Study of Radio Resource Allocation Scheme for Single Carrier FDMA in LTE Network

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Abstract— **Single carrier frequency division multiple access (SC-FDMA) is applied as the transmission technology for the uplink traffic in LTE networks. The radio resource allocation is one of the most important issues to achieve effective wireless communication. Most researches focus on maximizing the system throughput of SC-FDMA under changing channel condition. However, users may require different quality of services (QoS) for different applications. This paper studies the radio resource allocation for QoS users in using localized SC-FDMA transmission. The proposed scheme is divided into the matching algorithm and the radio resource assignment algorithm. The Gale-Shapley algorithm is applied to find the optimal matching of resource block (RB) by considering the channel condition and the desired QoS of UE. The Recursive Maximum Expansion (RME) algorithm is modified in this paper to effectively assign radio resource for UEs with different bandwidth demands. The video streaming, VoIP, and FTP traffic types were adopted for simulations. Our results show that the proposed scheme achieves better QoS satisfaction than that without matching mechanism.**

Keywords- SC-FDMA, Gale-Shapley Algorithm, Radio Resource Allocation

I. INTRODUCTION

The 3rd Generation Partnership Project (3GPP) is currently the dominant standards development group for mobile radio system. And the Long Term Evolution (LTE) is recognized as supporting the expansion of service provision beyond voice calls towards a multiservice air interface [1-3]. The effective radio resource utilization receives more attention because the emerging mobile services require quality of services (QoS) and the number of mobile users also increases exponentially. Generally, the bearer traffic of LTE can be categorized into guaranteed bit rate (GBR) and non-guaranteed bit rate (Non-GBR) services. Each service further defines its characteristics by the parameters of QoS class identifier (QCI) and allocation and retention priority (ARP). The resource allocation shall consider the spectrum efficiency, which depends on channel condition, and the required QoS of each connection. In LTE, the eNodeB (eNB) is responsible for protecting data against channel errors using adaptive modulation and coding (AMC) scheme based on the channel quality. The mobility management entity (MME) is responsible for the connection and QoS management of bearers. The user equipment (UE) may adopt multiple antennas to get higher spectrum throughput. The orthogonal frequency division multiple access (OFDMA) technology has the advantages of flexible subcarrier allocation and adaptive modulation with respect to channel conditions and is widely adopted in recent communication systems. However, due to concurrent upstream transmissions from many UEs to single eNB architecture, the single carrier frequency division multiple access (SC-FDMA) scheme is adopted for the uplink in LTE networks to avoid the high level of intra-cell interference [4, 5]. In addition, the SC-FDMA can effectively reduce peak-to-average power ratio (PAPR) and this characteristic has better power efficiency when compared to OFDMA system.

Basically, there are two approaches, localized and distributed, to perform the subcarrier mapping for the uplink transmission. The localized mapping is done within the adjacent subcarriers while the distributed approach maps the subcarriers randomly. The localized mapping approach is more practical to be implemented in real application because it can avoid inter carrier interference owing to Doppler frequency shift. The bandwidth requirement and QoS demand of various kinds of network services are quite different. And the radio channel conditions of UEs are distinct and always change from time to time. From the system throughput point of view, eNB shall arrange radio resource to the UEs that receive better channel quality, however, it may sacrifice the UE that has strict QoS demand but with poor channel condition. And it may introduce the unfairness of resource allocation. The purpose of effective radio resource allocation is to properly arrange suitable radio channels to UEs so that their QoS can be satisfied while the spectrum utilization can be maximized as well. When compared to the centralized SC-FDMA, the localized SC-FDMA shall confine its radio channels to be allocated in a continuous way for each UE. This constraint limits the flexibility during resource allocation for uplink traffic. Hence this is the purpose of this paper to study this issue.

This paper is organized as follows. The following section briefly overviews the background and the previous related works. The Gale-Shapley algorithm based matching algorithm and the resource assignment algorithm of the proposed scheme are described in Section 3. Section 4 provides the simulation results with discussion. Then, the conclusions of this paper are provided in the last section.

II. BACKGROUND OVERVIEW AND RELATED WORKS

Unlike the circuit switching technology used in the traditional cellular systems, LTE proposes packet based switching to achieve the demand of multiservice. Generally, in LTE, subcarriers are grouped into resource blocks (RB) to convey data. The RB is the basic unit of radio resource allocation. There are localized and distributed approaches to allocate RB. The distributed approach, e.g. interleaved SC-FDMA, has the diversity property in subcarrier grouping. However, in addition to avoiding inter-carrier interference, the localized approach has better rate-sum capacity [4]. The eNB may need to allocate more than one RB to the UE that requires more bandwidth. In this case, the localized SC-FDMA approach shall allocate consecutive RBs to the UE. An example illustrates these two approaches that allocate 12 RBs to 3 UEs, where 4 RBs for each UE, is shown in Figure 1. It is a challenge issue to properly allocate radio resource under changeable channel condition so that each UE can satisfy its QoS and the system throughput can also be maximized.

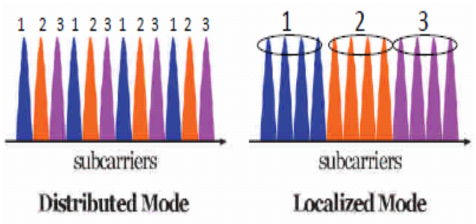


Figure 1 The distributed and localized SC-FDMA

Each UE may have different channel condition on the subcarriers of each RB. And the channel dependent scheduling (CSD) concept is always applied to arrange radio resource under this circumstance. However, it is an NP problem to find the optimal allocation between RBs and UEs. Several researches [6, 7, 8] adopted greedy algorithm to deal with this issue in a heuristic way. The main purpose of the above schemes aims to maximize the system throughput. In [6], the authors proposed the recursive maximum expansion (RME) scheme to tackle this issue. Basically, the RME scheme performs the allocation in two steps. In the first step, the scheme chooses the UE with the best channel condition on a specific RB as the starting point and extends its neighbor RBs in consecutive manner till reach the cross point. The cross point means that there is the other UE that has better channel condition than the extending one. The RME scheme keeps seeking for the residual UE with the best channel condition of the residual RBs and repeats the above procedure until either all UEs have been allocated with RBs or all RBs have been allocated. If there is RB left, the scheme allocates the RB to the UE which will not violate the continuity property of localized SC-FDMA system. Thus the above schemes allocate consecutive RB(s) to UEs, which have different channel condition, in a heuristic manner to maximize the system throughput. However, in practical applications, each UE may have different bandwidth demand and QoS requirement. In addition to maximizing the system throughput, the resource allocation shall be more sophisticated to meet individual service needs.

Obviously, the RB allocation problem can be regarded as a many to many matching issue. Each UE prefers to use the RB that has the best channel quality, however, each RB can only be allocated to a specific UE. And each UE can only transmit its data within one continuous RB segment in one frame duration. If the QoS and required bandwidth are taken into consideration, the matching process will become much more complex. The Gale-Shapley algorithm was proposed to solve the stable matching problem [9, 10]. In this paper, we apply the concept of Gale-Shapley algorithm to find the stable matching point of each UE over the radio spectrum as the start of extending point and propose the expansion algorithm to assign suitable RB for each UE in the following section.

III. THE PROPOSED GALE SHAPLEY BASED ALLOCATION SCHEME

The Gale-Shapley algorithm was originally designed to solve the many to many matching problem between two sets of elements given a set of preferences for each element [9]. Typical example is the friend (or marriage) matching between a set of boys and a set of girls. The purpose of this algorithm is to find a stable matching between these two sets. A stable matching means that there does not exist any alternative pairing (A, B) in which both A and B are individually better off than they would be with the element to which they are currently matched. In this paper, we apply this concept to match the sets of RBs and UEs. However, unlike the original Gale-Shapley matching problem, the RB set and UE set may have different numbers of elements. The number of UE is assumed to be less than or equal to the number of RBs since the RB is the basic unit for resource allocation. The proposed scheme adopts the concept of Gale-Shapley algorithm and defines the preference matrix to find the stable matching of each UE and a specific RB. The matching point is then applied as the start point to extend the neighbor RBs continuously for the desired bandwidth. The proposed scheme can be divided into two algorithms, which are the matching mechanism and the radio resource assignment mechanism, as shown in Figure 2.

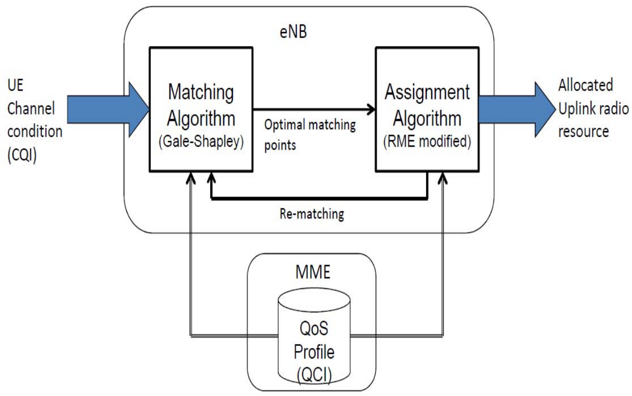


Figure 2 The proposed Gale Shapley based allocation framework

(A) Matching Algorithm

The preference represents the matching degree on each member of the other set from individual member point of view.

The purpose of Gale Shapley algorithm is to compromise the preference conflict among members and to perform a stable matching. In the radio resource allocation, each UE prefers to acquire RB with the best channel quality and the eNB prefers to allocate RB to the priority UE according to their QoS requirements. However, each RB can only be "matched" to an UE. Basically, the UE prefers the RB with higher modulation and coding scheme (MCS) level and wider consecutive available RBs. The width of consecutive RBs means the number of unallocated RBs between two cross points (or allocated RB). We define the UE *i* preferences of RB *j*, $U_{i,j}$, in the following equation:

$$U_{i,j} = order(rb_j, S_j) + MCS_{i,j} * W_{i,j} \qquad (1)$$

The UE reports its channel quality indication (CQI) to the eNB in per sub-band basis. Each sub-band consists of several of RBs, e.g. 8 RBs/subband in 20MHz bandwidth. And the CQI is the average channel condition of these RBs. All RBs of the same subband are reported with the same channel condition. The term of $order(rb_j, S_j)$ in equation (1) denoted the order of RB *j* in its belonging subband (S_j). This term makes the RB with the highest order, i.e. the edge RB of the associated subband, have the highest preference value for the RBs in the same subband. The reason to choose the edge RB of a subband is that choosing the edge RB as the start point to extend will minimize the fragment phenomenon when compared to starting with the center RB.

From the RB point of view, RB prefers to be allocated to the UE with the higher scheduling priority. In addition, the RB welcomes the UE that can have consecutive RBs if being allocated this RB. It is noted that different US may have different width because the channel conditions among RBs are different. The preference value of RB *i* to UE *j*, $R_{i,j}$, are defined in the following equation:

$$R_{i,j} = \frac{QoS_j}{W_{i,j} + \alpha} \qquad (2)$$

The QoS_j means the QoS of UE *j* and the UE with the lowest QoS_j value has the highest scheduling priority. Thus, unlike $U_{i,j}$, the smaller value the $R_{i,j}$ is, the more preferable the RB *i* chooses UE *j*. And the value of α is the designed parameter to adjust the preference weight of QoS and width. The proposed Gale-Shapley based matching algorithm is stated as follows. It is noted that, the UE chooses RB first in lines 1-4, the proposed algorithm tends to match UE's preference first. The purpose of the matching algorithm determines the starting point to allocate RB only. The following assignment algorithm extends neighbor RBs to satisfy the bandwidth requirement of each UE.

Matching Algorithm

/*UE*i* chooses the RB*j* with the highest $U_{i,j}$ value
1. **For** every UE*i*
2. choose the RB*j* with the highest $U_{i,j}$ from the RBs that have not been proposed
3. let UE*i* proposes this RB and adds this UE*i* in this RB*j*'s waiting list
4. **End For**

/*RB*i* chooses the UE*j*, which the RB*i* has the lowest $R_{i,j}$ value, from its waiting list
5. **While** each UE in the waiting list
6. **For** every RB*i* in the system
7. **If** number of UE in its waiting list > 0 **then**
8. choose the UE*j* of RB*i* that has the lowest $R_{i,j}$ value
9. reject the other UEs in this list
10. **End If**
11. **End For**

/*The re-proposing procedure
12. **For** the UE that is not in waiting list
13. let this UE propose the RB*j* with the highest $U_{i,j}$ value from the residual RBs
14. adds this UE*i* in this RB*j*'s waiting list
15. **End For**
16. **End While**

/*Matching the residual RB and UE
17. **For** erery RB*j* in system
18. **If** RB*j*'s waiting list is not empty then
19. match RB*j* and UE*i* that is in the list
20. **End If**
21. **End For**

The RME algorithm [6] chooses the UE, which has the best channel condition on a specific RB, to extend neighbor RBs till the cross points. This approach is suitable to maximize the overall system throughput, however, it is not workable for QoS scheduling. Because this scheme is unable to allocate radio resource to the UE whose CQI is worse than other UEs over the whole spectrum even when this UE has the highest priority. Then, unlike the traditional RME scheme, the proposed assignment algorithm chooses the starting points by using the above matching algorithm, which effectively reflects the QoS demand and the available RB distribution. The proposed scheme allocates RBs to each UE according to its bandwidth demand and the associated channel condition. It is noted the RBs that are allocated to the same UE shall adopt the same modulation and coding scheme. We assume that the proposed assignment algorithm allocates resource to the UE with GBR1, GBR2, and non-GBR requirements, where GBR1 has higher scheduling priority than GBR2. If there are more than one UE belongs to the same scheduling priority, the round robin (RR) method will be applied within the same scheduling group. The GBR connection has the requirement of minimum bit rate. On the other hand, the non-GBR connection is assumed to provide the best effort service. The eNB allocates as much RBs as possible to the non-GBR UE under the continuity constraint of the RBs. Assume that RB *i* is the matched point of UE *j*, the assignment algorithm will extend its neighbor RBs, RB *i+1* and RB *i-1*, continuously until its required bandwidth is satisfied. The assignment process shall consider whether it is valuable to extend the neighbor RB because it needs to downgrade its MCS level is the neighbor RB has worse channel condition than its current acquired RBs. If it encounters the allocated RB in one end during the extension, it will extend the other end only. If there are allocated RBs at two ends, the assignment procedure will be terminated and the allocated bandwidth of this UE may not be satisfied. If the cross point is encountered during the extension, the algorithm will extend the side without cross point. And the extension procedure will extend the RB with higher MCS level at one end if two ends all reach the cross points. It is noted that the matching point RB of the UE may be allocated to the UE that has been assigned. In this case, the re-matching process is triggered to obtain new matching points. The proposed assignment algorithm is stated in the following.

Assignment Algorithm

```
IF there are UEs in GBR1 who request bandwidth then
  use RR(Round Robin) to pick one UE_i
  End If
  Else If there are UEs in GBR2 who request bandwidth then
    use RR(Round Robin) to pick one UE_i
  End Else If
  Else If there are UEs in non-GBR who request bandwidth then
    use RR(Round Robin) to pick one UE_i
  End Else If
    according to the stable system, find RB_j pair with UE_i
  If RBj has already been assigned to other UE then
      {re-matching process}
End If
If UE_i is belong to GBR1 or GBR2 then
  Do right extension and left extension until guaranteed bit rate is achieved or
  one side is either a cross point or the RB that has been assigned.
  If guaranteed bit rate is not achieved then
    If right side unassigned RB's SNR ratio is better then left side RB then
      Do right extension until guaranteed bit rate is achieved or reaches the side that
       has been assigned. And these RBs is assigned to UE_i
    End If
    Else
      Do left extension until guaranteed bit rate is achieved or reaches the side that has
       already been assigned. And these RBs is assigned to UE_i
  End Else
  End If
End If
Else If UEi is belong to non-GBR then
      Do right and left extension until both side are cross points or reach the RBs that
       have already been assigned.
End Else
For every RB which is not assigned to any UE Do
    Assign this RB to adjcent non-GBR UE
End For
```

IV. EXPERIMENTAL SIMULATIONS

In order to investigate the efficiency of the proposed scheme, exhaustive simulations were conducted to examine the resource allocation performance of UEs with different QCI and minimum bandwidth demands. Table 1 specifies the simulation environment and related parameters. The simulation results of the proposed scheme are compared with that of the RME-modified scheme, which is regarded as the no-matching scheme. In order to support QoS scheduling, the RME-modified scheme chooses the UE for allocation according to their scheduling priority and sets its starting point of assignment to be the RB with the best CQI without matching. Then the RB assignment is the same as the proposed scheme.

Table 1 Simulation environment

Parameters	Content
Channel Model	ITU Veh-A
Frequency	20MHz
Subcarrier per RB	12
RB number	100
RB number per subband	8
UE number	GBR1:5 to 40 GBR2: 5 to 40 nonGBR:10
QoS type	GBR1: Video Stream GBR2: VoIP Non-GBR: FTP
α	8
Allocation cycle	5ms&10ms
MCS	QPSK 1/2、2/3、3/4、4/5 16QM 1/2、2/3、3/4、4/5
GBR minimum bit rate(kbps)	GBR1 : 800 GBE2 : 300

Three kinds of traffic models, video streaming, VoIP, and FTP, were adopted for simulations. The parameters of these three models [11, 12] are listed in Table 2, 3, and 4, respectively. Here the video streaming and VoIP traffic were regarded as GBR1 and GBR2 traffic types, respectively, and the FTP traffic was treated as the non-GBR service.

Table 2 Video streaming traffic model [11]

Parameters	Content
Inter-arrival time between frames	50ms
FPS(frame per second)	20
Number of packets/slices in a frame	8
AVG bit rate	640kbps
Packet/slice size	Truncated Pareto : Mean 500Byte 、Max 2500Byte
Inter-arrival time between slices	Truncated Pareto : Mean 2.5ms max 6ms
Video length	As simulation time

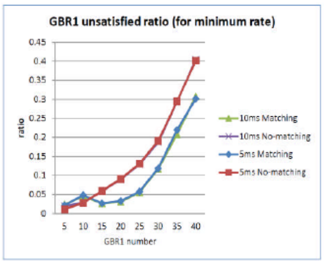
Table 3 VoIP traffic model [11]

Parameters	Content
Talk time	Exponential mean=1026ms
Silent time mean	Exponential mean=1171ms
Packet size	63byte(3byte compressed header)
Generating packets cycle	20ms
Average call holding time	As simulation time
AVG bit rate	32kbps

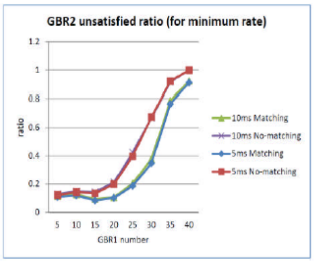
Table 4 FTP traffic model [12]

Parameters	Content
File size	Truncated Lognormal ： Mean = 2Mbytes Std. Dev. = 0.722 Mbytes Maximum = 5 Mbytes
Reading time	Exponential mean= 180 sec

Two resource allocation periods, 5 ms and 10 ms, were assumed during the simulations. Both of the unsatisfied ratio and delay time are examined and compared. Figure 3 illustrates the unsatisfied ratios of GBR1 and GBR2 by increasing the number of GBR1 and the numbers of GBR2 and non-GBR UEs are all fixed to be 10. The simulation results show that the proposed scheme, which adopts the matching algorithm, demonstrates better performance than the no-matching scheme. It notes that the GBR2 has higher unsatisfied ratio than GBR1 because GBR1 has higher scheduling priority than GBR2.



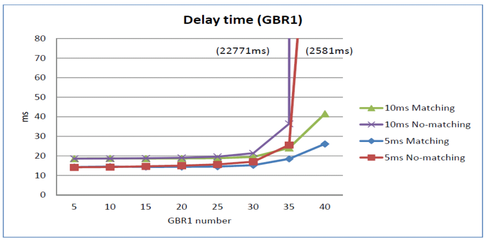
(a) GBR1



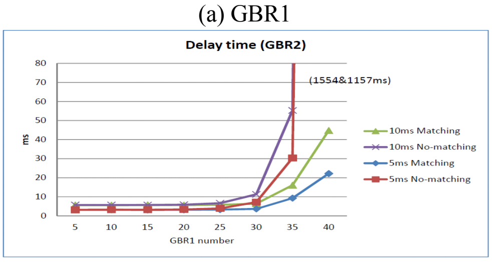
(b) GBR2

Figure 3 Unsatisfied ratios of GBR1 and GBR2

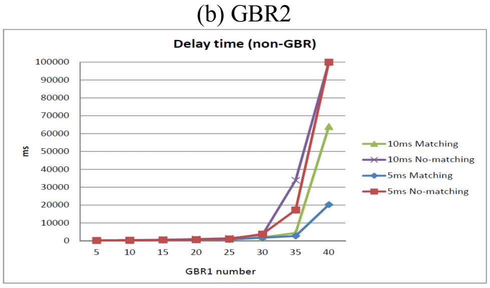
Figure 4 illustrates the delay times of these three kinds of traffics. It shows that the proposed scheme can effectively allocate radio resources and results in much lower delay time, especially for the high traffic load, when compared with the no-matching scheme. In addition, the shorter allocation period, i.e. 5 ms, can improve the delay performance because the resource can be more effective utilized due to more precise allocation.



(a) GBR1



(b) GBR2



(c) Non-GBR

Figure 4 Delay times of GBR1, GBR2, and non-GBR

V. CONCLUSIONS

This study deals with the radio resource allocation issue in localized SC-FDMA system. Basically, it is and NP problem to get the optimum allocation for multiple UEs with various and changeable channel condition. The proposed matching algorithm adopts the stable matching concept of the Gale-Shapley algorithm to obtain the appropriate RB of each UE by considering QoS, channel quality, and bandwidth. Then the assignment algorithm allocates consecutive RBs to satisfy the bandwidth requirement of UE. Simulation results show that the proposed scheme achieves a significant improvement when compared with the scheme without matching.

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