Resource Allocation with Radar Spectrum Sharing using MATLAB

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Review Article with MATLAB Instructions

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Chapter 1

Introduction

The article provides a MATLAB simulation tutorial for the published paper [1]. We have a brief background on the problem of resource allocation followed by a literature review of the topic. We include the simulation parameters used in [1] with MATLAB simulation steps.

1.1 Motivation, Background, and Related Work

The need for an increase of wireless throughput is on the rise [2–5]. With that increase, enhancement of quality of service (QoS) [6–8] and quality of experience (QoE) [9, 10] is crucial. In [11–14], authors address network layer QoS of Open Systems Interconnection (OSI) Model [15]) while in [16, 17] authors address physical layer QoS and in [18, 19] authors address application layer QoE. Other methods use game theory [20, 21], microeconomics [22, 23], energy efficiency for network layer QoS [24–26] for 3GPP, LTE third generation partnership project [27–29]. Other researchers conduct QoS research on standards such as Worldwide Interoperability for Microwave Access (WiMAX) [30–32], Universal Mobile Terrestrial System (UMTS) [33,34] in [35], and Mobile Broadband [36] in [37].

Cross-layer designs of OSI model for enhancing QoS are presented in [38, 39]. Routers shaping and scheduling for QoS improvement are designed in [40, 41] for integrated services, differentiated services are studied in [42–44], Asynchronous Transfer Mode (ATM) is studied in [45, 46], and battery life and embedded-based QoS are discussed in [47–51].

Delay tolerant traffic [21, 52] is the type of traffic historically studied for resource allocation optimization as in [53–55] for proportional fairness and in [56–59] for and max-min fairness. The optimal solution of delay tolerant traffic resource allocation is presented in [60–63] while approximate solutions are shown in [64–66]. In [67], the optimal solution for real-time traffic is shown using convex optimization techniques [68]. The result is extended to multiple types of traffic in [69–75].

In [76–80], authors present carrier aggregation using non-convex optimization methods. The optimal solution for resource allocation with carrier aggregation is shown in [81–85]. The President Council of Advisers on Science and Technology (PCAST) [86] recommends the sharing of underutilized spectrum for commercial use [87–89]. The Federal Communications Commission (FCC) suggests that the radar spectrum [90, 91] can be shared with commercial cellular spectrum [92, 93]. The National Telecommunications and Information Administration (NTIA) [94–96] provided studies on the interference effects of radar and communications coexistence. Further studies on on radar and communications coexistence problem [97–100] are presented in [101–103].

Simulation tools used in this article is applicable to machine to machine (M2M) communications [104–106], multi-cast network [107], ad-hoc networks [108–111], and other wireless networks [112–115].

1.2 Sample of Users' Applications Utilities

In the simulation presented in [1], sigmoid utility functions [66, 116, 117] are used to represent real-time applications. The corresponding 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 [118]:

```
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));
```

Logarithmic utility functions [55,119,120] are used to represent delay-tolerant applications. The corresponding mathematical representation is as follows:

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

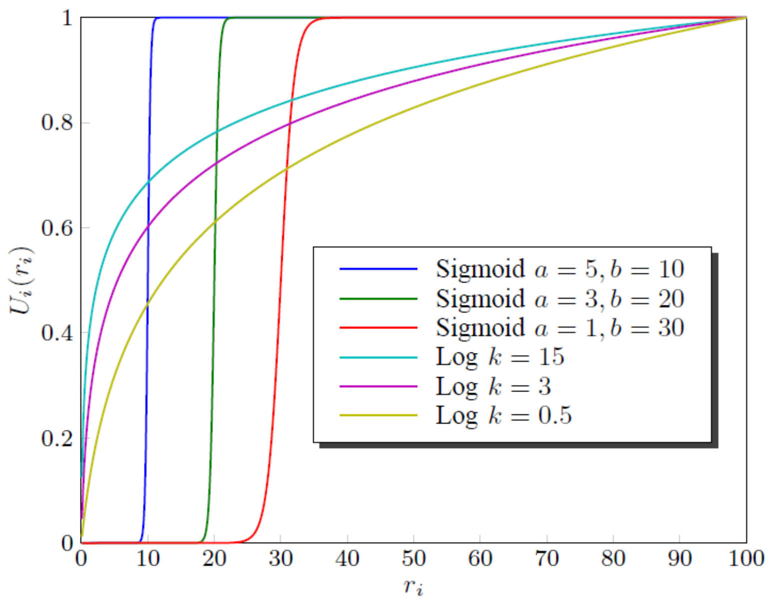

Figure 1.1: A sample of Applications' Utilities [118]

where $r^{\max}$ and k are 100% user satisfaction rate and rate increase, respectively, with MATLAB code [118]:

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

In Figure 1.1 [121–123], sigmoid and logarithmic functions samples are presented. In [118, 124, 125], realistic parameters' values of youtube and FTP applications are presented. In [126], the parameters in Table 1.1 are used. The corresponding MATLAB code is:

In MATLAB:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Sector 1 eNodeB 1 %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k11 = [ 1.1  1.2  1.3]';
a11 = [ 3    2    1  ]';
b11 = [ 10.0    10.5    11.0 ]';
%%%%% Sector 1 eNodeB 2 %%%%%%%%%%%%%%%
k21 = [ 1.4  1.5  1.6]';
```

```
a21 = [ 3    2    1  ]';
b21 = [ 11.5    12.0    12.5 ]';
%%%%% Sector 1 eNodeB 3 %%%%%%%%%%%%%%%
k31 = [ 1.7  1.8  1.9]';
a31 = [ 3    2    1  ]';
b31 = [ 13.0    13.5    14.0  ]';
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Sector 2 eNodeB 1 %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k12 = [ 1   2   3  ]';
a12 = [ 3   2   1  ]';
b12 = [ 10  11  12 ]';
%%%%% Sector 2 eNodeB 2 %%%%%%%%%%%%%%%
k22 = [ 4   5   6  ]';
a22 = [ 3   2   1  ]';
b22 = [ 13  14  15 ]';
%%%%% Sector 2 eNodeB 3 %%%%%%%%%%%%%%%
k32 = [ 7   8   9  ]';
a32 = [ 3   2   1  ]';
b32 = [ 16  17  18 ]';
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%% Sector 3 eNodeB 1 %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
k13 = [ 10  11  12 ]';
a13 = [ 3   2   1  ]';
b13 = [ 15.1  15.3  15.5 ]';
%%%%% Sector 3 eNodeB 2 %%%%%%%%%%%%%%%
k23 = [ 13  14  15 ]';
a23 = [ 3   2   1  ]';
b23 = [ 15.7  15.9  17.3 ]';
%%%%% Sector 3 eNodeB 3 %%%%%%%%%%%%%%%
k33 = [ 16  17 18 ]';
a33 = [ 3   2  1  ]';
b33 = [ 17.5  17.7  17.9 ]';
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Table 1.1: Application Utility Functions.

Sector 1 - Cell A						
A1	Sig	a = 3	b = 10.0	A4	Log	k = 1.1
A2	Sig	a = 3	b = 10.3	A5	Log	k = 1.2
A3	Sig	a = 1	b = 10.6	A6	Log	k = 1.3
Sector 2 - Cell A						
A7	Sig	a = 3	b = 10.0	A10	Log	k = 1
A8	Sig	a = 3	b = 15.3	A1	Log	k = 2
A9	Sig	a = 3	b = 12.0	A12	Log	k = 3
Sector 3 - Cell A						
A13	Sig	a = 3	b = 15.1	A16	Log	k = 10
A14	Sig	a = 3	b = 15.3	A17	Log	k = 11
A15	Sig	a = 3	b = 15.5	A18	Log	k = 12
Sector 1 - Cell B						
B1	Sig	a = 3	b = 15.9	B4	Log	k = 1.4
B2	Sig	a = 3	b = 11.2	B5	Log	k = 1.5
B3	Sig	a = 1	b = 11.5	B6	Log	k = 1.6
Sector 2 - Cell B						
B7	Sig	a = 3	b = 13	B10	Log	k = 4
B8	Sig	a = 3	b = 14	B11	Log	k = 5
B9	Sig	a = 1	b = 15	B12	Log	k = 6
Sector 3 - Cell B						
B13	Sig	a = 3	b = 15.7	B16	Log	k = 13
B14	Sig	a = 3	b = 15.9	B17	Log	k = 14
B15	Sig	a = 3	b = 17.3	B18	Log	k = 15
Sector 1 - Cell C						
C1	Sig	a = 3	b = 11.8	C4	Log	k = 1.7
C2	Sig	a = 3	b = 12.1	C5	Log	k = 1.8
C3	Sig	a = 1	b = 12.4	C6	Log	k = 1.9
Sector 2 - Cell C						
C7	Sig	a = 3	b = 16	C10	Log	k = 7
C8	Sig	a = 3	b = 17	C11	Log	k = 8
C9	Sig	a = 1	b = 18	C12	Log	k = 9
Sector 3 - Cell C						
C13	Sig	a = 3	b = 17.5	C16	Log	k = 16
C14	Sig	a = 3	b = 17.7	C17	Log	k = 17
C15	Sig	a = 3	b = 17.9	C18	Log	k = 18

Chapter 2

Resource Allocation with Radar Spectrum Sharing

2.1 System Model of Radar Spectrum Sharing

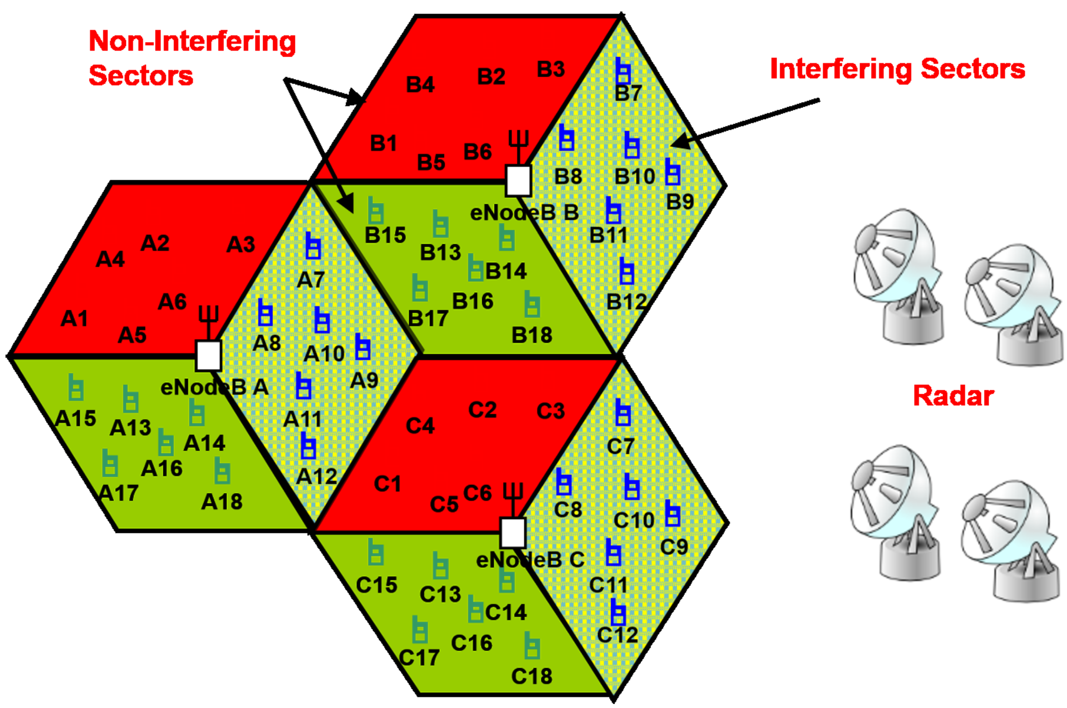

Figure 2.1: System Model of Frequency Reuse with Radar Spectrum Sharing

In [1], the network consists of cells with sectors. Sectors are interfering or non-interfering with radar transmission. The radar spectrum can be utilized in the non-interfering sectors. The network consists of $k = 3$ eNodeBs in $k = 3$ cells. There are $L = 3$ sectors per cell and $M = 54$ mobile users in these cells.

This simulation setup is shown in Figure 2.1.

In MATLAB:

```
%%%%%%%%%%% Paramters %%%%%%%%%%%%%%%%%%%%%
M_sector = 6; % number of users in each sector
Rate_Radar = 200;
Rate_Comm = 400;
i_rate_max = floor((Rate_Radar + Rate_Comm) /50);
L = 3;
R_sector = zeros(i_rate_max, L)
```

2.1.1 Algorithm of Radar Spectrum Sharing

The resource allocation with frequency reuse algorithm in [126] 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 [83]:

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

  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} 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.

  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 users in its coverage $W^l(n) = \sum_{i=1}^{M} w_i^l(n)$ to MME.

  In MATLAB:

```
function [p, R_sector] = sectorRate(w, Rate, L)
W = sum(w);           % sum of columns
[R_sector] = MMErate(W, Rate);  % 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] = MMErate(W, Rate)
R_MME = Rate;  % the total MME rate
for iMME = 1:length(W)
    R_sector(iMME) = W(iMME)./sum(W).*R_MME;  %
       allocated sector rate
end
```

- At stage 1, radar spectrum is allocated to non-interfering sectors of the cells and no resources are passed to radar-interfering sectors' UEs using $r_{i,\text{radar}}^l(n) = \arg\max_{r_{i,\text{radar}}^l} \left(\log U_i(r_{i,\text{radar}}^l) - P_{\text{radar}}^l(n) r_{i,\text{radar}}^l \right)$.

  In MATLAB:

```
if Rate_switch < Rate_Radar + 1
    [p_mode(time,:), R_sector_mode2(time,:)] = sectorRate(w,Rate(i_rate),L);
    p_mode2(time,:) = [p_mode(time,:) 0];
```

- At stage 2, radar spectrum is allocated to non-interfering sectors of the cells and no resources are passed to radar-interfering sectors' users using $r^l_{i,\text{comm}}(n) = \arg \max_{r^l_{i,\text{comm}}} \left(\log U_i(r^l_{i,\text{comm}} + r^{l,\text{opt}}_{i,\text{radar}}) - P^l_{\text{comm}}(n) r^l_{i,\text{comm}} \right)$.

  In MATLAB:

```
else
    [p_mode2(time,:), R_sector_mode2(time,:)] = sectorRate(w,Rate(i_rate),L);
    a = max(R_sector_ss(i_rate-1,1),R_sector_mode2(time,1));
    b = max(R_sector_ss(i_rate-1,2),R_sector_mode2(time,2));
    R_sector_mode2(time,:) = [a b Rate(i_rate)-a-b]
end
```

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

  In MATLAB

```
p(time,:)= p_mode2(time,:);
R_sector(time,:) = R_sector_mode2(time,:);
```

- Each user solves for the rate r_i that maximizes the 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.

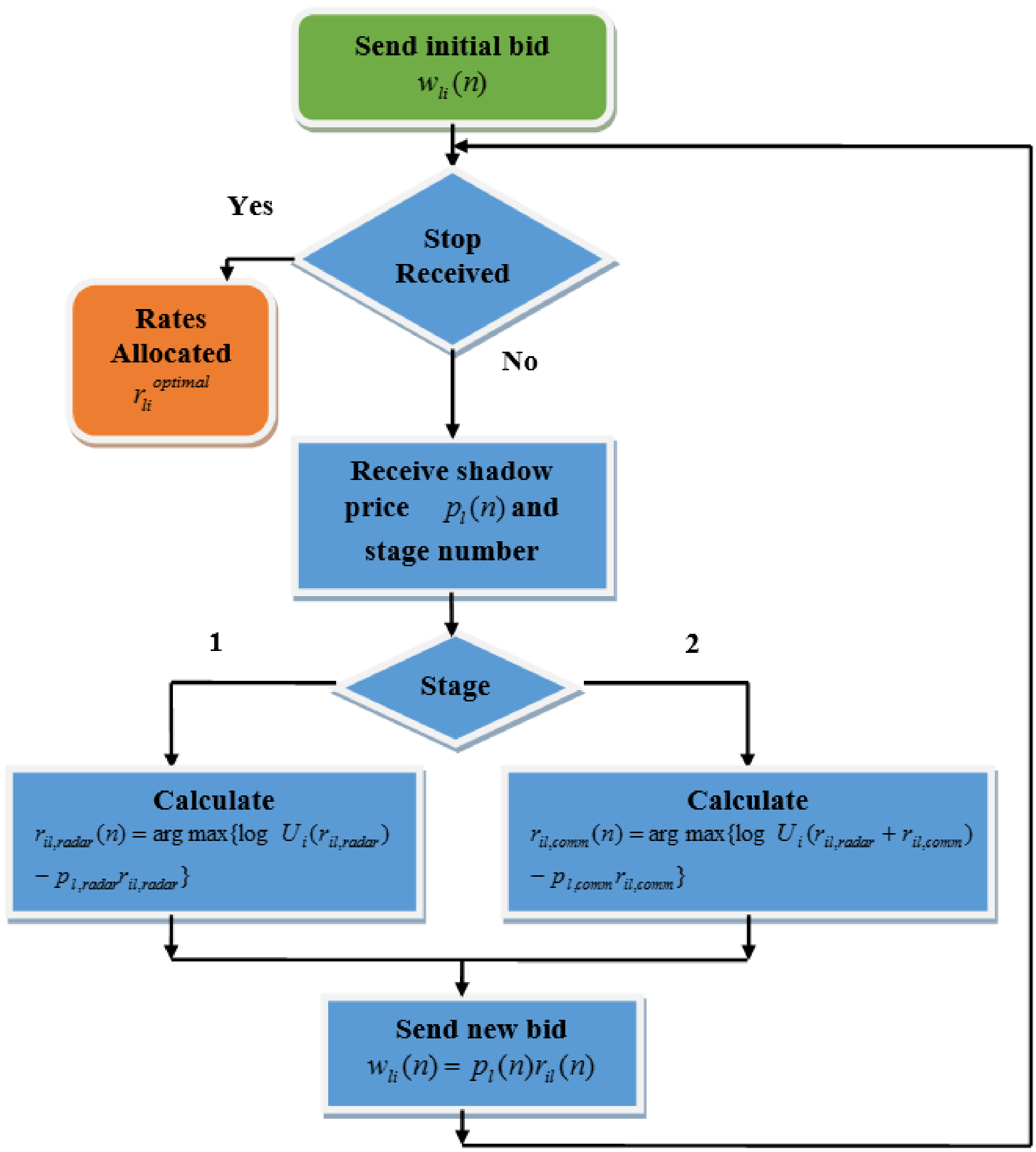

Figure 2.2: UE Algorithm of Radar Spectrum Sharing

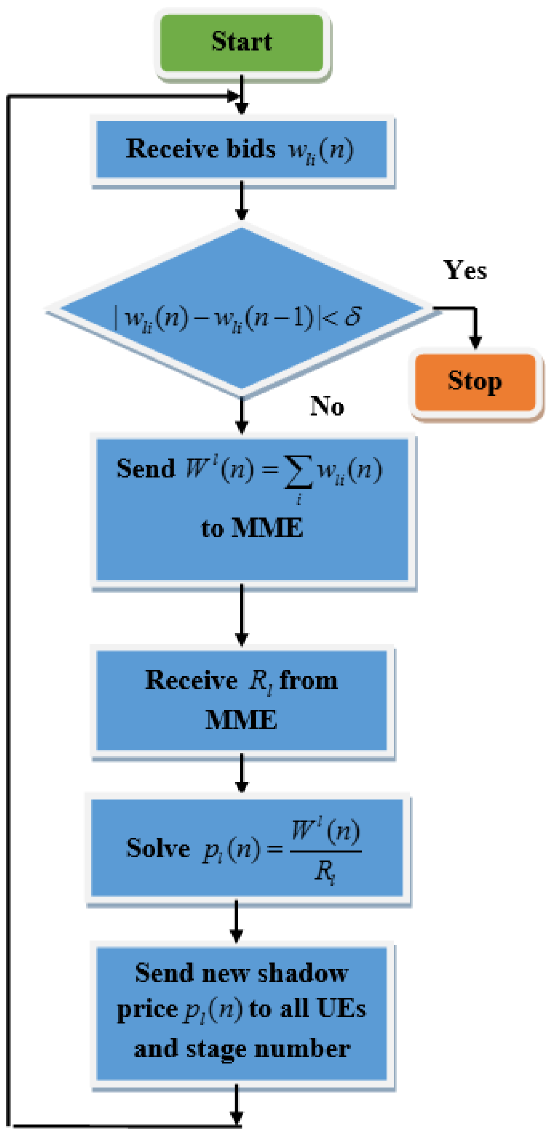

Figure 2.3: Sector Algorithm of Radar Spectrum Sharing

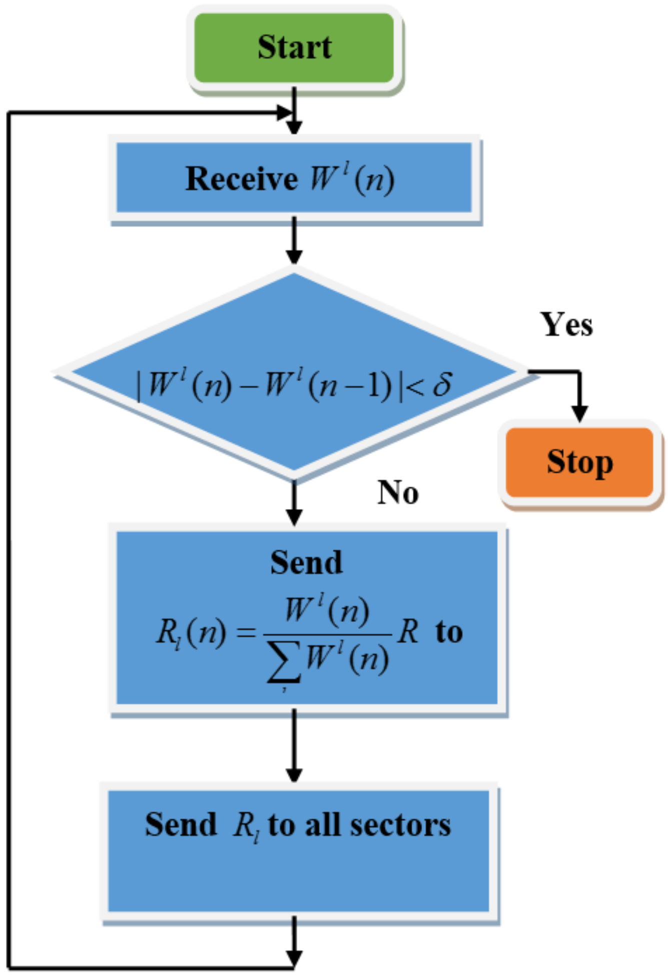

Figure 2.4: MME Algorithm of Radar Spectrum Sharing [127]

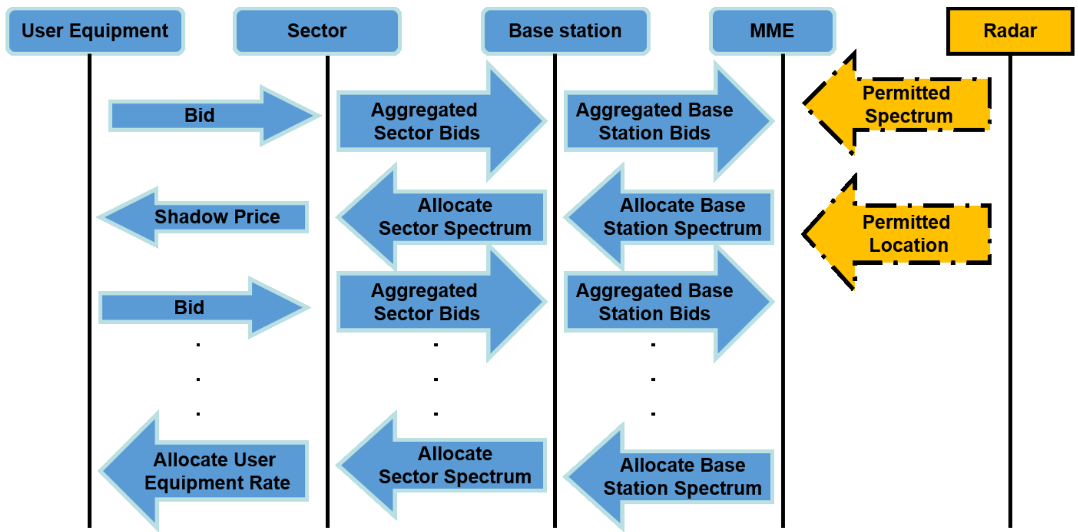

Figure 2.5: Transmission of Frequency Reuse Algorithm with Radar Spectrum Sharing

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