IEEK Transactions on Smart Processing and Computing

Improved Scheduling Approach IN SC-FDMA

Saleh.y.elshakwi and Tarek Abdulrahman

Wireless Communication Center, University of Technology Malaysia / Johor, Malaysia
chakwi44@gmail.com, tarek@utm.fke.com.my

***** Corresponding Author: Saleh.y.elshakwi

Received July 14, 2013; Revised July 29, 2013; Accepted September 12, 2013; Published December 31, 2013

** Regular Paper*

Abstract**:** Single Carrier Frequency Domain Multiple Access (SC-FDMA) has proven to be the best long term evolution for uplink multiple access because of its low Peak to Average Power Ratio (PAPR), a feature that leads to low power consumption. This is achievable only if the resource allocation is performed in a contiguous manner. This paper proposes a new approach with an improvement in the global resources allocation. The new approach presented utilizes the gain function, which adopts some of the procedures deduced from the older Recursive Maximum Expansion (RME) algorithm. The experiment proved that the new approach is better than the original RME algorithms and in most cases, is closer to the optimal solution.

Keywords**:** Resource allocation, Scheduling algorithms, LTE uplink, SC-FDMA, Contiguity

1. Introduction

The Long Term Evolution (LTE) network consists of base stations (BS) called Evolved Node B (eNodeB) and user equipment (UE). One of the functionalities, which has been moved to eNodeBs, is Radio Resource Management (RRM), which plays a key role in LTE networks. The scheduler in a LTE network is responsible for allocating shared radio resources among the UE. The decisions taken by the scheduler in the eNodeB rely on a number of factors, such as the type of traffic flow running over the LTE interface and the channel condition. These factors provide awareness to the scheduler. The channel condition must be known per UE to adapt the transmission in both uplink and downlink directions.

The correct exploitation will maximize the UE diversity because only UE experiencing good channel conditions will be mapped to the Resource Block (RB). Therefore, the awareness of the channel condition is significant in the scheduler design. The Signal to Noise Ratio (SNR) is used as one of judges in the election criteria. Regarding the standard, the 3rd Generation Partnership Project (3GPP) chose the Single Carrier Frequency Division Multiple Access (SC-FDMA) as the uplink access scheme for the Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE) owing to its low Peak-to-average Power Ratio (PAPR) [1-4]. To keep the PAPR low, the RBs are assigned in a contiguous manner. The contiguity paradigm is the key design in many proposed algorithms in SC-FDMA due to the contiguous allocation constraint of the scheduling design. The problem was proven to be a difficult Non-deterministic Polynomial (NP) hard problem [5] because finding the optimal solution can be exhausting.

The scheduling algorithms require a resource allocation matrix as the input, which requires the formulation of the matrix. The formulation was performed using two paradigms: proportional fairness (PF) and channel-dependent (CD) paradigms. LTE uses a channel sounding technique that allows the eNodeB to monitor the channel condition of all UE over the entire bandwidth [8]. Each single UE sends periodically (1m/s) a sounding reference signal (SRS) to the eNodeB, which extracts the channel state information (CSI) and forwards it to the CSI manager. The CSI manager generates a metric for each RB for each UE, creating a matrix called the channel conditions matrix, as shown in Fig. 1, which is used by the scheduling algorithms for resource allocation.

	1	.	.	N_{RB}
1				
.				
.				
N_{UE}				

Fig. 1. UE - RB matrix.

This paper is organized as follows. Section 2 reviews previous work in scheduling algorithms in relation to the LTE uplink. Section 3 provides details of the proposed algorithm. This section also states some of the major drawbacks in the FME and RME that are addressed in the algorithm.

2. Related Work

In reference [6], three scheduling algorithms were proposed: First Maximum Expansion (FME), Recursive Maximum Expansion (RME), and Minimum Area Difference Envelope (MADE). FME selects the maximum value in the matrix and expands to the left or right depending on which side has the second highest metric value, then to the opposite side, allocating a RB with the highest metric value while maintaining the contiguity constraint. As a result, there is no guarantee that the users' equipment will be allocated the best RB due to the contiguity constraint. RME provides a better solution to this problem. RME expands the resource allocation on both sides simultaneously, along the bandwidths, thereby allocating a good percentage of the RBs with highest metric to the UE. Although it provides better results than FME, the total metric of the allocated RBs is reduced if the neighboring RBs (to one allocated earlier) have significantly lower metric values. Therefore, a change in the expanding procedure improves the global optimality. The third algorithm, MADE, uses the minimum difference between the cumulative metric of all users and the scheduling metric of a specific user. MADE allocates the RBs to users whose area difference with respect to the RB is the minimum area.

In addition, in reference [7] two scheduling algorithms, Improved Recursive Maximum Expansion (IRME), and Improved Tree-based Recursive (ITRME), were proposed. They claim higher spectral efficiency and lower calculation complexity compared to RME, in which UE expands the resource allocation on the neighboring RBs with the maximum metrics. The improved scheme expands based on the ranking threshold. IRME achieves higher scheduling gain, but it increases the calculation complexity slightly. The ITRME depends on the matrix values, root number, and ranking threshold. The algorithm introduces more starting points and gives more freedom but with the same allocation results. In references [9, 10], Myung, Lim and Goodmand examined the Channel-Dependent resource Scheduling (CDS) for a SC-FDMA system in uplink communications with the assumption of perfect knowledge of channel state information (CSI). They reported that CDS increases the system throughput significantly. Furthermore, the increase reaches 80% if a localized subcarrier mapping scheme rather than a distributed mapping scheme is used. On the other hand, the contiguity constraint was not considered in the RB allocation.

Calabrese et al. [11] proposed a search-tree based algorithm whose assumption of equal shared resources between users limits the flexibility and affects the multi-user diversity gain. K. Kim, et al. [12] examined joint subcarrier and power allocation schemes in an uplink Orthogonal Frequency Division Multiple Access (OFDMA) system. Their simple and effective allocation schemes were greedy-based algorithms. In reference [13], the authors introduced a channel gain difference-based selection strategy. The algorithm showed a good increment for the throughput of SC-FDMA. In addition, they suggested a contiguity assigning method. The drawback of the method is the assumption of equality between the users and RBs, which creates a need for grouping resources "chunks." The same grouping strategy was used in reference [14] but with the well-known Hungarian algorithm.

More heuristic algorithms have been presented to provide near optimal solutions under the contiguity constraint [15-17]. The algorithms are based on a well-known greedy allocation strategy through which they find the best RB-to-user assignment among all pairs of one user and one set of RBs. The work in reference [17] suggests a universal objective function for the Frequency Domain Packet Scheduler (FDPS) and approximation algorithms based on greedy strategy. Using selected sets of contiguous RBs, they divide the FDPS problem into several sub-problems according to their profit. Subsequently, they apply a greedy technique to each sub problem followed by choosing the best sub-problem showing largest total profit. On the other hand, the above work requires more investigation, particularly from a power degradation perspective. In reference [19], an interference aware joint scheduling algorithm was proposed. This algorithm considers the CSI received by two or more cells in the same eNodeB to perform the resource allocation. This proposal is for a single cell, without taking any external effects into account, which is applicable for future work.

A few selected algorithms for a performance evaluation have been reported [23]. Both channel dependent and proportional fairness paradigms were used in this evaluation. The results made it clear that both paradigms showed the best results with riding peaks algorithm. Few challenges were also pointed out in the paper, such as mobility issue, starvation issue and dynamic nature of mobile networks. an extended work [20] considered the QoS for a better evaluation specially in scenarios when the UEs with high priority data pending for transmission have poorer channel conditions than those with lower priority data. The QoS-Awareness decreases the starvation problem because another balancing factor is added. The main weakness of such an approach is lowering the system throughput. Another type of awareness was presented [19], which is the cooperative interference. The proposed interference-aware joint scheduling scheme was based on proportional fairness for the uplink of a 3GPP UTRAN LTE system, where different BSs cooperate with each other via a fast backhaul network to jointly allocate frequency resources to the various UEs, taking the caused inter-cell interference into account. This shows the possibility of predicting the inter-cell interference level and with high performance. This algorithm considers the CSI received by two or more cells in the same eNodeB to perform the resource allocation. The proposal is for a single cell, without taking any external effects into account, which is applicable for future modification work.

An estimation of the performance was reported, where different segments that are part of the similar site collaborate searching for the improvement in the system [21]. This shows a transitional step in the direction of coordinated multi point (CoMP) systems, in which the system that belongs to dissimilar sites can also collaborate. The joint detection and joint link adaption both are considered for this evaluation. A possible and practical approach to this implementation shown in the result standardization may also be required. Finally, many different factors can be noticed, which can be used to evaluate the algorithms, and it was also found that an excellent algorithm in one case might not be good in another case. Therefore, to prove the concept, this study started with an algorithm calculation in general form.

3. Proposed resource allocation algorithm

This algorithm pays considerable attention to rows rather than columns, unlike the FME and RME, where, once the highest number is identified in a given column, the entire column is considered to be done despite having better metric values. Furthermore, the FME and RME consider the RBs with the highest scheduling metric at a given point, and then expands sideways, allocating the contiguous RBs to the same user without paying attention to the highest possible benefits, such as the highest sum of the metrics of the contiguous RBs allocated.

3.1. Calculation and Problem Formulation

Consider the matrix in Fig. 2 with metric values for various UE and respective RBs. Let the number of user machines be N and that of the RBs be N_{RB}

The following procedure was adopted

1. Determine the gain matrix for the RBs.

where the entries $G_{RB}(i,j)$, are given by

$$G_{RB}(i,j) = N \cdot M_{(i,j)} + \sum_{i=1}^{N} M_{(i,j)},_{RB} \qquad (1)$$

$$i = 1, 2, 3, \ldots, N;\ j = 1, 2, 3, \ldots, N$$

Thus

Determine the overall gain matrix whose entries are given by the following equation.

2. Identify the unique maximum values in each column of the gain matrix.
3. Identify the maximum values that appear more than once based on the contiguity of the columns.
4. Having the maximum values in each column of the gain matrix, identify the corresponding values in the original matrix.
5. Based on the selected values, allocate the corresponding RB to the user machines.

This is the optimal allocation using the gain function.

$$G(i,j) = G_{RB}(i,j) + MAX\left(G_{RB}(i,j-1), G_{RB}(i,j+1)\right) \qquad (2)$$

An illustration of the gain function was considered.

	RB_1	RB_2	...	RB_{j-1}	RB_j	RB_{j+1}	. . .	$RB_{N_{RB}}$
UE_1	$M_{1,1}$	$M_{1,2}$		$M_{1,j-1}$	$M_{1,j}$	$M_{1,j+1}$		$M_{1,N_{RB}}$
UE_2	$M_{2,1}$	$M_{2,2}$		$M_{2,j-1}$	$M_{2,j}$	$M_{2,j+1}$		$M_{2,N_{RB}}$
:								:
UE_{i-1}	$M_{i-1,1}$	$M_{i-1,2}$		$M_{i-1,j-1}$	$M_{i-1,j}$	$M_{i-1,j+1}$		$M_{i-1,N_{RB}}$
UE_i	$M_{i,1}$	$M_{i,2}$		$M_{i,j-1}$	$M_{i,j}$	$M_{i,j+1}$		$M_{i,N_{RB}}$
UE_{i+1}	$M_{i+1,1}$	$M_{i+1,2}$		$M_{i+1,j-1}$	$M_{i+1,j}$	$M_{i+1,j+1}$		$M_{i+1,N_{RB}}$
:								
UE_N	$M_{N,1}$	$M_{N,2}$	...	$M_{N,j-1}$	$M_{N,j}$	$M_{i-1,j+1}$	. . .	$M_{N,N_{RB}}$

Fig. 2. Input scheduling matrix.

	RB_1	RB_2	RB_3	RB_4	RB_5
UE_1	34	60	48	61	63
UE_2	56	63	40	38	42
UE_3	40	57	65	58	54
UE_4	52	39	55	69	58

Fig. 3. Original problem with the scheduling metrics.

For example, consider Fig. 3 with the scheduling metrics for different combinations of RB and user machines.

The gain function was used to determine the optimal allocation.

The gain matrix for the RBs was determined using Eq. (1)

$$G_{RB}(i,j) = N \cdot M_{(i,j)} + \sum_{i=1}^{N} M_{(i,j)},$$
$$i = 1,2,3,\dots,N;\ j = 1,2,3,\dots,N_{RB}$$

N is the number of users, rows. In this case, N = 4.

Consider the value in the first column/ first row, i.e., $(i,\ j) = (1,\ 1)$. It follows that $M_{(i,\ j)}$ = 34. The expression, $\sum_{i=1}^{N} M_{(i,j)}$, is the sum of all values in the first column.

Therefore,

$$Gain_{RB}\ (1,1) = 4 \cdot 34 + (34 + 56 + 40 + 52) = 318$$

Consider the value in the fourth column/ third row, i.e. $(i,\ j) = (3,\ 4)$. $M_{(i,\ j)} = 58$. The expression $\sum_{i=1}^{N} M_{(i,j)}$ is the sum of all values in the fourth column.

Therefore

$$Gain_{RB}\ (3,4) = 4 \cdot 58 + (61 + 38 + 58 + 69) = 458$$

	RB_1	RB_2	RB_3	RB_4	RB_5
UE_1	318	459	400	470	469
UE_2	406	471	368	378	385
UE_3	342	447	468	458	433
UE_4	390	375	428	502	449

Fig. 4. Resource block gain matrix.

Finding the gain matrix using formula (2),

$$G(i,j) = G_{RB}(i,j) + MAX\left(G_{RB}(i,j-1), G_{RB}(i,j+1)\right)$$

where $G_{RB}(i,j)$ is a value in the above RB gain matrix table and $G_{RB}(i,j-1)$ is the value in the same row to the left of $G_{RB}(i,j)$ while $G_{RB}(i,j+1)$ is the value in the same row to the right of $G_{RB}(i,j)$.

	RB_1	RB_2	RB_3	RB_4	RB_5
UE_1	777	859	870	939	939
UE_2	877	877	839	763	763
UE_3	789	915	926	926	891
UE_4	765	803	930	951	951

Fig. 5. Gain matrix.

Using steps 3 and 4, identify the maximum values in each column

	RB_1	RB_2	RB_3	RB_4	RB_5
UE_1	777	859	870	939	939
UE_2	877	877	839	763	763
UE_3	789	915	926	926	891
UE_4	765	803	930	951	951

Fig. 6. Allocation in the Gain matrix.

The corresponding original matrix is

	RB_1	RB_2	RB_3	RB_4	RB_5
UE_1	34	60	48	61	63
UE_2	56	63	40	38	42
UE_3	40	57	65	58	54
UE_4	52	39	55	69	58

Fig. 7. Allocation in the original matrix.

Therefore, the allocation is $UE_2 - RB_1$
$UE_3 - RB_2$
$UE_4 - RB_3, RB_4$ and RB_5

3.2. Steps flowcharted

The concept can be summarized in two stages.

a. Stage one: Preprocessing

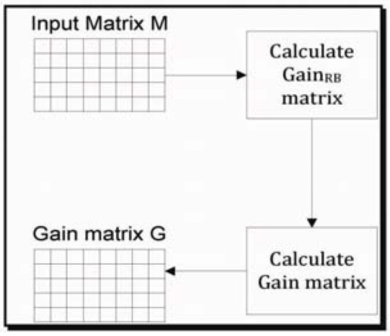


Fig. 8. Preprocessing.

b. Stage two Allocate Resources

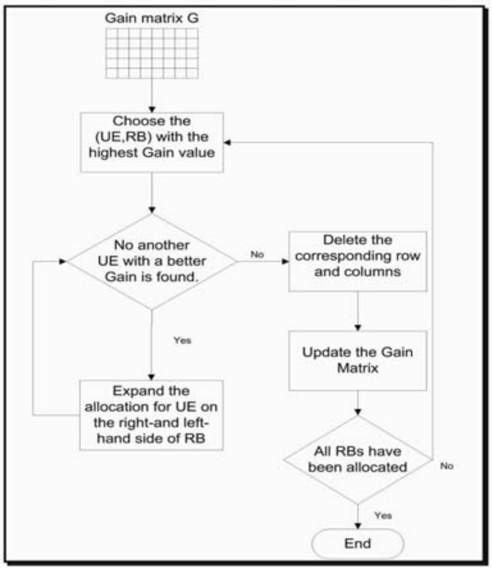
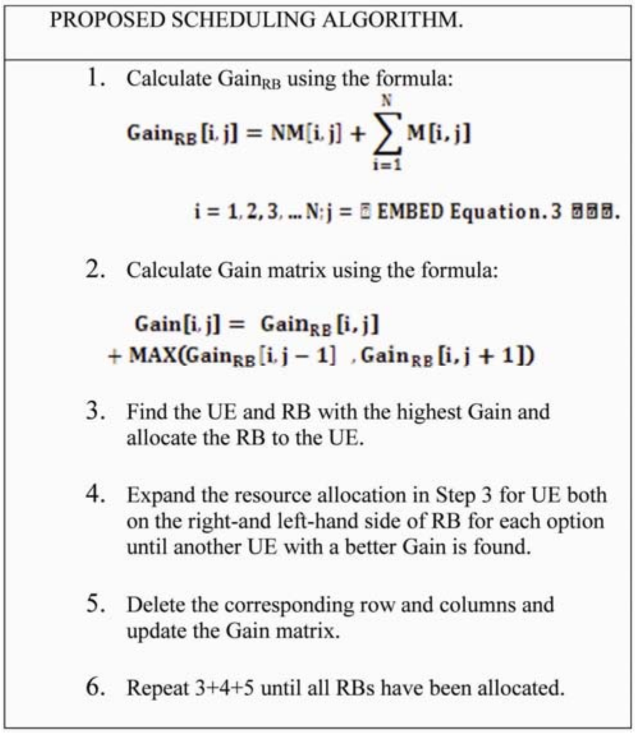


Fig. 9. Resource allocation flow chart.

3.2 Algorithm Pseudo Code



```
PROPOSED SCHEDULING ALGORITHM.
1. Calculate Gain_RB using the formula:
       $Gain_{RB}[i,j] = NM[i,j] + \sum_{i=1}^{N} M[i,j]$
       $i = 1,2,3,\ldots N; j =$ ▯ EMBED Equation.3 ▯▯▯.
2. Calculate Gain matrix using the formula:
       $Gain[i,j] = Gain_{RB}[i,j] + MAX(Gain_{RB}[i,j-1], Gain_{RB}[i,j+1])$
3. Find the UE and RB with the highest Gain and
   allocate the RB to the UE.
4. Expand the resource allocation in Step 3 for UE both
   on the right-and left-hand side of RB for each option
   until another UE with a better Gain is found.
5. Delete the corresponding row and columns and
   update the Gain matrix.
6. Repeat 3+4+5 until all RBs have been allocated.
```

Fig. 10. Algorithm pseudo code.

4. Evaluation and Performance

4.1 Comparison

Consider the following RB-UE matrix:

10	20	30	40	42	50
20	10	33	38	42	50
30	35	15	10	20	25

Fig. 11. RB-UE matrix.

After obtaining the corresponding values and performing the selection with the same items in the original array, the following can be derived:

10	20	30	40	42	50
20	10	33	38	42	50
30	35	15	10	20	25

Fig. 12

Therefore, the resource allocation result is 230 while the result using RME and Improved RME is 227 and 228, respectively.

The RME result is:

10	20	30	40	42	50
20	10	33	38	42	50
30	35	15	10	20	25

Fig. 13. RME result.

The Improved RME result is:

10	20	30	40	42	50
20	10	33	38	42	50
30	35	15	10	20	25

Fig. 14. Improved RME result.

4.2 SC-FDMA and system consideration

In general, different transmit powers or different constellations may be allocated to different chunks (group of RBs) when a user occupies multiple chunks [9]. On the other hand, the improvement in throughput may not be significant enough. This study also evaluated the algorithm without adding complexity. Therefore, the use of Equal-Bit-Equal Power (EBEP) [18] is practical.

Thus, the power assigned to each subcarrier begins with the assumption $P_k^{(sub)} = \frac{P_k}{|I_{sub,k}|}$

where:

P_k is the total transmit power of user k,

$I_{sub,k}$ is the subcarrier index set assigned to user k,

$|I_{sub,k}|$ is the number of subcarriers assigned to user k.

In addition, $I_{sub,k}$ is the assigned chunk set of user k and $I_{sub}^{(n)}$ denotes the set of subcarriers in chunk n.

Therefore:

$$I_{sub,k} = \bigcup_{n \in I_{ch,k}} I_{sub}^{(n)} \qquad (4)$$

The SNR for the data delivered with chunks $I_{ch,k}$ can be derived as (6)

$$\gamma(P_k, I_{ch,k}) = \left(\frac{1}{\frac{1}{|I_{sub,k}|} \sum_{i \in I_{sub,k}} \frac{\gamma_{i,k}}{\gamma_{i,k}+1}} - 1 \right)^{-1} \qquad (5)$$

$$\gamma_{i,k} = \frac{P_k^{(sub)} H_{i,k}}{\sigma_i^2} \qquad (6)$$

σ_i^2 is the noise power of each subcarrier

$H_{i,k}$ is the channel gain of each subcarrier

By applying Shannon's formula, the achievable data rate of the chunk for user k has the upper bound:

$$C_k(P_k, I_{ch,k}) = \frac{B|I_{ch,k}|}{N} \cdot \log_2[1 + \gamma(P_k, I_{ch,k})] \qquad (7)$$

Note that the effective bandwidth occupied by user k is B/NHz, because one chunk is allocated to user k and there are N chunks in bandwidth BHz. Depending on the last equations with the selected parameters in Table 1, the upper spectral efficiency of each user in each chunk is calculated.

Table 1. Simulation Parameters.

Parameter	Value
System bandwidth	10 MHz
Sampling Frequency	15.36 MHz
Used Subcarriers	600
FFT size	1024
Subcarrier spacing	15 KHz
RB size	12 subcarriers
Carrier Frequency	2 GHz
Channel model	6 paths
Scheduling metric	Max C/I

The new approach was tested and compared with two algorithms: the original RME, which is described in [6], and one of the improvements in RME (IRME), which is described in [7]. Fig. 15 shows the upper spectral efficiency results for the three scheduling algorithms. The results in Fig. 15 and the comparison in section 4.1 prove that this approach outperforms both algorithms. Although IRM shows about 13-17% gain over RME, the new approach provides 16-24% gain over RME, which means up to 10% gain over RME.

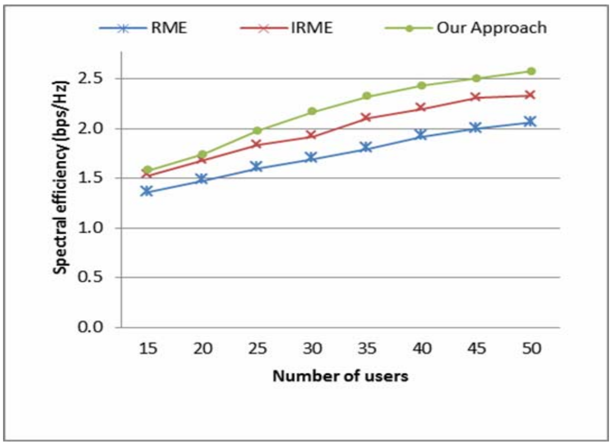


Fig. 15. Comparison of the results of this approach with RME.

5. Conclusion

This paper evaluated a new scheduling algorithm for RB allocation to user machines in SC-FDMA. In this study, the gain function was proposed to be used in a simpler and more efficient manner under the contiguity constraint. The algorithm using the gain function was analyzed in detail. Furthermore, the proposal showed how widening the context of processing prevents local optimal problems. The proposed algorithm showed improvement over RME scheduling algorithm. The algorithm outperformed the RME with up to 24% gain and up to 10% gain over IRME. This study concentrates on the algorithm calculation and the proof of concept. Further studies will be needed to consider other aspects, such as fairness, QoS and number of users.

References

[1] 3GPP TS 25.913 V7.3.0, "Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (EUTRAN)," March 2006. Article (CrossRef Link)

[2] 3GPP TR 25.811 V1.4.0, "Physical Layer Aspects for Evolved UTRA," May 2006. Article (CrossRef Link)

[3] D. Falconer, S. L. Ariyavisitakul, A. Benyamin-Seeyar, B. Eidson, "Frequency domain equalization for single-carrier broadband wireless systems", *IEEE Com. Magazine*, Vol. 40, No. 4, April, 2002, 58-66 Article (CrossRef Link)

[4] H. Myung, J. Lim, D. J Goodmand, "Single carrier FDMA for uplink wireless transmission", *IEEE Veh. Tech. Magazine*, Vol. 1, Sept. 2006, 30-38 Article (CrossRef Link)

[5] S.-B. Lee, I. Pefkinakis, A. Meyerson, S. Xu and S. Lu, "Proportional Fair Frequency-Domain Packet Scheduling for 3GPP LTE Uplink," *in UCLA TR-*090001, 2009. Article (CrossRef Link)

[6] L. Ruiz de Temino et al., "Channel-aware scheduling algorithms for SC-FDMA in LTE uplink", *IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications*, Sept. 2008, 1-6 Article (CrossRef Link)

[7] Liu, Fang, and Yuan-an Liu. "Improved Scheduling Algorithms for Uplink Single Carrier FDMA System." *Journal of Information & Computational Science* 9: 11 (2012) 3211–3219. Article (CrossRef Link)

[8] 3GPP, TS 36.321, "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification," July 2013. Article (CrossRef Link)

[9] H. Myung, J. Lim, D. J Goodmand, "Channel-Dependent Scheduling of Uplink Single Carrier FDMA Systems," *IEEE Vehicular Technology Conference* (VTC) 2006 Fall, Montreal, Canada, Sep. 2006. Article (CrossRef Link)

[10] J. Lim, H. G. Myung, K. Oh, and D. J. Goodman, "Proportional Fair Scheduling of Uplink Single-Carrier FDMA Systems," *The 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '06)*, Helsinki, Finland, Sep. 2006. Article (CrossRef Link)

[11] ED. Calabrese et al.., "Search-tree based uplink channel aware packet scheduling for UTRAN LTE," *IEEE Proc. of the 67th Veh. Tech. Conf.*, May 2008. Article (CrossRef Link)

[12] Keunyoung Kim, Youngnam Han and Seong-Lyun Kim "Joint Subcarrier and Power Allocation in Uplink OFDMA systems," *Communications Letters, IEEE*, vol. 9, pp.526-528, June. 2005. Article

(CrossRef Link)

[13] Donggeun Kim Jeongchan K. Hoonk.Keunyoung k Youngnam. "An Efficient Scheduler for Uplink Single Carrier FDMA System." *IEEE 21st international symposium on personal indoor and mobile radio communications* 2010. Article (CrossRef Link)

[14] Medina-Acosta, Gerardo Agni, and José Antonio Delgado-Penín. "On the feasibility of a channel-dependent scheduling for the SC-FDMA in 3GPP-LTE (mobile environment) based on a prioritized-bifacet Hungarian method." *EURASIP Journal on Wireless Communications and Networking* 2011.1 (2011): 1-10. Article (CrossRef Link)

[15] L. Ruiz de Temino, G. Berardinelli, S. Frattasi and P. Mogensen, "Channel-aware Scheduling Algorithms for SC-FDMA in LTE Uplink," *in PIMRC 2008. IEEE 19th International Symposium on*, vol., no., pp.1-6, 15-18 Sept. 2008. Article (CrossRef Link)

[16] S.-B. Lee, I. Pefkianakis, A. Meyerson, S. Xu and S. Lu, "Proportional Fair Frequency-Domain Packet Scheduling for 3GPP LTE Uplink," in *INFOCOM 2009, IEEE*, vol., no., pp.2611-2615, 19-25 April 2009. Article (CrossRef Link)

[17] H. Yang, F. Ren, C. Lin and J. Zhang, "Frequency-Domain Packet Scheduling for 3GPP LTE Uplink," INFOCOM, 2010 Proceedings IEEE,vol., no., pp.1-9, 14-19 March 2010. Article (CrossRef Link)

[18] T. Shi, "Capacity of single carrier systems with frequency-domain equalization", *in Proc. IEEECASSET'04*, Vol. 2, June 2004, 429-432. Article (CrossRef Link)

[19] P. Frank, A. Muller, H. Droste, J. Speidel, "Cooperative interference-aware joint scheduling for the 3GPP LTE uplink," *in Personal Indoor and Mobile Radio Communications (PIMRC), 2010 IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications pp.2216-2221, 26-30 Sept. 2010.* Article (CrossRef Link)

[20] H. Safa, W. El-Hajj, K.Tohme, "A QoS-Aware Uplink Scheduling Paradigm for LTE Networks," *Advanced Information Networking and Applications (AINA), 2013 IEEE 27th International Conference on Telecommunications, pp.1097,1104, 25-28 March 2013.* Article (CrossRef Link)

[21] P. Frank, A. Muller, H. Droste, J. Speidel, "Performance of the LTE Uplink with Intra-Site *Joint Detection and Joint Link Adaptation," 2010 IEEE 71st Vehicular Technology Conference, 16-19 May, 2010.* Article (CrossRef Link)

[22] H. Safa, K.Tohme, "LTE Uplink Scheduling Algorithms: Performance and Challenges," *2012 19th International Conference on Telecommunications, 23-25 April, 2012.* Article (CrossRef Link)

[23] P. Frank, A. Muller, "Cooperative Interference Prediction for Enhanced Link Adaptation in the 3GPP LTE Uplink," *2010 IEEE 71st Vehicular Technology Conference, 16-19 May, 2010.* Article (CrossRef Link)

Copyrights © 2013 The Institute of Electronics Engineers of Korea

Saleh elshakwi is a PhD student in university technology Malaysia (UTM). He received his B.S.degree in telecommunication engineering from faculty of electronic and electrical engineering Benghazi Libya 2002. In 2008, he completed his master degree in telecommunication engineering from university technology Malaysia (UTM). He was involved in different projects during his research including WiFi studies, Rf planning, cognitive radios, and spectrum sensing. He worked with Libyan and Malaysian government projects. His current research as a PhD student is in LTE algorithms.

Tharek Rahman is a Professor at Faculty of Electrical Engineering, University Technology Malaysia (UTM). He obtained his BSc. in Electrical & Electronic Engineering from University of Strathclyde UK in 1979, MSc in Communication Engineering from UMIST Manchester UK and PhD in Mobile Radio Communication Engineering from University of Bristol, UK in 1988. He is the Director of Wireless Communication Centre (WCC), UTM. His research interests are radio propagation, antenna and RF design and indoors and outdoors wireless communication. He has also conducted various short courses related to mobile and satellite communication to the Telecommunication Industry and Government body since 1990. He has published more than 120 papers related to wireless communication.