A QoS-based Power Allocation for Cellular Users with Different Modulations

Ying Wang*, Ahmed Abdelhadi†
*EECS, University of Michigan, wying@umich.edu,
†Hume Center, Virginia Tech, aabdelhadi@vt.edu

Abstract—In this paper, we propose a novel optimal power allocation method that features a power limit function and is able to ensure more users reach the desired Quality-of-Service (QoS). In our model we use sigmoidal-like utility functions to represent the probability of successful reception of packets at user equipment (UEs). Given that each UE has a different channel quality and different location from base station (BS), it has different CQI and modulation. For each CQI zone, we evaluate the power threshold which is required to achieve the minimum QoS for each UE and show that the higher CQI the lower power threshold is. We present a resource allocation algorithm that gives limited resources to UEs who have already reached their pre-specified minimum QoS, and provides more possible resources to UEs who can not reach it. We also compare this algorithm with the optimal power allocation algorithm in [1] to show the enhancement.

Index Terms—Resource Allocation, Quality of Service, Power Limit, CQI, LTE

I. INTRODUCTION

In recent years, the user demand for higher data rates and QoS is increasing significantly. The main requirements for the new access network are higher spectral efficiency and higher peak data rates [2]. These needs lead to the existing of 3GPP long term evolution (LTE), the access part of the Evolved Packet System (EPS), to provide higher modulation schemes such as QPSK, 16-QAM, and 64-QAM and. LTE equips the Medium Access Control (MAC) protocol layer. LTE scheduler prioritizes the QoS requirements among the UEs and allocates resources to the UEs based on the information that is feedback from the UEs. This information is the Channel Quality Indicator (CQI) which indicates the perceived quality and the data rate can be supported by the downlink channel. It is carried out when a Block Error Rate (BLER) is smaller than 10% and the thresholds are set to the SINR values with the BLER smaller than 10%. Each UE has a different channel quality, i.e CQI value, based on its location from the BS and the environment surrounding it. It was shown in [6] that the sigmoidal-like utility function is a good approximation for the CQI verses power allocated. Therefore, in our paper we represent each CQI with a sigmoidal-like function.

Opportunistic resource allocation algorithms has been proposed in [7] to improve the system efficiency, however the QoS requirements of users and fairness in allocation failed to be addressed. In our work, we focus on the enhancement of the resource allocation problem with a sigmoidal-like utility function for each UE. The optimization problem is to achieve the fairness in resource allocation and ensure each UE receives the maximal possible resources to achieve its minimal QoS.

A. Related Work

Early in [8], the authors characterized the resource allocation problem as a global optimization problem and proposed utility proportional fairness criterion to solve this problem. They also showed the bandwidth utility values were ensured to be proportional fair in equilibrium. In [9], both utility-based resource management and QoS framework and resource allocation algorithms were studied. The authors also showed an efficient resource allocation for heterogeneous traffic with various QoS requirements.

The study in [10] proposed a non-convex optimization algorithm to maximize the utility functions in wireless networks. This optimization framework included a distributed-gradient-based algorithm that solves the optimization problems when the duality gap is zero. In cases of non-zero duality gap, they presented the fair-allocation heuristic and led to an approximated optimal solution.

In [11], the study modeled the user’s utility function using sigmoidal like functions and it provided an algorithm for optimal power allocation in a cellular network. Utility proportional fairness was considered and the optimization problem was stated as a product of utilities of all users. In [11] and [12], a similar approach for optimal power allocation was introduced.
In LTE, the frequency domain scheduler allocates a certain resource block (RB) at a certain transmit rate to a UE basing on the CQI feedback from UEs [13]. In [13], the authors proposed a trackable model for the CQI feedback schemes in LTE. And in [14], the author proposed a dynamic resource allocation algorithm with imperfect channel sensing. Their algorithm keeps tracking the change in channel quality and uses discrete stochastic optimization method to the joint power and channel allocation problem.

In [15], the authors formulated and solved the power allocation problem for multihop transmission. They suggested that the system enhancement is required especially when the highly unbalanced communication links or a large number of hops in the systems, and this enhancement is done by the power optimization. The study in [16] proposed an optimal resource allocation for a set of time-invariant additive white Gaussian noise broadcast channels for code division and time division.

The research work in [17] presented a suboptimal solution that fairly allocates resources and meets the QoS constraints. They showed that the algorithm efficiently converges close to the optimal, and performances well in terms of fair scheduling among users. In [18], the study presented a resource allocation framework in multiuser orthogonal frequency division multiplexing (MU-OFDM) systems to achieve variable proportional fairness constraints. This algorithm maximizes the sum channel capacities while maintaining proportional fairness among all UEs.

B. Our Contributions

The main contributions of this paper are:

- we proposed a novel optimal power allocation algorithm that includes the power limit feature.
- we simulated and showed that the optimal power allocation with power limit would ensure more UEs reach the desired QoS, and more power would be allocated to UEs who can not reach the power limit.
- we compared this algorithm with the optimal power allocation algorithm in [1] to measure the improvements.

This paper is structured as follow. Section II gives the overview of the system model. In Section III we present the process of how we mapped the CQIs to utility functions, and list the resulted parameters corresponding to each CQI along with discussions. The optimal power allocation with power limit algorithm is described in detail in Section IV Section V discusses the simulation results and compares the results with the one of algorithm in [1]. Finally, Section VI concludes the paper.

II. SYSTEM MODEL

In this paper, we consider a single cellular system consisting of a single BS and $M$ UEs. Each UE is placed in a different CQI zone and has a different CQI and corresponding modulation. The set up is shown in Figure 1. The UE feeds back CQI to indicate the downlink channel quality. It scales from 0 to 15 as shown in Table I. A larger CQI indicates a better channel quality. Based on the CQI information, the BS selects an appropriate modulation scheme and code rate for downlink transmission. The BS distributes its total power $P_T$ to all UEs in the cell.

III. CQI MAPPING TO UTILITIES

The path-loss is calculated in (1) to map each CQI to its corresponding distance from BS as shown in Figure 2. $\alpha$ in (1) is the path loss exponent and in a urban environment it equals to 3.5. Therefore each CQI zone will have different distances from the BS as well as the UEs’ location.

$$P_{UE} = \frac{P_{BS} f}{c(4\pi d)^\alpha} \tag{1}$$

where $f$ is the carrier frequency and $c$ is speed of the light.

The probability of the successful package reception is calculated from the efficiencies of different CQI values in
Table I Utility Parameters

| CQI Index | Modulation | Code Rate X 1024 | Efficiency  | a    | b    |
|-----------|------------|------------------|-------------|------|------|
| 1         | QPSK       | 78               | 0.1523      | 0.8676 | 6.2257 |
| 2         | QPSK       | 120              | 0.2344      | 0.8761 | 6.1057 |
| 3         | QPSK       | 193              | 0.3880      | 0.8466 | 6.3812 |
| 4         | QPSK       | 308              | 0.6016      | 0.8244 | 6.5526 |
| 5         | 16QAM      | 449              | 0.8770      | 0.8789 | 6.1467 |
| 6         | QPSK       | 602              | 1.1758      | 1.0188 | 5.3029 |
| 7         | 16QAM      | 378              | 1.4766      | 0.5077 | 9.8303 |
| 8         | 16QAM      | 490              | 1.9141      | 0.6086 | 8.1999 |
| 9         | 16QAM      | 616              | 2.4063      | 0.7524 | 6.6333 |
| 10        | 64QAM      | 406              | 2.7305      | 0.3697 | 12.5005 |
| 11        | 64QAM      | 567              | 3.3223      | 0.4722 | 9.7873 |
| 12        | 64QAM      | 666              | 3.9023      | 0.6248 | 7.3974 |
| 13        | 64QAM      | 722              | 4.5234      | 0.8376 | 5.5177 |
| 14        | 64QAM      | 873              | 5.1152      | 1.1510 | 4.0153 |
| 15        | 64QAM      | 948              | 5.5547      | 1.6471 | 2.8058 |

where $P_T$ is the total power of the BS, $M$ is the number of UEs and $P = \{P_1, P_2, ..., P_M\}$.

Given that the objective function in (3) is strictly concave, the optimization problem is convex and therefore there exists a unique tractable global optimal solution.

B. Robust Distributed Algorithm with Power Limits

The power limit is the transmitter power that a UE requires to achieve his/her QoS. In our model, we assume the minimum QoS is to reach 95% successful packet, and the pre-specified power limits are the amount of power required to achieve this QoS. The algorithm is shown in Algorithm (1) and (2):

The algorithm is divided into a UE algorithm shown in Algorithm (1) and a BS algorithm shown in Algorithm (2). Each UE starts sending an initial bid $w_i(1)$ to the BS. The BS calculates the difference between the received bid $w_i(n)$ and the previously received bid $w_i(n-1)$ and compares its value to a pre-specified threshold $\delta$. If it is greater than the threshold $\delta$, the BS calculates the shadow price $p(n) = \sum_{n=1}^{M} w_i(n)$ and sends it to the UEs. Each UE receives the shadow price $p(n)$ from the BS and solves the power $P_i$ that maximizes $(\log U_i(\gamma_i(P_i)) - p(n)P_i)$, then compares $P_i$ to its power limit $Power Limit_i$ and the user stays in the process if $P_i < Power Limit_i$. If it is greater the UE$_i$ exists the power allocation and $P_i$ is subtracted for the total power $P_T$. After that each remaining UE calculates a new bid $w_i(n) = p(n)P_i(n)$ and decreases the difference between the current bid and previous bid $w_i(n) - w_i(n-1)$ using exponential function $\Delta w(n) = \frac{1}{2}e^{\Delta}$. The reason that we use this exponential function is that when $\sum_{i=1}^{M} P_i^{inf} = \sum_{i=1}^{M} b_i \geq P_T$ the convergence to the optimal powers can no longer be guaranteed if it fluctuates about the global optimal solution. Therefore the exponential fluctuation decay function is introduced to resolve the problem. Each remaining UE sends the new bid $w_i(n) = w_i(n-1) + \text{sign}(w_i(n) - w_i(n-1))\Delta w(n)$ to BS.
This process repeats until $|w_i(n) - w_i(n-1)|$ is less than the pre-specified threshold $\delta$.

V. SIMULATION RESULTS

The BS has total power $P_T = 150$W to distribute to 15 UEs. Each UE stands in a different CQI zone and is represented by a sigmoidal-like utility function. Algorithm 1 and 2 were simulated in MATLAB. The simulation results showed that the optimal powers were allocated to all users as shown in Figure 4. The bidding process for 15 UEs is plotted in Figure 5.

We also provided a comparison of the allocated power for each UE between the optimal power allocation algorithm with power limit and without it in Table II. We assumed the minimal QoS is to reach at least a 95% success package transmission at UEs. Column 2 in Table II indicates the power that required by each UE to achieve the minimal QoS, and we set those values to be the power thresholds. For example, UE 15 requires 5.213W to reach the minimal QoS, after it receives

| UE  | Power to reach QoS (W) | Power with PL (W) | Power without PL (W) | Reach desired QoS |
|-----|-----------------------|------------------|----------------------|------------------|
| 1   | 23.240                | 10.491           | 9.122                | No               |
| 2   | 18.210                | 10.401           | 9.045                | No               |
| 3   | 17.650                | 10.723           | 9.318                | No               |
| 4   | 14.720                | 10.978           | 9.5337               | No               |
| 5   | 13.760                | 10.373           | 9.0218               | No               |
| 6   | 11.910                | 9.0968           | 7.9388               | No               |
| 7   | 11.350                | 11.502           | 13.6145              | Yes              |
| 8   | 11.060                | 11.223           | 11.6935              | Yes              |
| 9   | 10.790                | 10.849           | 9.7709               | Yes              |
| 10  | 10.690                | 12.291           | 16.7008              | Yes              |
| 11  | 10.650                | 11.376           | 13.6879              | Yes              |
| 12  | 10.260                | 10.397           | 10.8536              | Yes              |
| 13  | 9.181                 | 9.2056           | 8.4798               | Yes              |
| 14  | 7.485                 | 7.4862           | 6.4664               | Yes              |
| 15  | 5.213                 | 5.2229           | 4.7468               | Yes              |
5.2229W from the BS it quits the algorithm and the remaining power is allocated to the rest of the UEs. There are more UEs achieving their minimal QoS, e.g. UE 13 receives 9.2056W and achieves the desired QoS using our algorithm while it only receives 8.4798W and fails to meet the QoS with the algorithm without power limit. With our new algorithm there are 9 UEs achieving the minimal QoS while the algorithm without power limit in only has 5 UEs meeting the QoS requirements. Even for those UEs who do not reach the desired QoS, our algorithm still allocates higher power to them than the algorithm without power limit. For example, UE 1 receives 10.491W by using our algorithm while 9.122W is allocated to it with the algorithm without the power limit.

VI. CONCLUSION

In this paper, we proposed a new optimal power allocation algorithm with power limit feature that ensures more UEs achieve the desired QoS and guarantees more power to be allocated to UEs that can not meet the QoS requirements. We simulated this algorithm with one BS and 15 different CQI UEs. We showed that this new algorithm allows more users to reach their desired QoS, and at the same time more power is allocated to the users who do not reach the power limits comparing to the algorithm in [1].

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