

**Power Allocation with different modulations for
Cellular Networks using MATLAB**

by

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Chapter 1

Introduction

This article presents a tutorial for MATLAB simulation in the published paper [1]. The article starts with a concise background on the problem of power allocation with the relevant literature review of this topic. Then, it provides the MATLAB Simulation steps used to plot the figures in [1].

1.1 Motivation, Background, and Related Work

The need for throughput increase can be strongly witnessed for wireless communications [2–5]. This is accompanied with the need for enhancement to quality of service (QoS) [6–8] and quality of experience (QoE) [9, 10]. For instance in [11–14], QoS of Open Systems Interconnection (OSI) Model is addressed for network layer, in [15, 16] for physical layer, and in [17, 18] for application layer. Game theory was also used in [19–22], network layer energy efficiency in [23–25] for LTE third generation partnership project (3GPP) [26–28]. Worldwide Interoperability for Microwave Access (WiMAX) was investigated in [29–31], Mobile Broadband [32] in [33], and Universal Mobile Terrestrial System (UMTS) [34, 35] in [36].

Additionally, authors utilize the benefits of cross-layer design of OSI model for enhancing QoS in [37, 38]. Scheduling and shaping in routers to improve QoS are shown for integrated services in [39, 40], differentiated services in [41–43], Asynchronous Transfer Mode (ATM) in [44, 45], and battery life and embedded-based QoS research in [46–50].

Delay-tolerant traffic [20, 51] for resource allocation optimization is historically studied for proportional fairness in [52–54] and for and max-min fairness in [55–58]. The solution of delay-tolerant traffic with optimality is shown in [59–62] while approximate solutions are presented in [63–65]. The optimal

solution of real-time applications with sigmoid utility functions is introduced in [66] using convex optimization techniques [67]. Extensions to this seminal work for different scenarios are shown in [68–74].

Carrier aggregation methods for resource allocation using non-convex optimization techniques are shown in [75–79]. While the optimal solution using convex optimization techniques is presented in [80–84]. The extensions of this research work on carrier aggregation and following the President Council of Advisers on Science and Technology (PCAST) recommendations [85, 86] for sharing underutilized spectrum are presented in [87, 88]. Additionally, recommendations from the Federal Communications Commission (FCC) to share the radar spectrum with commercial cellular spectrum [89–92] and that from the National Telecommunications and Information Administration (NTIA) [93–95] encouraged further studies in [96–102].

The provided simulation tools in this article can be utilized for other applications as well, e.g. multi-cast network [103], ad-hoc networks [104–107], machine to machine (M2M) communications [108–110], and other wireless networks [111–114].

1.2 Example of Utility verses Power

In the simulation presented in [1], sigmoid utility functions [115–124] are used to represent different modulations, see Table 1.1. The corresponding mathematical representation is as follows:

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

where $c = \frac{1+e^{ab}}{e^{ab}}$ and $d = \frac{1}{1+e^{ab}}$ with MATLAB code [121]:

```

1  %%%%%%%%%%
2
3  c = (1+exp(a.*b)) ./ (exp(a.*b));
4  d = 1 ./ (1+exp(a.*b));
5  y(i) = c(i) .* (1 ./ (1+exp(-a(i) .* (x-b(i)))) - d(i));
6
7  %%%%%%%%%%

```

Table 1.1: Channel Quality Indicator [1]

CQI Index	Modulation	Code Rate X 1024	Efficiency
0	No transmission		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3880
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	722	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

In Figure 1.1, cumulative distribution functions (CDF) of the packet successful reception for different modulation schemes are shown [1]. The corresponding MATLAB code is:

In MATLAB:

```

1  %%%%%%%%%%
2
3  for j = 1:15
4      M = [4 4 4 4 4 4 16 16 16 64 64 64 64 64 64];
5      SE = [0.1523 0.2344 0.377 0.6016 0.8770 1.1758
            1.4766 1.9141 2.4063 2.7305 3.3223 3.9023 4.5234
            5.1152 5.5547];

```

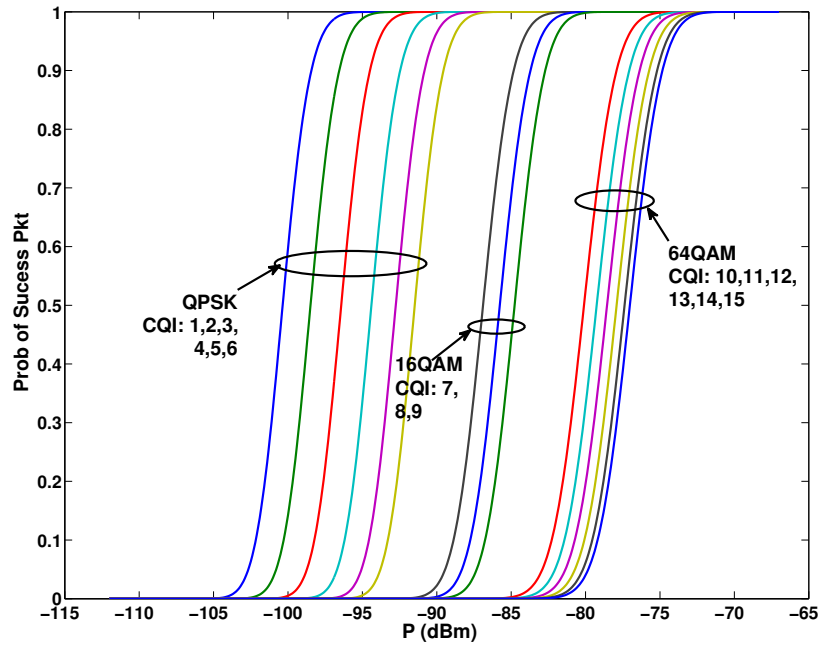


Figure 1.1: CDFs of successful packet reception of different modulations with different CQIs [1].

```

6     SNR = -15:0.1:30;
7     k = log2(M); % Number of bits per symbol
8     % Convert from SNR to EbNo.
9
10    EbNo = SNR - 10*log10(SE(j));
11
12    for ii=1:100
13        ber = berawgn(EbNo,'qam',M(j));
14        ProbOfSuccessReal(ii,:) = 1-ber;
15    end
16
17    ProbOfSucessPktReal(j,:) = prod(ProbOfSuccessReal);
18
19 end

```

```

20
21 P_dBm = SNR -97;
22
23
24 plot(P_dBm, Prob of Sucess Pkt Real);
25 xlabel('P (dBm)'); ylabel('Prob of Sucess Pkt');
26
27 %%%%%%%%%%

```

Chapter 2

Resource Allocation with Radar Spectrum Sharing

2.1 System Model of Power Allocation

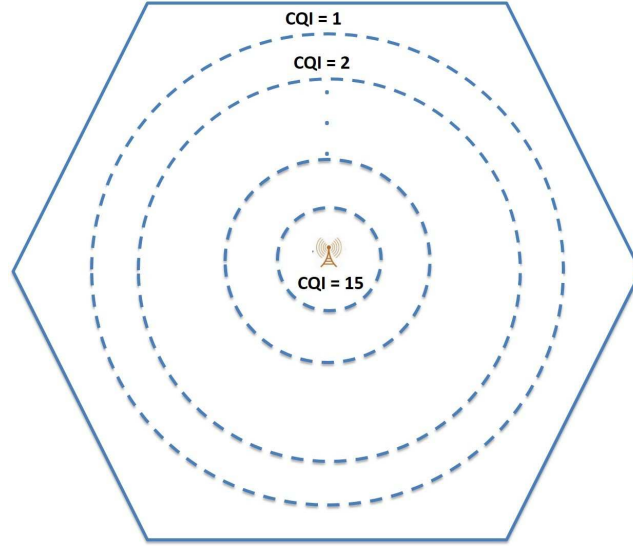


Figure 2.1: System Model

In [1] simulation, the cellular network consists of a single cell and M user equipments (UE)s. Based on the location of the UE, it is assigned a specific channel quality indicator (CQI) by the base station (BS). UEs closer to the BS are assigned higher CQIs with higher modulations. The goal is to optimally allocate power to these UEs to maximize the overall probability of successful reception of the system, see Figure 2.1.

2.1.1 Used Algorithm for Power Allocation

First, we start by curve fitting the CDFs of successful packet reception of different modulations shown in Figure 1.1 to the sigmoid function in equation (1.1). Hence, we can determine the values of a and b of equation (1.1) using the following MATLAB code.

In MATLAB:

```
1  %%%%%%%%%%
2
3  clear all
4  clc
5
6  [r,c] = size(ProbofSucessPktReal);
7
8  for i = 1:15
9
10     xdata =P_W_tx(i,:);
11     xdatafiltered = xdata(xdata<35);
12
13     ydata = ProbofSucessPktReal(i,:);
14     ydatafiltered = ydata(1:length(xdatafiltered));
15
16     x0 = [0 1]; % inital value
17
18     lb = [0,0]; % lower bound
19     ub = [10,50]; % upper bound
20
21     options=optimset('LargeScale','off','MaxFunEvals',
22                     ,100000,'TolFun',1e-6,'MaxIter',1000000,'
23                     Algorithm','levenberg-marquardt');
24
25     x = lsqcurvefit(@utility_fn,x0,xdatafiltered,
26                     ydatafiltered,lb,ub,options);
27
28     parameter_a(i) = x(1); % values for parameter a
29     parameter_b(i) = x(2); % values for parameter b
```

```

28     Utility_para = utility_fn(x,xdatafiltered);
29
30     plot(xdatafiltered,Utility_para,'r','LineWidth',2)
31
32     hold on
33
34     plot(xdatafiltered,ydatafiltered,'b','LineWidth',2)
35
36 end
37
38 hold off
39
40 xlabel('\bf P_{tx} (dBW)','FontSize',18);
41 ylabel('\bf Prob of Sucess Pkt','FontSize',18)
42 legend('Parameterization result','Actual utility')
43
44 %%%%%%%%%%

```

The resulting values of a and b are shown in Table 2.1.

These resulting a and b values are inputs to an optimal power allocation algorithm [1,121]. This power allocation algorithm is distributed between a single base station and users with the pre-determined values of a and b for their corresponding CQIs. The solution is iterative for allocating the power resources with proportional fairness. The algorithm is divided into a user algorithm and a base station algorithm, see [1] for more details.

- Users start by bid initialization $w_i(1)$ and bids are sent to the base station.

In MATLAB

```

1  %%%%%%%%%%
2
3  % Initial Bids
4  w = [10 10 10 10 10 10];
5
6  %%%%%%%%%%

```

Table 2.1: Utility parameters [1]

CQI Index	Modulation	a	b	MSE
1	QPSK	0.8676	6.2257	4.2188E-4
2	QPSK	0.8761	6.1657	3.8427E-4
3	QPSK	0.8466	6.3812	3.5274E-4
4	QPSK	0.8244	6.5526	3.2596E-4
5	QPSK	0.8789	6.1467	3.0182E-4
6	QPSK	1.0188	5.3029	2.8198E-4
7	16QAM	0.5077	9.8303	2.8698E-4
8	16QAM	0.6086	8.1999	2.7031E-4
9	16QAM	0.7524	6.6333	2.5546E-4
10	64QAM	0.3697	12.5005	2.5862E-4
11	64QAM	0.4722	9.7873	2.4527E-4
12	64QAM	0.6248	7.3974	2.3374E-4
13	64QAM	0.8376	5.5177	2.2324E-4
14	64QAM	1.1510	4.0153	2.1364E-4
15	64QAM	1.6471	2.8058	2.0938E-4

- The base station continuously evaluates the difference between currently the received bids $w_i(n)$ and the previously received bids $w_i(n-1)$. The algorithm exits with optimal power allocation if these differences are less than a pre-specified threshold δ .

In MATLAB

```

1  %%%%%%%%%%
2
3  while (delta > 0.001)
4
5      :
6      :
7      :
```

```

8         :
9
10        delta = max(abs(w - w_old))
11    end
12
13    %%%%%%%%%%

```

- For initialization purposes, the initial bids used for comparison are $w_i(0) = 0$. If the comparison between sent bids and initial bids are greater than the threshold δ , the base station uses $p(n) = \frac{\sum_{i=1}^M w_i(n)}{P_T}$ to calculate the shadow price and sends that value to all users.

In MATLAB

```

1    %%%%%%%%%%
2
3    function [p] = base_station(w,Power)
4
5    P_T = Power;
6    p = sum(w)/P_T; % shadow price
7
8    %%%%%%%%%%

```

- Each user uses the shadow price to calculate the power P_i that maximizes $\log U_i(P_i) - p(n)P_i$.

In MATLAB

```

1    %%%%%%%%%%
2
3    for i = 1: length(a)
4        y(i) = log(c(i).*(1./(1+exp(-a(i).*(x-b(i)))))-d
5            (i)));
6
7    end
8
9    for i = 1: 2*length(a)
10        dy(i) = diff(y(i),x);
11    end
12
13    %%%%%%%%%%

```

```

11  :
12  :
13
14  S(i) = dy(i)-p(time);
15  soln(i,:) = double(solve(S(i)));
16
17  :
18  :
19
20  %%%%%%%%%%

```

- The new power value is used to compute the new bid $w_i(n) = p(n)P_i(n)$.

In MATLAB

```

1  %%%%%%%%%%
2
3  w(i) = P_opt(i) * p(time);
4
5  %%%%%%%%%%

```

- Then users transmit the values of their new bid $w_i(n)$ to the base station. This algorithm is repeated until the difference $|w_i(n) - w_i(n-1)|$ is less than the pre-specified threshold δ .

In MATLAB

```

1  %%%%%%%%%%
2
3  while (delta > 0.001)
4      :
5      :
6      :
7      :
8      delta = max(abs(w - w_old))
9  end
10
11  %%%%%%%%%%

```

Using numerical non-linear equation solution techniques to find the optimal solution:

- The P_i s that solve the optimization problem $P_i(n) = \arg \max_{P_i} \left(\log U_i(P_i) - p(n)P_i \right)$ are the same P_i s that solve equation $\frac{\partial \log U_i(P_i)}{\partial P_i} = p(n)$.

In MATLAB:

```

1  %%%%%%%%%%
2
3  dy_sig(i) = a(i).*m(i)./( (1+m(i)).*(1-d(i).*(1+m(i)
      ))) ; % where m(i) = exp (-a(i).*(x - b(i)))
4
5  %%%%%%%%%%

```

- This solution is simply the intersection between the horizontal line $y = p(n)$ with the function $y = \frac{\partial \log U_i(P_i)}{\partial P_i}$ which is calculated for each user utility.

In MATLAB:

```

1  %%%%%%%%%%
2
3  soln(i) = fzero(@ (x) utility_UE(x,ii,pp), [.001
      1000]) ;
4
5  %%%%%%%%%%

```

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