Resource Allocation with Frequency Reuse using MATLAB

by

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Review Article with MATLAB Instructions

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Chapter 1

Introduction

This review article provides steps for plotting the figures provided in the published paper [3]. This article starts with a brief background on the problem of resource allocation. A literature review is included for readers interested in further reading on the topic. The utilities used in the MATLAB code for our resource allocation with frequency reuse algorithm is mentioned. Finally, a step by step MATLAB guide for implementing the algorithm in [1] is presented.

1.1 Motivation, Background, and Related Work

With the increase in usage of wireless applications [5–8], quality of service (QoS) [9–11] and quality of experience (QoE) [12, 13] enhancement are becoming critically important for end user experience. Research done on QoS and QoE usually focus on one of the Open Systems Interconnection (OSI) Model layers [14]). For instance, in [15–18] authors focus on network layer QoS while [19, 20] focus on physical layer and [21, 22] focus on application layer. Other directions for addressing this research topic use game theory methods [23, 24] and microeconomics utilization [25, 26]. Energy efficiency for network layer QoS is presented in [27–29] for 3GPP, LTE third generation partnership project [30–32]. Other authors conducted studies on QoS for WiMAX [33–35], Universal Mobile Terrestrial System (UMTS) [36,37] in [38], and for Mobile Broadband [39] in [40].

For additional improvement to service quality, cross-layer design of OSI model was utilized in [41,42]. Shaping and scheduling of routers for QoS improvement were studied in [43, 44] for Integrated Services, in [45–47] for Differentiated Services and in [48, 49] for Asynchronous Transfer Mode (ATM). In [50–54], battery life and embedded-based QoS improvement were discussed.

Elastic traffic, i.e. delay tolerant traffic, [24, 55] was the focus of resource allocation optimization problem, e.g. proportional fairness [56–58], and max-min fairness [59–62]. Optimal solution for resource allocation with elastic traffic was presented in [63–66] and approximate solutions were presented in [67–69]. Optimal solution using convex optimization [70] for inelastic traffic, i.e. real-time applications, was introduced in [71]. This work was extended with many applications per user in [72–78].

Non-convex optimization methods for carrier aggregation scenarios were presented in [79–83]. The resource allocation optimal solution with carrier aggregation was introduced for this problem in [84–88]. Per the President Council of Advisers on Science and Technology (PCAST) recommendations [89], carrier aggregation between underutilized spectrum and over crowded spectrum is crucial for future spectrum sharing [90–92]. The sharing of radar band [93,94] with cellular band [95,96] was suggested by the Federal Communications Commission (FCC). In [97–99], the interference effects of radar and communications coexistence was studied by the National Telecommunications and Information Administration (NTIA). A particular study on radar/comm coexistence problem [100–103] with optimal allocation was presented in [104–106].

The simulation tools provided in this article can be extended to the problem in [107–109] for machine to machine communications (M2M), in [110] for multi-cast network, in [111–114] for ad-hoc network, and in [115–118] for other wireless networks.

1.2 Sample of Users' Applications Utilities

In the simulation in [3], we use sigmoid utility functions [69, 119, 120] to represent real-time applications. The mathematical representation is as follows:

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

where $c = \frac{1+e^{ab}}{e^{ab}}$ and $d = \frac{1}{1+e^{ab}}$ with MATLAB code [2]:

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

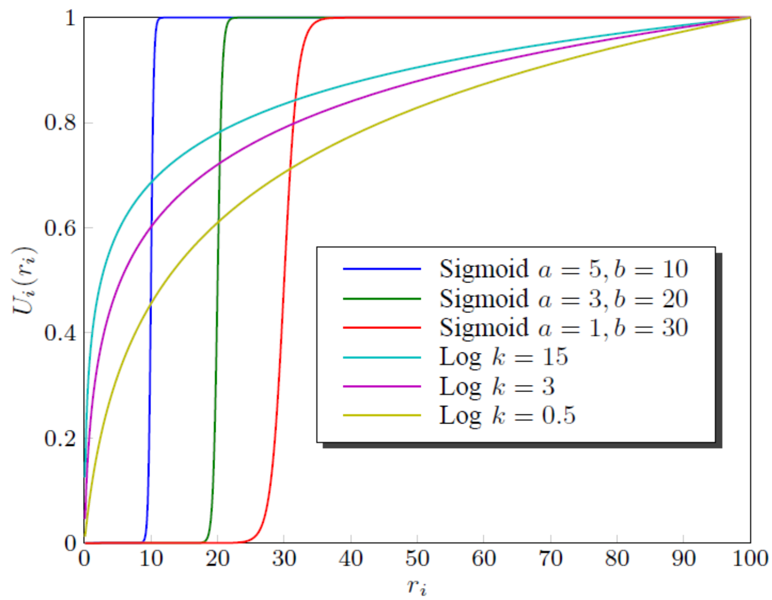

Figure 1.1: A sample of Applications' Utilities [2]

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

We use logarithmic utility functions [58, 121, 122] to represent delay-tolerant applications. The mathematical representation is as follows:

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

where $r^{\max}$ and k are 100% user satisfaction rate and rate increase, respectively, with MATLAB code [2]:

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

In Figure 1.1 [123–125], a sample of sigmoid and logarithmic functions is presented. In [2, 126, 127], we present realistic parameters values of youtube and FTP applications. In [3], the parameters in Table 1.1 are used. The parameters used in the MATLAB code are:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Sector 1 eNodeB 1 %%%%%%%%%%%%%%
```

Table 1.1: Users and their utilities [1]

Sector 1 eNodeB A			
A1	Sig $a = 3,\ b = 10.0$	A4	Log $k = 1.1,\ r_{max} = 100$
A2	Sig $a = 3,\ b = 10.3$	A5	Log $k = 1.2,\ r_{max} = 100$
A3	Sig $a = 1,\ b = 10.6$	A6	Log $k = 1.3,\ r_{max} = 100$
Sector 2 eNodeB A			
A7	Sig $a = 3,\ b = 10$	A10	Log $k = 1,\ r_{max} = 100$
A8	Sig $a = 3,\ b = 11$	A11	Log $k = 2,\ r_{max} = 100$
A9	Sig $a = 1,\ b = 12$	A12	Log $k = 3,\ r_{max} = 100$
Sector 3 eNodeB A			
A13	Sig $a = 3,\ b = 15.1$	A16	Log $k = 10,\ r_{max} = 100$
A14	Sig $a = 3,\ b = 15.3$	A17	Log $k = 11,\ r_{max} = 100$
A15	Sig $a = 3,\ b = 15.5$	A18	Log $k = 12,\ r_{max} = 100$
Sector 1 eNodeB B			
B1	Sig $a = 3,\ b = 10.9$	B4	Log $k = 1.4,\ r_{max} = 100$
B2	Sig $a = 3,\ b = 11.2$	B5	Log $k = 1.5,\ r_{max} = 100$
B3	Sig $a = 1,\ b = 11.5$	B6	Log $k = 1.6,\ r_{max} = 100$
Sector 2 eNodeB B			
B7	Sig $a = 3,\ b = 13$	B10	Log $k = 4,\ r_{max} = 100$
B8	Sig $a = 3,\ b = 14$	B11	Log $k = 5,\ r_{max} = 100$
B9	Sig $a = 1,\ b = 15$	B12	Log $k = 6,\ r_{max} = 100$
Sector 3 eNodeB B			
B13	Sig $a = 3,\ b = 15.7$	B16	Log $k = 13,\ r_{max} = 100$
B14	Sig $a = 3,\ b = 15.9$	B17	Log $k = 14,\ r_{max} = 100$
B15	Sig $a = 3,\ b = 17.3$	B18	Log $k = 15,\ r_{max} = 100$
Sector 1 eNodeB C			
C1	Sig $a = 3,\ b = 11.8$	C4	Log $k = 1.7,\ r_{max} = 100$
C2	Sig $a = 3,\ b = 12.1$	C5	Log $k = 1.8,\ r_{max} = 100$
C3	Sig $a = 1,\ b = 12.4$	C6	Log $k = 1.9,\ r_{max} = 100$
Sector 2 eNodeB C			
C7	Sig $a = 3,\ b = 16$	C10	Log $k = 7,\ r_{max} = 100$
C8	Sig $a = 3,\ b = 17$	C11	Log $k = 8,\ r_{max} = 100$
C9	Sig $a = 1,\ b = 18$	C12	Log $k = 9,\ r_{max} = 100$
Sector 3 eNodeB C			
C13	Sig $a = 3,\ b = 17.5$	C16	Log $k = 16,\ r_{max} = 100$
C14	Sig $a = 3,\ b = 17.7$	C17	Log $k = 17,\ r_{max} = 100$
C15	Sig $a = 3,\ b = 17.9$	C18	Log $k = 18,\ r_{max} = 100$

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k11 = [ 1.1  1.2  1.3]';
a11 = [ 3    3    1  ]';
b11 = [ 10.0    10.3    10.6 ]';
%%%%% Sector 1 eNodeB 2 %%%%%%%%%%%%%%%
k21 = [ 1.4  1.5  1.6]';
a21 = [ 3    3    1  ]';
b21 = [ 10.9    11.2    11.5 ]';
%%%%% Sector 1 eNodeB 3 %%%%%%%%%%%%%%%
k31 = [ 1.7  1.8  1.9]';
a31 = [ 3    3    1  ]';
b31 = [ 11.8    12.1    12.4  ]';
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Sector 2 eNodeB 1 %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k12 = [ 1   2   3  ]';
a12 = [ 3   3   1  ]';
b12 = [ 10  11  12 ]';
%%%%% Sector 2 eNodeB 2 %%%%%%%%%%%%%%%
k22 = [ 4   5   6  ]';
a22 = [ 3   3   1  ]';
b22 = [ 13  14  15 ]';
%%%%% Sector 2 eNodeB 3 %%%%%%%%%%%%%%%
k32 = [ 7   8   9  ]';
a32 = [ 3   3   1  ]';
b32 = [ 16  17  18 ]';
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Sector 3 eNodeB 1 %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k13 = [ 10  11  12 ]';
a13 = [ 3   3   3  ]';
b13 = [ 15.1  15.3  15.5 ]';
%%%%% Sector 3 eNodeB 2 %%%%%%%%%%%%%%%
k23 = [ 13  14  15 ]';
a23 = [ 3   3   3  ]';
b23 = [ 15.7  15.9  17.3 ]';
%%%%% Sector 3 eNodeB 3 %%%%%%%%%%%%%%%
```

```
k33 = [ 16  17 18 ]';
a33 = [ 3   3  3  ]';
b33 = [ 17.5  17.7  17.9 ]';
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k   = [ k11  k12  k13;
        k21  k22  k23;
        k31  k32  k33]
a   = [ a11  a12  a13;
        a21  a22  a23;
        a31  a32  a33]
b   = [ b11  b12  b13;
        b21  b22  b23;
        b31  b32  b33]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Chapter 2

Resource Allocation with Frequency Reuse

2.1 System Model of Frequency Reuse

A cellular network model [3] consisting of cells with sectors is considered. The model used in the simulation consists of $k = 3$ eNodeBs in $k = 3$ cells. Each cell is divided into $L = 3$ sector and $M = 54$ UEs distributed among these cells. This simulation setup is shown in Figure 2.1.

2.1.1 Algorithm of Frequency Reuse

The resource allocation with frequency reuse algorithm in [3] allocates resources from Mobility Management Entity (MME) to eNodeBs' sectors based on UEs' applications. The algorithm is divided into a i^{th} UE algorithm shown in the flow chart in Figure 2.2), a l^{th} eNodeB sector algorithm shown in the flow chart in Figure 2.3 and MME algorithm in the flow chart in Figure 2.4. In the allocation process shown in Figures 2.2), 2.3 and 2.4 is as follows [86]:

- The i^{th} UE with a cell starts with an initial bid $w_{li}(1)$ which is sent to the l^{th} carrier eNodeB.

  In MATLAB:

```
% Initial Bids w[sector1; sector2; sector3]
w = [10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
    10 10 10; 10 10 10 10 10 10 10 10 10 10 10 10 10
     10 10 10 10 10; 10 10 10 10 10 10 10 10 10 10
    10 10 10 10 10 10 10 10]';
```

- The l^{th} eNodeB sector evaluates the difference between the received bid $w_{li}(n)$ and the previously received bid $w_{li}(n-1)$ and exits if and only if it is less than a provided threshold δ.

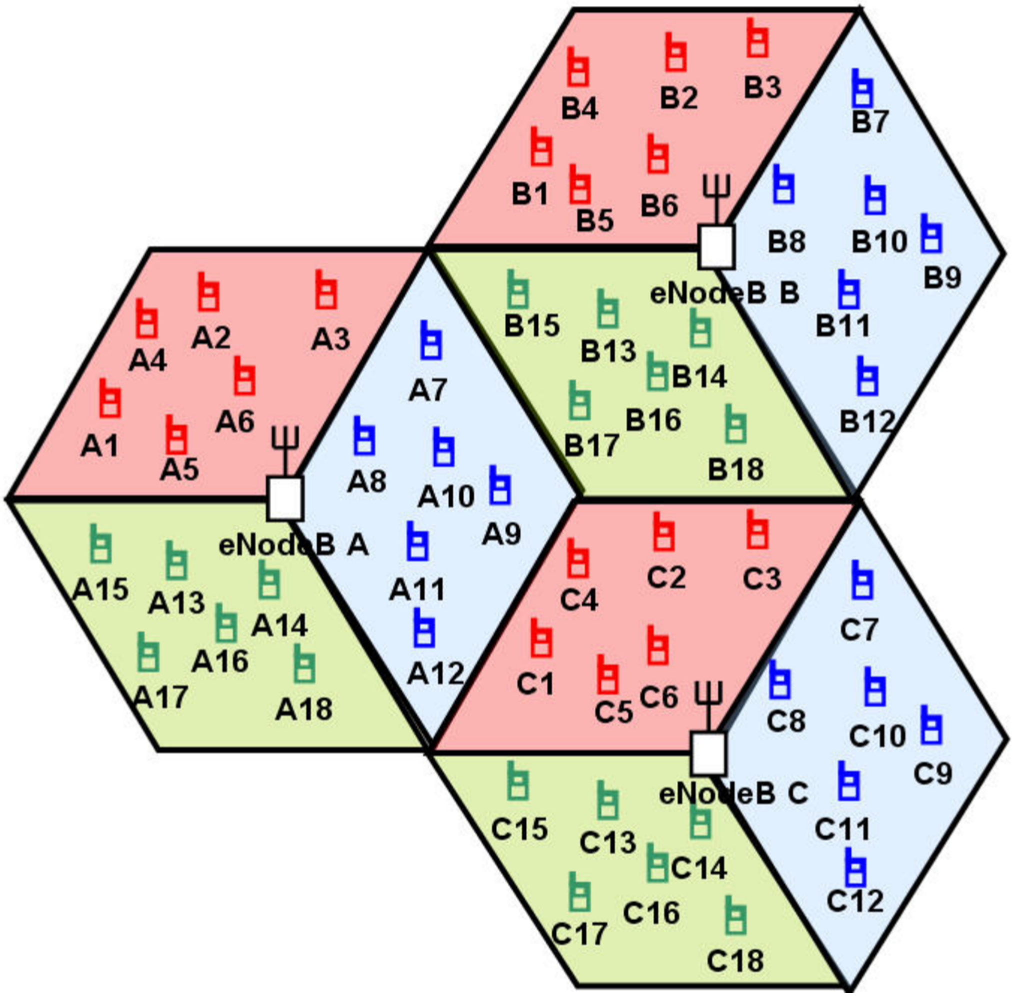

Figure 2.1: System Model of Frequency Reuse [3]

In MATLAB:

```
while  (delta > 0.001)
        :
        :
        :
        :
          delta = max(max(abs(w-w_old)))
end    % (while) end of the time iteration
```

- The l^{th} sector sends the aggregated bids from all UEs under its coverage $W^l(n) = \sum_{i=1}^{M} w_i^l(n)$ to MME.

  In MATLAB:

```
function [p, R_sector] = sector(w)
L = 3;                  % number of sectors
W = sum(w);             % sum of columns
[R_sector] = MME(W);    % calculate the sector rate
for isector = 1:L
   p(isector) = W(isector)./R_sector(isector);    % calculate the shadow price
end
```

- MME calculates the sector rates $R^l(n) = \frac{W^l(n)}{\sum_{l=1}^{L} W^l(n)} R$ and sends it to the corresponding sectors.

  In MATLAB:

```
function [R_sector] = MME(W)
R_MME = 450;                         % the total MME rate
for iMME = 1:length(W)
    R_sector(iMME) = W(iMME)./sum(W).*R_MME;   % allocated sector rate
end
```

- Each user receives from sector the value of R_l and p_l.

  In MATLAB

```
[p(time,:), R_sector(time,:)] = sector(w);   % sent from sector
```

- Each user receives the shadow price to solve for the rate r_i that maximizes objective function.

  In MATLAB

```
dy(i,j) = diff(y(i,j),x);   % diff of utility function
```

```
:
:
S(i,j) = dy(i,j)-p(time,j);

soln(i,j,:) = double(solve(S(i,j)));

r_opt(i,j) = soln(i,j,2);
:
:
```

- That rate is used to calculate the new bid.

  In MATLAB

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

- Each user sends the value of its new bid $w_i(n)$ to corresponding sector. This process is repeated until $|w_i(n) - w_i(n-1)|$ is less than the pre-specified threshold δ.

  In MATLAB

```
while  (delta > 0.001)
      :
      :
      :
      :
        delta = max(max(abs(w-w_old)))
end   % (while) end of the time iteration
```

The transmission digram is shown in Figure 2.5.

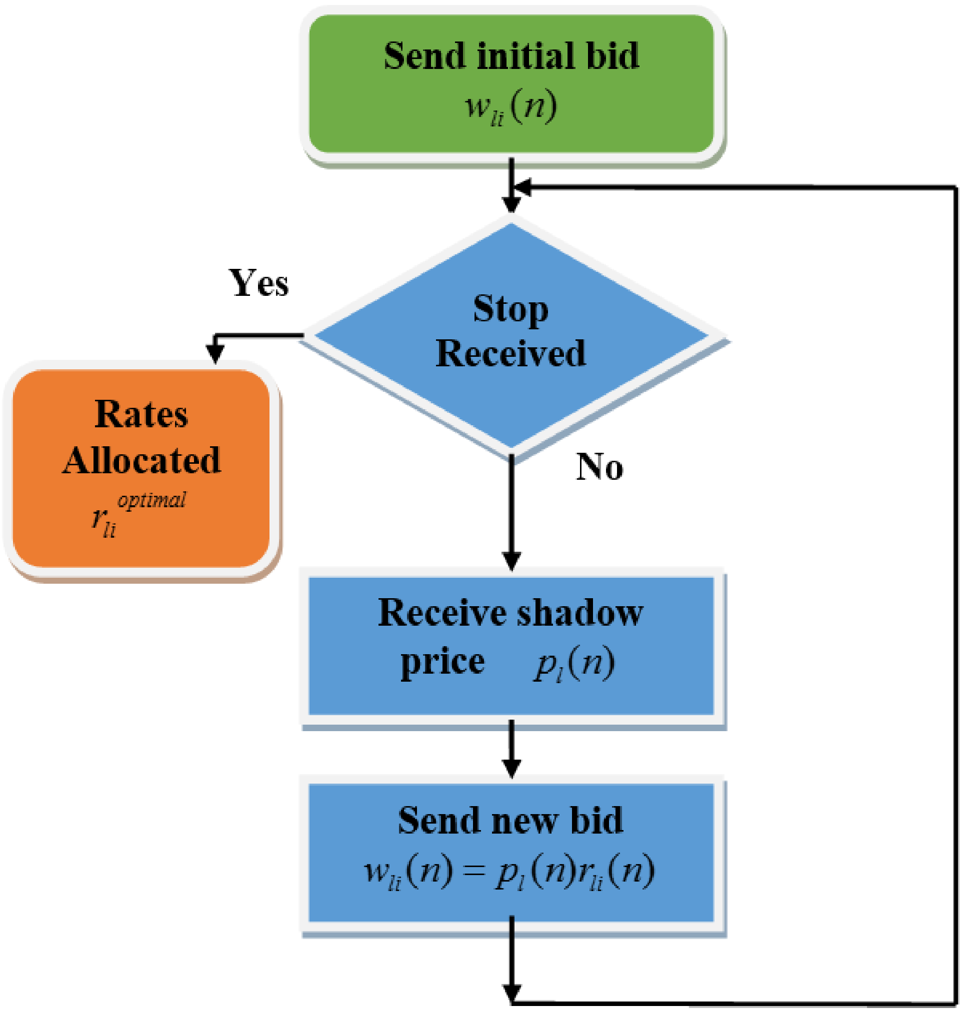

Figure 2.2: UE Algorithm of Frequency Reuse

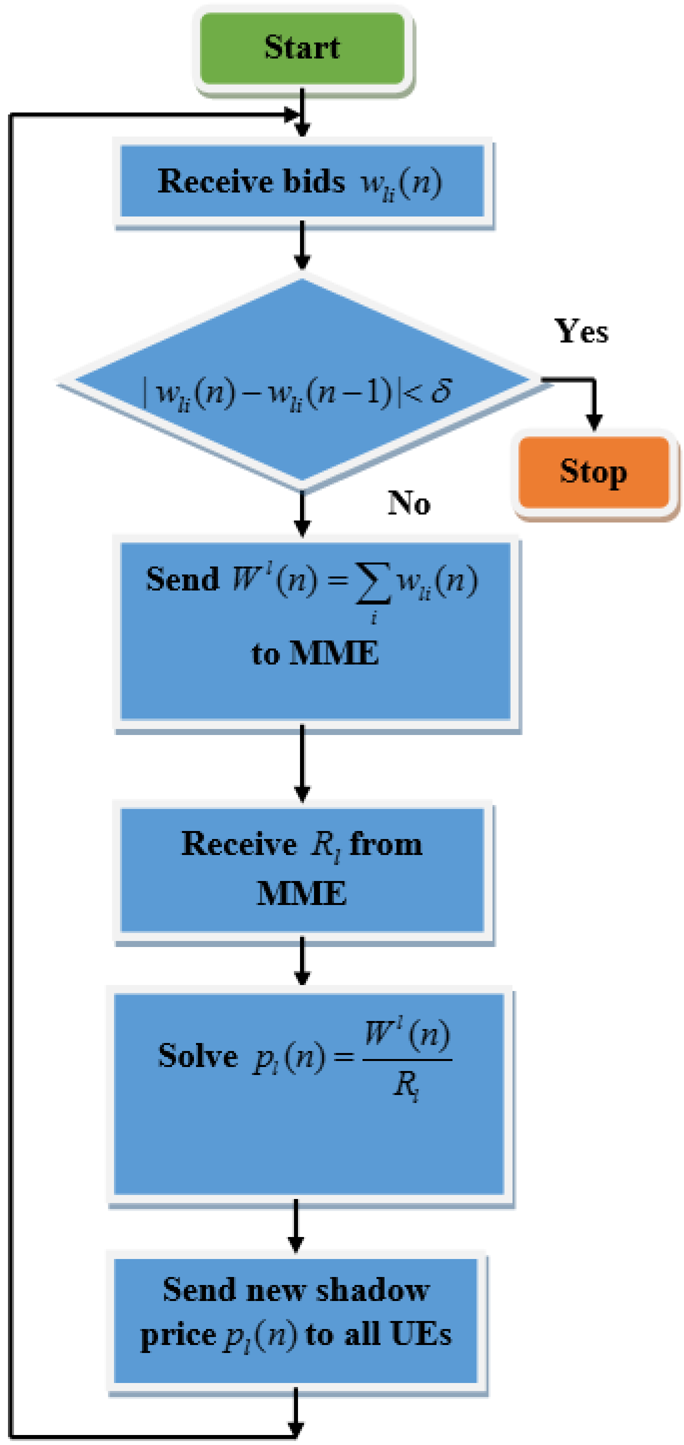

Figure 2.3: Sector Algorithm of Frequency Reuse

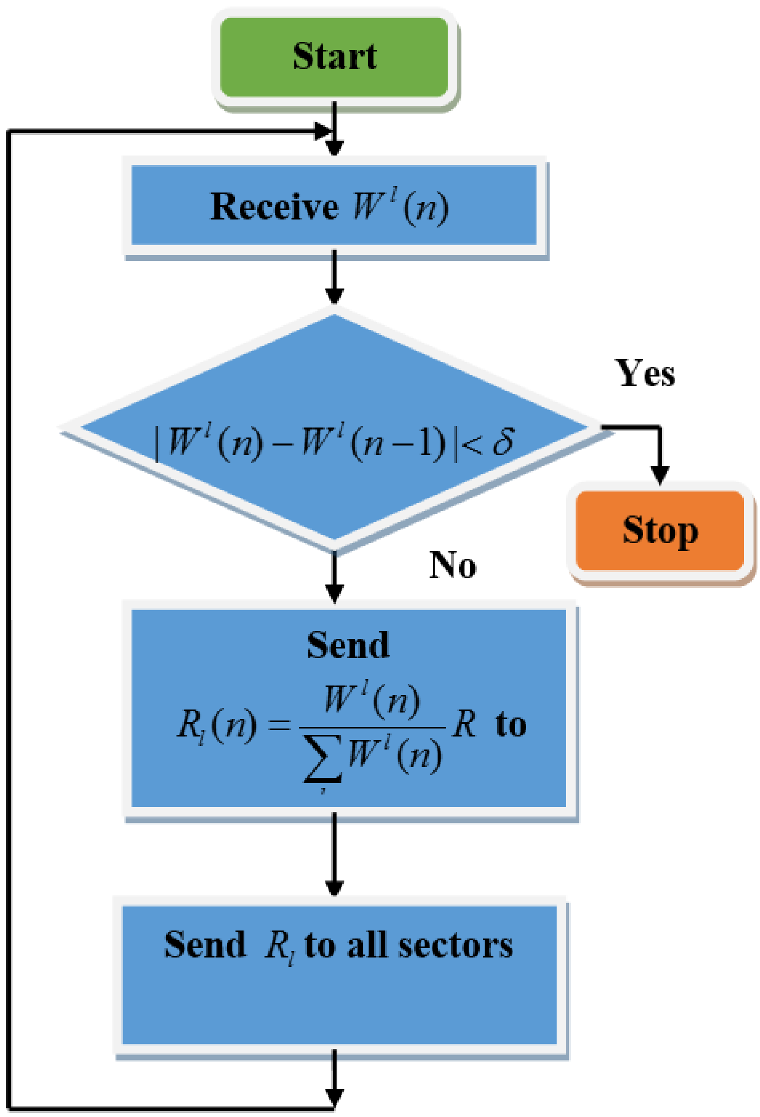

Figure 2.4: MME Algorithm of Frequency Reuse [4]

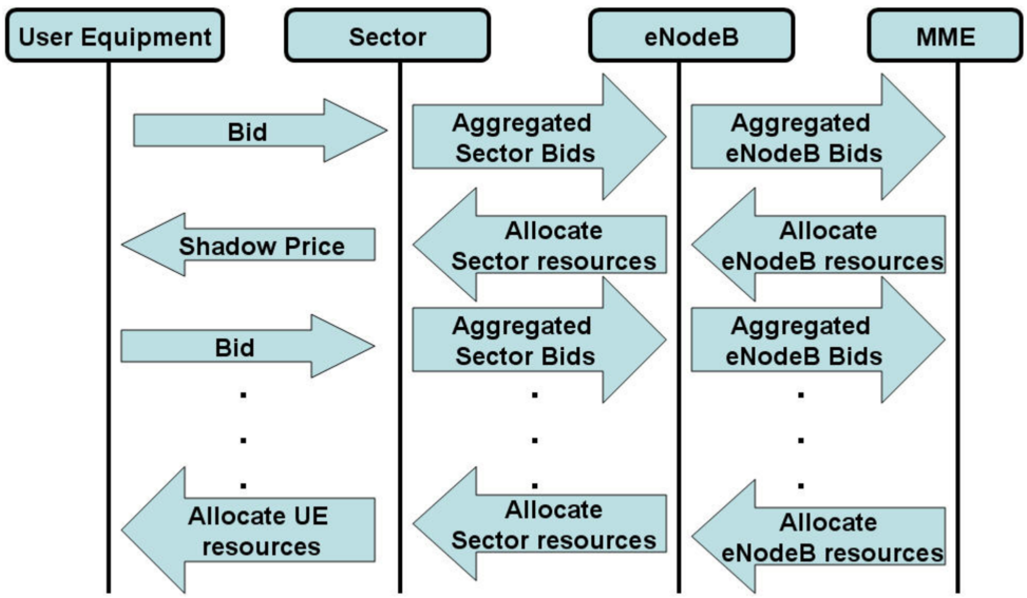

Figure 2.5: Transmission of Frequency Reuse Algorithm [1]

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