Update the average throughput Tk, n (t) based on equations (1.3) and (1.4).

RESULTS AND DISCUSSION

System Throughput and Fairness Index

The obtained throughput and fairness results shown based on the number of subscribers. The manual scheduling algorithm started from 2 to 20 users who are randomly distributed in a WiMAX single cell as indicated in figure 3. During the execution, the distribution will be different from the previous case. Hence, a new data rate value computed based on the new channel gain, which affected by the distance from the centralized BS.

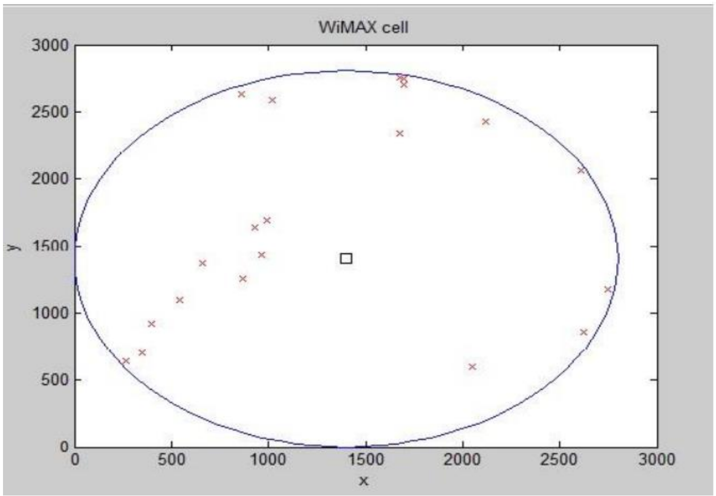

Figure 3. Randomly users are distributed in a WiMAX single cell

The next figures will show that, obtained throughput before and after applying manual fairness algorithm. When the number of subscribers that served by WiMAX system is limited, the shared radio resources considered highly fair. By increasing the number of users, fairness among them become a critical issue. Figures 4&5 indicate that it is possible to guarantee a certain degree of fairness with small number of subscribers, this leads to fairness of radio resource sharing. Hence, the data rate is approximately same for all users regardless the distances from the BS.

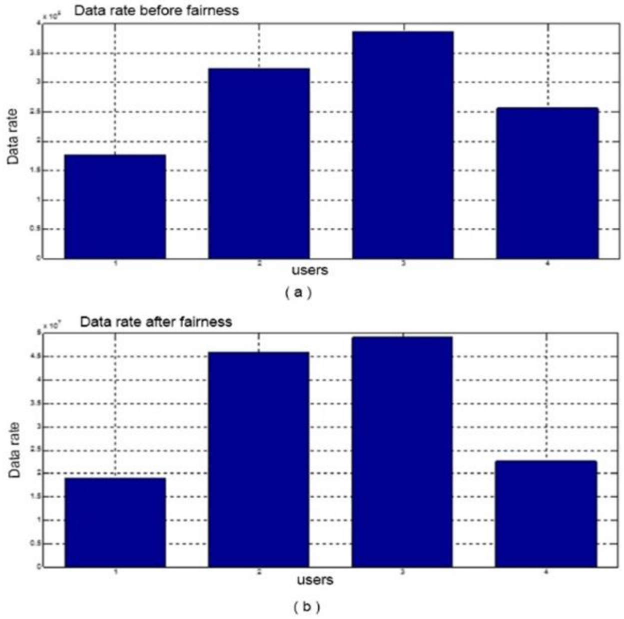

Figure 4. (a) Throughput of 4 users before applying fairness algorithm (b) Throughput of 4 users after applying fairness algorithm

Figures 5 illustrate the fact that manual scheduling algorithm does not have the ability to keep a certain level of fairness when the number of subscribers increases. By assigning subcarriers among users, the fairness cannot be guaranteed since the channel conditions keep changing and subscribers distributed randomly. As a result, the assigned subcarriers may not be enough for some users to achieve a desired fairness level.

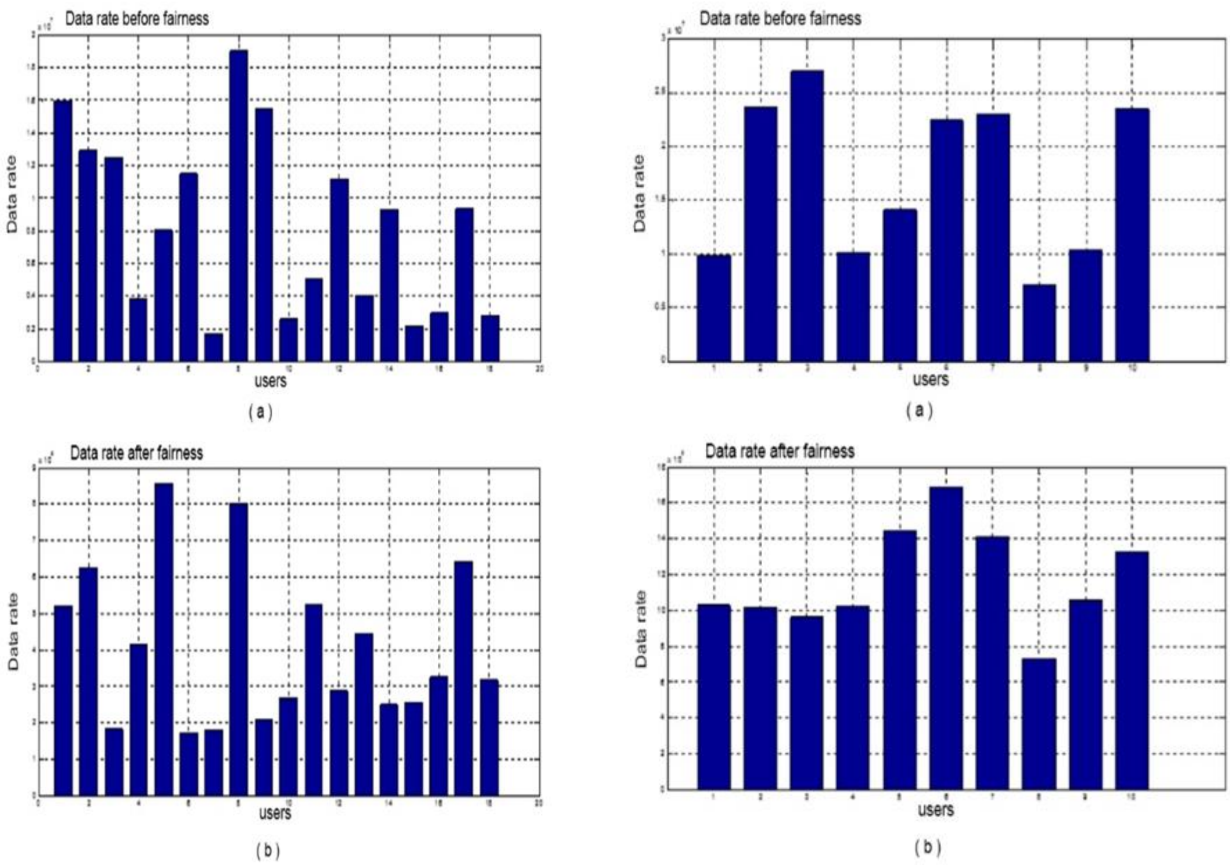

Figure 5. (a) Throughput of 10 & 18 users before fairness algorithm, (b) Throughput of 10 & 18 users after fairness algorithm

The system throughput and fairness index results before and after the fairness algorithm are represented in Figures 6 a &b, shows the fairness algorithm prevents the user who has high data rate from some subcarriers which have been assigned to another one to achieve a certain level of fairness, this leads to an inverse relationship between system throughput and fairness index. It is possible to guarantee sharing of radio resources with limited subscribers, but the challenge is how to keep on with the same fairness level since the random distribution of users affects the system performance. This is one of the disadvantages of this method where the algorithm should be executing many times.

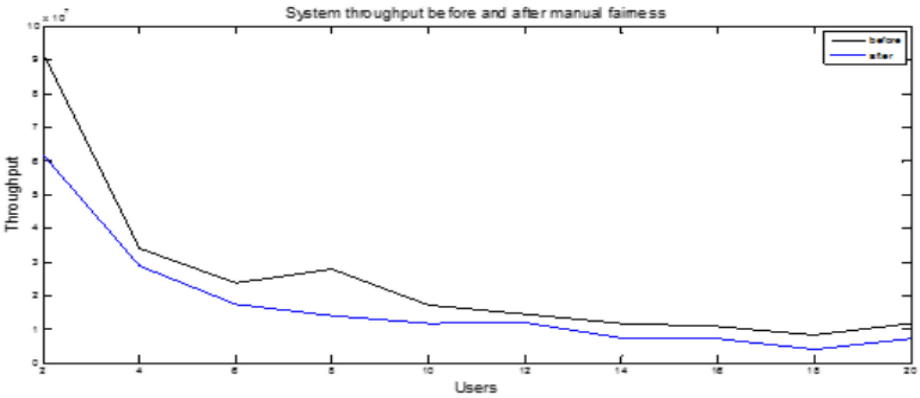

Figure 6a. Throughput before and after fairness algorithm

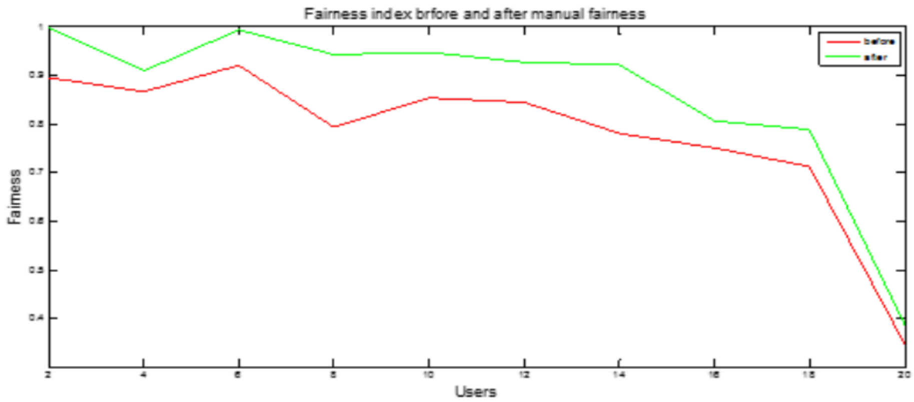

Figure 6b. Fairness before and after fairness algorithm

Downlink Scheduling Algorithms

In this section, Max Rate, RR and PFS are implement and compared with each other based on system throughput and fairness. MATLAB simulations is using in order to analyze the performance of these algorithms. To measure the fairness, an arbitrary period was need, so a 100 time slots will be consider evaluating the fairness index. System Throughput and Fairness index. The simulation results in terms of fairness for different sets of users are show in Figure 7.

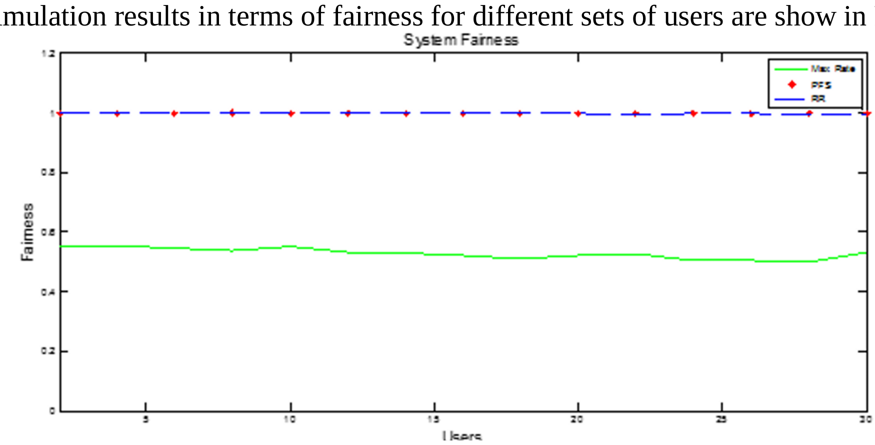

Figure 7. System fairness index

The RR and PFS algorithms have good results, since they depend on the tc parameter. The PFS algorithm achieves high fairness without sacrificing system throughput when tc value is low. The Max Rate algorithm allocates the system resource to the subscribers who have the highest channel gains. Therefore, when a large number of users are demanding the service from the WiMAX system, the Max Rate algorithm will only serve the users who have the same channel conditions and this is the reason for the lower fairness index achieved by this algorithm.

According to the system throughput, the Max Rate algorithm produces the best result due to the working mechanism where the system resources are allocating to subscribers who have the highest channel gains. At the same time, the Max Rate algorithm maximizes the system throughput. With a large number of users, the throughput increases due to the high probability of getting channel stronger when there are much more users.

The RR scheduling algorithm has achieved the lowest value compared with the other algorithms. According to the RR algorithm, all subcarriers are allocating to one user at each time slot independently of users' channel response and rate requirements. At the same time, the RR algorithm does not take into account the effect of multiuser diversity. Since the propagation channels between the BS and MSs are independent from each other, the PFS algorithm exploits this effect of multiuser diversity. The PFS has achieved a good level of system throughput without compromising fairness as 42 indicated in Figure 8. The competition among users is not directly depending on their SNRs but only by their respective average throughputs, compared with the Max Rate algorithm, the PFS has obtained a lower throughput because it manages to achieve a good fairness.

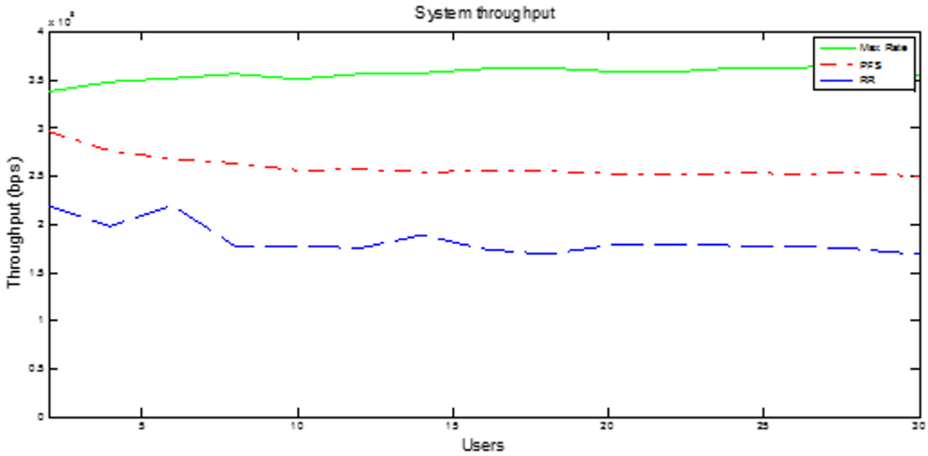

Figure 8: System throughput

CONCLUSION

In this paper, two algorithms were implemented to achieve a certain degree of fairness among different groups of users in a single cell. The purpose of the first algorithm was to perform manual subcarriers allocation where the subcarriers are allocating based on the previous throughput of users. The second algorithm was implemented with three different downlink schedule algorithms by considering an OFDMA scenario. The Max Rate algorithm always assign resources to the users who have the large SNRs, the RR assigns time slots to each MS in equal portions whereas the PFS algorithm keeps track of the average throughput of each user for each subcarrier and assigns resources to the user who has the largest throughput based on equation 3.2. The three-downlink algorithms were comparing with each other in terms of system throughput and fairness index. Based on the obtained results, manual scheduling algorithm is efficient with a small number of users, however the Max Rate algorithm is lack of fairness feature but it provides higher throughput when the WiMAX serves more subscribers. The RR and PFS algorithms are able to achieve the best fairness indices, and at the same time, the PFS algorithm provides good system throughput compared with the RR. 45 In conclusion, the FS is the sufficient scheduling algorithm that can be using in WiMAX system since it has a good level of system throughput without compromising fairness.

Conflict of interest. Nil

REFERENCES

1. Jun J, Sichitiu ML. Fairness and QoS in multihop wireless networks. In: 2003 IEEE 58th Vehicular Technology Conference. VTC 2003-Fall; 2003 Oct; Vol. 5. p. 2936-2940. IEEE.

2. Kanellopoulos DN. Recent progress on QoS scheduling for mobile ad hoc networks. J Organ End User Comput. 2019;31(3):37-66.
3. Luo C, Guo S, Guo S, Yang LT, Min G, Xie X. Green communication in energy renewable wireless mesh networks: routing, rate control, and power allocation. IEEE Trans Parallel Distrib Syst. 2014;25(12):3211-3220.
4. Reid C. Achieving soft real-time guarantees for interactive applications in wireless mesh networks [master's thesis]. Waterloo (ON): University of Waterloo; 2008.
5. Choi JG, Bahk S. Cell-throughput analysis of the proportional fair scheduler in the single-cell environment. IEEE Trans Veh Technol. 2007;56(2):766-778.
6. Zhu Z, Peng J, Gu X, Li H, Liu K, Zhou Z, Liu W. Fair resource allocation for system throughput maximization in mobile edge computing. IEEE Access. 2018;6:5332-5340.
7. Shreedhar M, Varghese G. Efficient fair queuing using deficit round-robin. IEEE/ACM Trans Netw. 1996;4(3):375-385.
8. Caire G, Muller RR, Knopp R. Hard fairness versus proportional fairness in wireless communications: The single-cell case. IEEE Trans Inf Theory. 2007;53(4):1366-1385.
9. Qi J. Mitigating delays and unfairness in appointment systems. Manage Sci. 2017;63(2):566-583.
10. Avi-Itzhak B, Levy H, Raz D. Quantifying fairness in queuing systems: principles, approaches, and applicability. Probab Eng Inform Sci. 2008;22(4):495-517.
11. Liu X, Chong EK, Shroff NB. Transmission scheduling for efficient wireless utilization. In: Proceedings IEEE INFOCOM 2001. Conference on Computer Communications. Twentieth Annual Joint Conference of the IEEE Computer and Communications Society (Cat. No. 01CH37213); 2001 Apr. Vol. 2. p. 776-785. IEEE.
12. Suri S, Varghese G, Chandranmenon G. Leap forward virtual clock: a new fair queuing scheme with guaranteed delays and throughput fairness. In: Proceedings of INFOCOM'97; 1997 Apr. Vol. 2. p. 557-565. IEEE.
13. Hassel V, Hanssen MR, Oien GE. Spectral efficiency and fairness for opportunistic round robin scheduling. In: 2006 IEEE International Conference on Communications; 2006 Jun. Vol. 2. p. 784-789. IEEE.
14. Zhang Z, He Y, Chong EK. Opportunistic scheduling for OFDM systems with fairness constraints. EURASIP J Wirel Commun Netw. 2008;2008:1-12.
15. Jain RK, Chiu DMW, Hawe WR. A quantitative measure of fairness and discrimination. East Res Lab, Digital Equip Corp, Hudson, MA. 1984;21(1).
16. Huaizhou SH, Prasad RV, Onur E, Niemegeers IGMM. Fairness in wireless networks: issues, measures and challenges. IEEE Commun Surv Tutorials. 2013;16(1):5-24.
17. Lan T, Kao D, Chiang M, Sabharwal A. An axiomatic theory of fairness in network resource allocation. In: IEEE; 2010. pp. 1-9.
18. Argyris N, Karsu Ö, Yavuz M. Fair resource allocation: using welfare-based dominance constraints. Eur J Oper Res. 2022;297(2):560-578.
19. Jain RK, Chiu DMW, Hawe WR. A quantitative measure of fairness and discrimination. Hudson (MA): Eastern Research Laboratory, Digital Equipment Corporation; 1984.
20. Bahillo Martinez A. Evaluation of multiuser scheduling algorithm in OFDM for different services [master's thesis]. Trondheim (Norway): NTNU; 2006.
21. Kim YY, Li SQ. Capturing important statistics of a fading/shadowing channel for network performance analysis. IEEE J Sel Areas Commun. 1999;17(5):888-901.
22. Wu M, Li K, Kwong S, Zhang Q. Evolutionary many-objective optimization based on adversarial decomposition. IEEE Trans Cybern. 2018;50(2):753-764.
23. Choi JG, Bahk S. Cell-throughput analysis of the proportional fair scheduler in the single-cell environment. IEEE Trans Veh Technol. 2007;56(2):766-778.
24. Zhu Z, Peng J, Gu X, Li H, Liu K, Zhou Z, Liu W. Fair resource allocation for system throughput maximization in mobile edge computing. IEEE Access. 2018;6:5332-5340.
25. Shreedhar M, Varghese G. Efficient fair queuing using deficit round-robin. IEEE/ACM Trans Networking. 1996;4(3):375-385.
26. Caire G, Muller RR, Knopp R. Hard fairness versus proportional fairness in wireless communications: The single-cell case. IEEE Trans Inf Theory. 2007;53(4):1366-1385.

https://journal.utripoli.edu.ly/index.php/Alqalam/index eISSN 2707-7179

إدارة الموارد اللاسلكية في شبكات Wimax المعتمدة على OFDMA مع مقارنة بين ثلاث خوارزميات لجدولة الارتباط الهابط

أسامة شيباني، عريبي يخلف*، أيوب العزابي

قسم الهندسة الكهربائية، المعهد العالي للتكنولوجيا الصناعية، طرابلس النجيلة، ليبيا

المستخلص

تركز هذه الدراسة على إدارة موارد الراديو التي تراعي المساواة في شبكات WIMAX المستندة إلى OFDMA من خلال مقارنة ثلاث خوارزميات، Max Rate وRR وPFS. ومن ثم تم تشكيل منتدى WiMAX ، الذي يروج للتكنولوجيا ويوفر التوافق والتشغيل المتبادل للمنتجات المستندة إلى 802.16. تكمن المشكلة في شبكات WiMAX غير المتجانسة في أن المستخدمين قد يمتلكون قدرات طاقة إرسال مختلفة ويختبرون تحقيقات قناة مستقلة. ونتيجة لذلك، فإن أولئك الذين لديهم قدرات طاقة أقل أو ظروف قناة سيئة سوف يعانون من نقص في حصة الإنتاجية. وقد لوحظ أن المستخدمين الذين لديهم ظروف قناة أفضل يسيطرون دائمًا على استخدام الطيف، مما يتسبب في انخفاض الإنتاجية للمستخدمين الذين لديهم ظروف قناة سيئة. درست هذه الورقة أداء خوارزميات جدولة الارتباط الهابط التي تقوم بتخصيص موارد الراديو من أجل تحسين أداء نظام WiMAX. هذه الخوارزميات هي Max Rate و Round Robin و Proportional Fair. بالإضافة إلى ذلك، تم تنفيذ خوارزمية الجدولة من أجل شرح مفهوم الإنصاف. تمت مقارنة الخوارزميات مع بعضها البعض من حيث معدل إنتاجية النظام ومؤشر العدالة. يتم إجراء تقييمات الأداء باستخدام برنامج MATLAB. تظهر النتائج المتزامنة أن خوارزمية الجدولة الأكثر ملاءمة من حيث مؤشر العدالة ومعدل إنتاجية النظام لشبكة WiMAX هي خوارزمية عادلة متناسبة. في الوقت نفسه، توفر Max Rate أعلى معدل إنتاجية، على الرغم من زيادة عدد المستخدمين.

الكلمات المفتاحية. مؤشر الإنصاف، الشبكات اللاسلكية، شبكات Wimax ، خوارزمية الحد الأقصى للسرعة، معدل إنتاج النظام.