Optimal Resource Allocation for Smart Phones with Multiple Applications with MATLAB Instructions

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Chapter 1

Introduction

This article describes the steps for implementing the algorithm presented in [2]. The article starts with a narrative of the motivation and background of resource allocation problem in wireless network. Then, this is followed by a description of the utility functions used in the problem presented in [2]. Finally, we present step by step MATLAB instructions for plotting the results in [2]. We drop the mathematical details of the problem from this article. More rigorous mathematical details on the subject can be found in [2] and more background on the subject can be found in [3].

1.1 Motivation and Background

Recently, the volume of mobile traffic per user has significantly increased along with the number of users using mobile service [4–7]. Therefore, researchers in the field of mobile communications focus on improving quality of service (QoS) [8–10], also known as quality of experience (QoE) [11], for cellular users [12]. Some researchers work on improving network layer, e.g. research in [13–16], others work on improving physical layer, e.g. research in [17,18]. Additionally, game theory and microeconomics have been utilized for improving QoE as in [19, 20] and [21, 22], respectively.

In the context of LTE third generation partnership project (3GPP) [23–25], network layer QoS with energy efficiency was studied in [26–28]. Similarly, it was studied for WiMAX [29] in [30, 31], Universal Mobile Terrestrial System (UMTS) [32, 33] in [34], and Mobile Broadband [35] in [36]. Embedded-based QoS improvements for cellular users was shown in [37–39] and with a focus on battery life was shown in [40, 41]. In [42, 43], authors focused on application layer QoS.

Cross-layer design for QoS between layer of Open Systems Interconnection (OSI) model [44] is addressed in [45,46], and for Asynchronous Transfer Mode (ATM) network protocol stack in [47, 48]. QoS for router in the form of scheduling and shaping for Integrated and Differentiated Services were proposed in [49, 50] and [51–53], respectively.

Resource allocation optimization problem has been tackled in numerous ways for elastic traffic [20, 54], e.g. max-min fairness [55–58] and proportional fairness [59–61]. Authors in [62, 63] presented an optimal solution for proportionally fair elastic traffic and authors in [64, 65] solved for weighted fair queuing (WFQ). For inelastic traffic, the author in [66] presented an approximate solution which is not optimal. In [67, 68], authors showed optimality for inelastic traffic using convex optimization techniques [69]. Multiple applications per user model was presented in [70–73] and multi-class service offering was shown in [74, 75].

The recommendations of PCAST, the President's Council of Advisers on Science and Technology, report [76] directs towards the use of federal spectrum to expand mobile communications spectrum and increase QoS to users [77]. Accordingly, the Federal Communications Commission (FCC) studied the use of federal spectrum, e.g. S-band radars [78, 79], with mobile spectrum [80, 81]. Additionally, the National Telecommunications and Information Administration (NTIA) studied the effect of mobile communications coexisting with radar and WiMAX [82–84].

Multiple carrier scenarios were proposed in [85–89] using non-convex optimization approaches, while [90, 91] presented convex optimization techniques. Carrier aggregation between radar and mobile systems was considered in [92–94], hence, addressing the problems presented in [95–98].

Extensions of the proposed methods in [2, 3] can include ad-hoc network [99–102], multi-cast network [103], and other wireless networks [104–107]. Implementation of these methods were demonstrated for machine to machine communications in [108–112].

1.2 User Applications Utilities

The application utility is a representation of user satisfaction with the provided service for that particular application with respect to the rate allocated by the service provider. In our system [2], we consider two types of applications real-time applications which are represented by sigmoid functions and delay-tolerant applications which are represented by logarithmic functions. Sigmoid applications, [75, 113, 114], have the following mathematical representation

$$U(r) = c\Big(\frac{1}{1+e^{-a(r-b)}} - d\Big) \tag{1.1}$$

where $c = \frac{1+e^{ab}}{e^{ab}}$ and $d = \frac{1}{1+e^{ab}}$. This corresponds to the MATLAB code [1]

```
c = (1+exp(a.*b))./(exp(a.*b));
d = 1./(1+exp(a.*b));
y(i) = c(i).*(1./(1+exp(-a(i).*(x-b(i))))-d(i));
```

while normalized logarithmic utility [61, 115, 116], have the following mathematical representation

$$U(r) = \frac{\log(1+kr)}{\log(1+kr^{\max})} \tag{1.2}$$

where $r^{\max}$ and k are 100% user satisfaction rate and rate increase, respectively. This corresponds to the MATLAB code [1]

```
y2(i) = log(k(i).*x+1)./(log(k(i).*100+1));
```

In [2], the parameters in Table 1.1 are used and shown in Figure 1.1 [117–119].

Table 1.1: Applications Utilities [1]

Sig1	$a = 5,\ b = 10$	e.g. VoIP	Log1	$k = 15,\ r_{max} = 100$
Sig2	$a = 3,\ b = 20$	e.g. SD video streaming	Log2	$k = 3,\ r_{max} = 100$
Sig3	$a = 1,\ b = 30$	e.g. HD video streaming	Log3	$k = 0.5, r_{max} = 100$

Realistic examples for values of a, b and k for real mobile applications, e.g. youtube and FTP, are shown in [1, 120, 121].

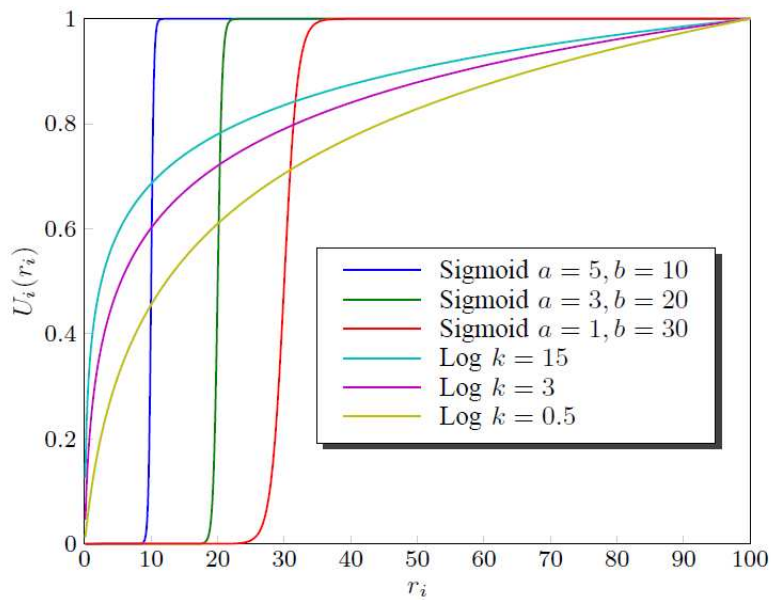

Figure 1.1: Applications Utilities [1]

Chapter 2

Single Carrier with Multiple Utility per User

2.1 System Model of Single Carrier with Multiple Utility per User

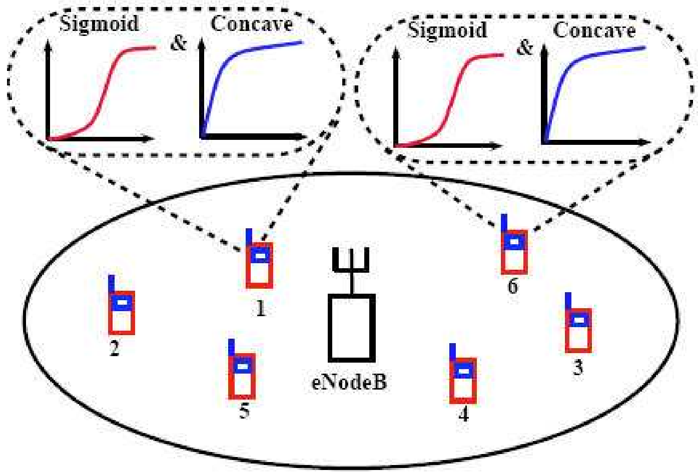

Figure 2.1: System Model of Single Carrier with Multiple Utility per User

A single cell mobile cellular system is considered consisting of a single eNodeB and M UEs shown in Figure 2.1. The rate allocated by the eNodeB to i^{th} UE is given by r_i. Each UE has its own utility function $V_i(r_i)$ that corresponds to the applications running on the UE. The objective is to determine the optimal rates the eNodeB shall allocate to the UEs with a utility proportional fairness objective function. We assume the user utility function $V_i(r_i)$ of i^{th} UE is given by:

$$V_i(r_i) = \prod_{j=1}^{N_i} U_{ij}^{\alpha_{ij}}(r_{ij}) \tag{2.1}$$

where $U_{ij}(r_{ij})$ is the j^{th} application utility function, r_{ij} is the rate allocated to the j^{th} application, and α_{ij} is the j^{th} application usage percentage on the i^{th} UE (i.e. $\sum_{j=1}^{N_i} \alpha_{ij} = 1$ and $r_i = \sum_{j=1}^{N_i} r_{ij}$).

In MATLAB the aggregated utility of two applications is coded as:

```
alpha = [0.1    0.5    0.9 0.1    0.5    0.9 ;  0.9    0.5    0.1 0.9    0.5    0.1];
k = [15 12 9  6   3  1  ];
a = [5  4  3  2   1  0.5];
b = [5  10 15 20  25 30 ];
c = (1+exp(a.*b))./(exp(a.*b));
d = 1./(1+exp(a.*b));
for i = 1: length(a)
    % Sigmoid utility function
    y(i) = c(i).*(1./(1+exp(-a(i).*(x-b(i))))-d(i));
    % Logarithmic utility function
    y2(i) = log(k(i).*x+1)./(log(k(i).*100+1));
    m(i) = exp(-a(i).*(x-b(i)));
    % Diff Sigmoid utility function
    dy_sig(i) = a(i).*m(i)./((1+m(i)).*(1-d(i).*(1+m(i))));
    % Diff Logarithmic utility function
    dy_log(i) = k(i)./((1+k(i).*x).*log(1+k(i).*x));
end
%%%%%%%%% the log utility functions %%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
z = log(y);
z2 = log(y2);
%%%%%%%%% the multiple utility functions %%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
u = alpha(1,:).*z + alpha(2,:).*z2;
```

2.2 Distributed Algorithm

The optimal rates are allocated in two-stages:

- In the first-stage, eNodeB UE resource allocation (EURA) algorithm

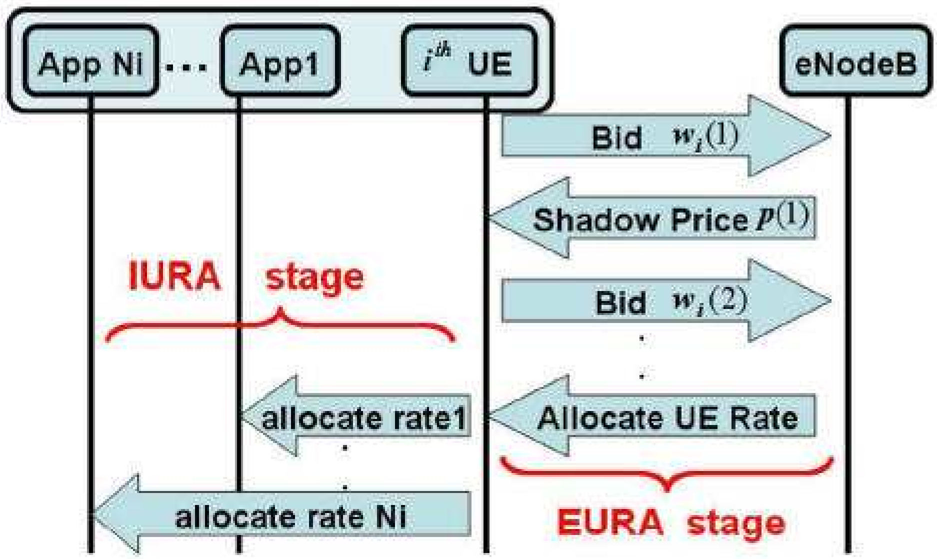

Figure 2.2: Transmission of Distributed Algorithm

allocates the users rates r_i with the fluctuation decay function for robust performance.

- In the second-stage, internal UE resource allocation (IURA) algorithm allocates the applications rates r_{ij} internally in the UEs.

2.2.1 EURA Algorithm

In this section, we present the first-stage of resource allocation where the rates r_i are allocated to the UEs. The algorithm is divided into a UE algorithm shown in Figure 2.3 and a eNodeB algorithm shown in Figure 2.4. The algorithm is a modification of the distributed algorithms in [2]. In Algorithm shown in Figure 2.3 and 2.4:

- Each UE starts with an initial bid $w_i(1)$ which is transmitted to the eNodeB.

```
w = [10 10 10 10 10 10]/10;
```

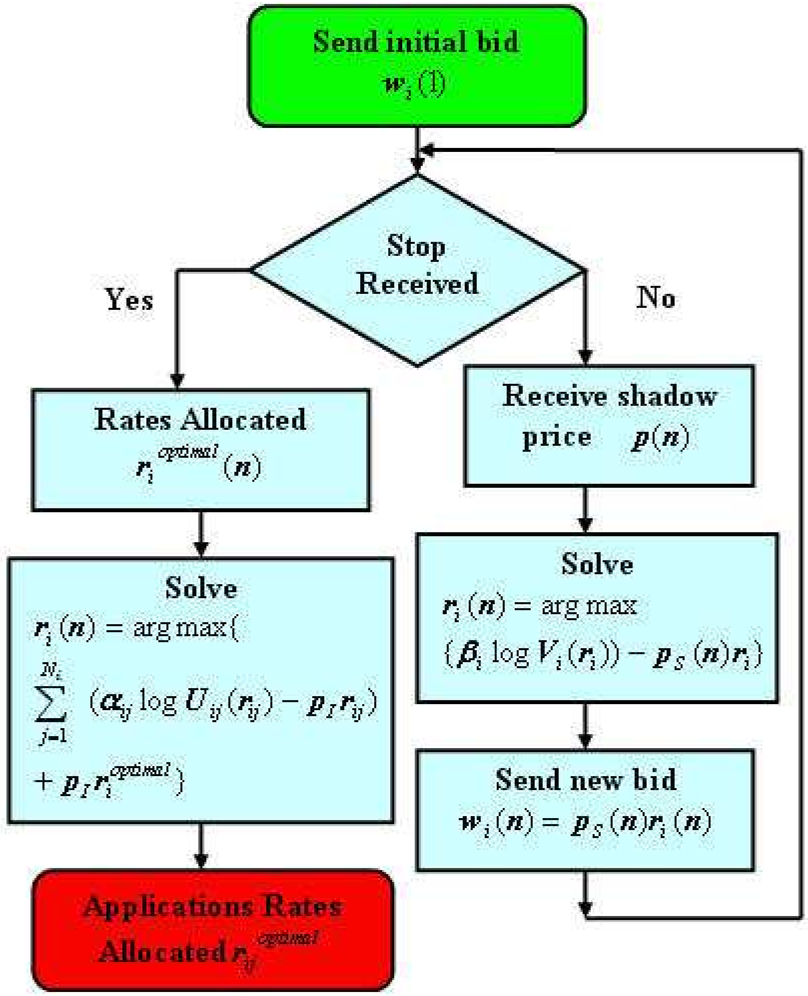

Figure 2.3: UE Distributed Algorithm

- The eNodeB calculates the difference between the received bid $w_i(n)$ and the previously received bid $w_i(n-1)$ and exits if it is less than a pre-specified threshold δ.

```
while  (delta > 0.001) %(time<80)%(
      :
      :
      :
```

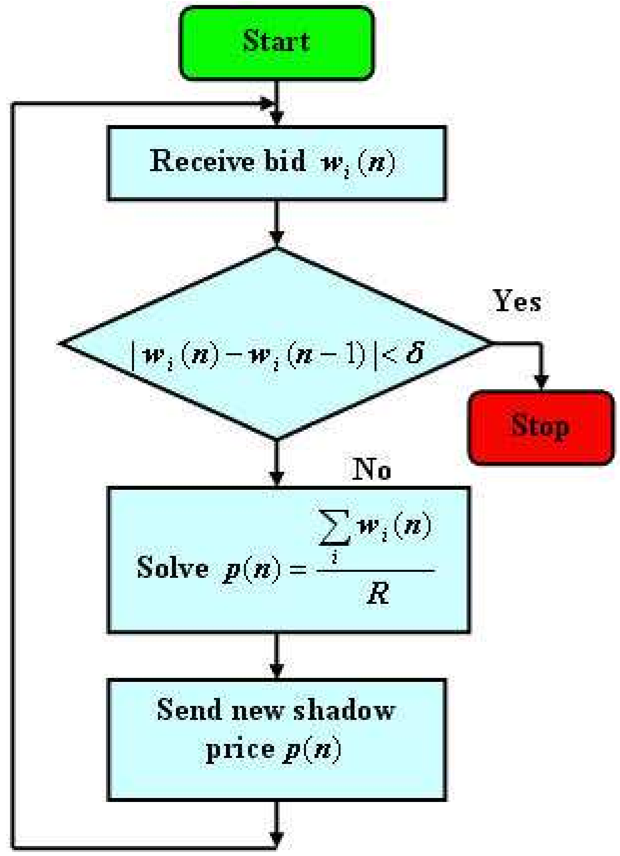

Figure 2.4: eNodeB Distributed Algorithm

```
    :
    delta = max(abs(w-w_old))
end
```

- We set $w_i(0) = 0$. If the value is greater than the threshold, eNodeB calculates the shadow price $p_E(n) = \frac{\sum_{i=1}^{M} w_i(n)}{R}$ and sends that value to all the UEs.

```
soln(i) = fzero(@(x) utility(x,ii,pp,time),[.001
   1000000]);
```

- Each UE receives the shadow price to solve the rate r_i that maximizes

$\log \beta_i V_i(r_i) - p_E(n) r_i$.

In MATLAB the derivative of the log of the aggregated utility function is:

```
k = [15 12 9   6    3   1   ];
a = [5   4   3   2    1   0.5];
b = [5   10 15 20   25 30 ];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

c = (1+exp(a.*b))./(exp(a.*b));
d = 1./(1+exp(a.*b));

for i = 1: length(a)

    m(i) = exp(-a(i).*(x-b(i)));
    dy_sig(i) = a(i).*m(i)./((1+m(i)).*(1-d(i).*(1+
       m(i))));
    dy_log(i) = k(i)./((1+k(i).*x).*log(1+k(i).*x))
       ;
end
dy = alpha(1,:).*dy_sig + alpha(2,:).*dy_log;

f = dy(ii)-pp;
```

In MATLAB the equation is solved by:

```
soln(i) = fzero(@(x) utility(x,ii,pp,time),[.001
   1000000]);
```

- That rate is used to calculate the new bid $w_i(n) = p_E(n) r_i(n)$.

```
 w(i) = r_opt(i) * p(time);
```

- Each UE sends the value of its new bid $w_i(n)$ to eNodeB. This process is repeated until $|w_i(n) - w_i(n-1)|$ is less than the threshold δ.

```
while  (delta > 0.001) %(time<80)%(
    :
```

```
    :
    :
    :
    delta = max(abs(w-w_old))
end
```

2.2.2 IURA Algorithm

In this section, we present the second-stage of resource allocation where the rates r_{ij} are allocated internally in the UE to its applications. The algorithm is:

- The UE uses the allocated rate in the first-stage r_{ij}^{opt} and solves the maximization problem $\mathbf{r}_i = \arg\max_{\mathbf{r}_i} \sum_{j=1}^{N_i} (\alpha_{ij} \log U_{ij}(r_{ij}) - p_I r_{ij}) + p_I r_{ij}^{\text{opt}}$. In MATLAB optimization problem is solved by solving a nonlinear equation:

```
soln(i) = fzero(@(x) utility(x,ii,pp,time),[.001
   1000000]);
```

- The UE allocates the rates r_{ij} to the corresponding applications.

2.3 Centralized Algorithm

To minimize the transmission overhead we introduce the centralized resource allocation algorithm. In this algorithm:

- Each UE sends the utility parameters to the eNodeB.
- The eNodeB solves the optimization problem and allocates the rates to the applications. The solution $\mathbf{r}$ of the optimization problem $\mathbf{r} = \arg\max_{\mathbf{r}} \sum_{i=1}^{M} \beta_i \sum_{j=1}^{N_i} \alpha_{ij} \log U_{ij}(r_{ij}) - p(\sum_{i=1}^{M} \sum_{j=1}^{N_i} r_{ij} - R)$.
- It is the value of r_{ij} that solves equation $\frac{\partial \log U_{ij}(r_{ij})}{\partial r_{ij}} = p(n)$.

  In MATLAB the functions are:

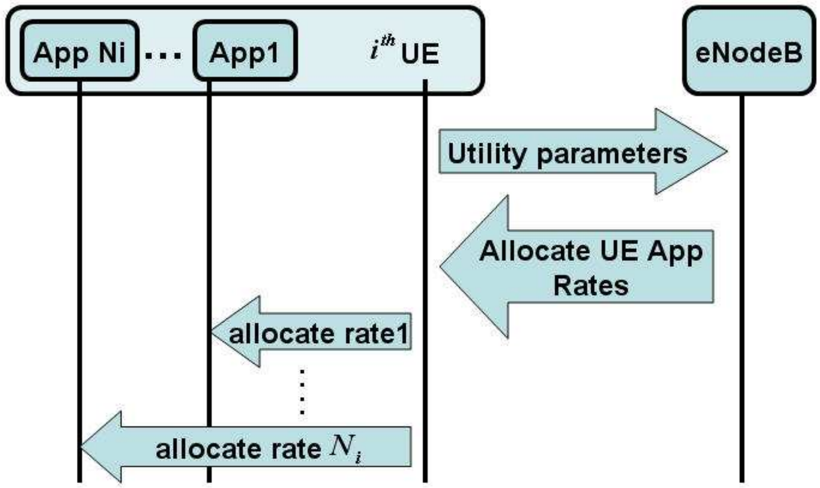

Figure 2.5: Transmission of Centralized Algorithm

```
k = [15 12 9   6    3   1   ];
a = [5   4   3   2    1   0.5];
b = [5   10 15 20   25 30 ];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

c = (1+exp(a.*b))./(exp(a.*b));
d = 1./(1+exp(a.*b));

for i = 1: length(a)

    m(i) = exp(-a(i).*(x-b(i)));
    dy_sig(i) = a(i).*m(i)./((1+m(i)).*(1-d(i).*(1+
        m(i))));
    dy_log(i) = k(i)./((1+k(i).*x).*log(1+k(i).*x))
        ;
end
dy = alpha(1,:).*dy_sig + alpha(2,:).*dy_log;

f = dy(ii)-pp;
```

It is the intersection of the horizontal line $y = p(n)$ with the curve

$y = \frac{\partial \log U_{ij}(r_{ij})}{\partial r_{ij}}$ which is calculated in the eNodeB.

In MATLAB it is solved by:

```
soln(i) = fzero(@(x) utility(x,ii,pp,time),[.001
   1000000]);
```

- The eNodeB transmit the allocated rates to the UE.

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