Assignment No. 3 Report

Availability Performance of Multi-Hop Wireless Networks with Mobile Terminals

Desempenho e Dimensionamento de Redes
MIECT, DETI, UA

Gabriel Silva (85129) & Gonçalo Vítor (85119)

The Results

For the first AP configuration [250 100]

Case	N	S(km/h)	W(meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	8,80E-02	1,77E-02	9,00E-04	1,40E-03
2	40	3	40	1,30E-01	6,40E-03	1,01E-02	7,00E-03
3	60	3	40	2,65E-01	1,07E-02	4,40E-02	1,04E-02
4	80	3	40	4,22E-01	1,74E-02	1,56E-01	2,29E-02
5	20	6	40	7,73E-02	6,00E-03	9,50E-03	1,06E-02
6	40	6	40	1,38E-01	1,24E-02	2,76E-02	1,89E-02
7	60	6	40	2,44E-01	1,49E-02	6,64E-02	3,18E-02
8	80	6	40	4,12E-01	1,30E-02	1,75E-01	2,19E-02
9	20	3	60	2,87E-01	2,07E-02	1,32E-01	4,26E-02
10	40	3	60	6,31E-01	1,87E-02	4,26E-01	3,08E-02
11	60	3	60	8,89E-01	1,17E-02	7,14E-01	4,26E-02
12	80	3	60	9,76E-01	2,50E-03	9,30E-01	5,30E-03
13	20	6	60	2,85E-01	2,10E-02	1,25E-01	4,44E-02
14	40	6	60	6,17E-01	2,12E-02	4,63E-01	5,34E-02
15	60	6	60	8,84E-01	7,30E-03	7,92E-01	1,61E-02
16	80	6	60	9,77E-01	1,90E-03	9,40E-01	7,00E-03
17	20	3	80	5,96E-01	2,84E-02	3,77E-01	6,34E-02
18	40	3	80	9,38E-01	8,60E-03	8,63E-01	1,97E-02
19	60	3	80	9,91E-01	2,80E-03	9,63E-01	7,60E-03
20	80	3	80	1,00E+00	2,00E-04	9,88E-01	8,60E-03
21	20	6	80	6,14E-01	2,08E-02	4,67E-01	5,49E-02
22	40	6	80	9,39E-01	7,00E-03	8,83E-01	1,44E-02
23	60	6	80	9,94E-01	1,20E-03	9,77E-01	8,70E-03
24	80	6	80	9,99E-01	2,00E-04	9,90E-01	3,00E-03

For the the second AP configuration [150 100; 350 100]

Case	N	S(km/h)	W(meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	1,53E-01	1,26E-02	2,58E-02	1,56E-02
2	40	3	40	2,61E-01	1,22E-02	8,77E-02	2,75E-02
3	60	3	40	4,36E-01	1,04E-02	1,57E-01	2,71E-02
4	80	3	40	6,32E-01	1,44E-02	3,61E-01	4,93E-02
5	20	6	40	1,53E-01	8,40E-03	6,81E-02	2,33E-02
6	40	6	40	2,55E-01	1,03E-02	1,23E-01	2,76E-02
7	60	6	40	4,25E-01	1,13E-02	1,80E-01	2,80E-02
8	80	6	40	6,33E-01	8,90E-03	3,67E-01	5,41E-02
9	20	3	60	4,99E-01	2,21E-02	2,53E-01	5,52E-02
10	40	3	60	8,12E-01	7,30E-03	6,23E-01	3,07E-02
11	60	3	60	9,51E-01	4,00E-03	8,35E-01	2,64E-02
12	80	3	60	9,84E-01	2,10E-03	9,27E-01	1,75E-02
13	20	6	60	5,11E-01	9,90E-03	4,08E-01	3,27E-02
14	40	6	60	8,10E-01	8,20E-03	6,37E-01	8,01E-02
15	60	6	60	9,47E-01	2,60E-03	8,80E-01	2,05E-02
16	80	6	60	9,87E-01	1,10E-03	9,60E-01	5,50E-03
17	20	3	80	8,47E-01	1,34E-02	6,75E-01	5,48E-02
18	40	3	80	9,79E-01	2,00E-03	9,17E-01	1,29E-02
19	60	3	80	9,98E-01	3,00E-04	9,79E-01	4,10E-03
20	80	3	80	1,00E+00	2,00E-04	9,91E-01	2,40E-03
21	20	6	80	8,38E-01	9,50E-03	7,29E-01	3,01E-02
22	40	6	80	9,75E-01	3,60E-03	9,27E-01	2,32E-02
23	60	6	80	9,97E-01	5,00E-04	9,83E-01	2,00E-03
24	80	6	80	1,00E+00	2,00E-04	9,92E-01	2,80E-03

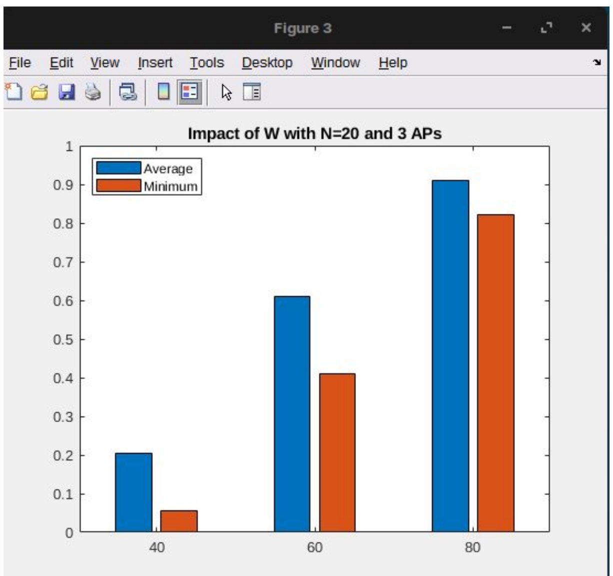
For the the third AP configuration [50 50; 250 100; 450 150]

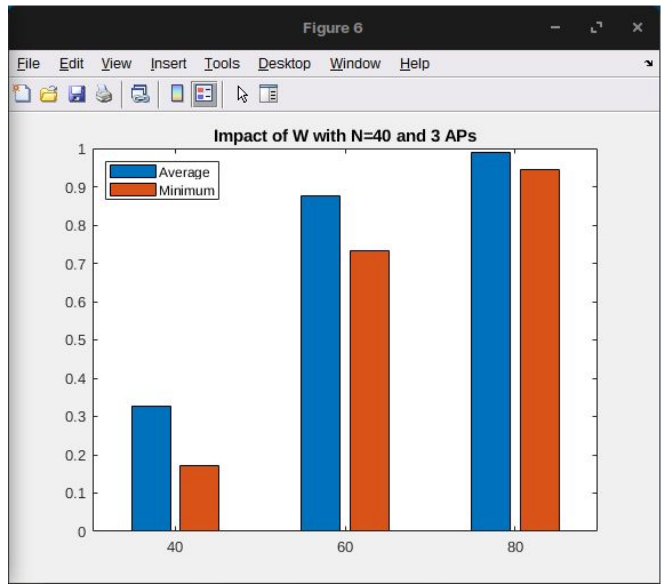
Case	N	S(km/h)	W(meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	2,04E-01	1,23E-02	5,46E-02	1,84E-02
2	40	3	40	3,27E-01	1,06E-02	1,71E-01	2,74E-01
3	60	3	40	5,11E-01	1,03E-02	2,87E-01	3,05E-01
4	80	3	40	7,33E-01	6,60E-03	5,60E-01	2,75E-02
5	20	6	40	2,15E-01	8,80E-03	8,86E-02	3,10E-02
6	40	6	40	3,45E-01	1,31E-02	2,04E-01	3,14E-02
7	60	6	40	5,15E-01	6,80E-03	3,06E-01	4,75E-02
8	80	6	40	7,24E-01	6,80E-03	5,69E-01	3,82E-02
9	20	3	60	6,10E-01	2,33E-02	4,10E-01	5,37E-02
10	40	3	60	8,75E-01	4,90E-03	7,33E-01	3,06E-02
11	60	3	60	9,74E-01	1,90E-03	9,14E-01	8,80E-03
12	80	3	60	9,94E-01	1,10E-03	9,58E-01	8,90E-03
13	20	6	60	5,99E-01	1,45E-02	4,53E-01	3,12E-02
14	40	6	60	8,80E-01	4,30E-03	7,82E-01	3,52E-02
15	60	6	60	9,72E-01	1,20E-03	9,21E-01	9,50E-03
16	80	6	60	9,94E-01	6,00E-04	9,65E-01	8,90E-03
17	20	3	80	9,09E-01	6,40E-03	8,23E-01	1,28E-02
18	40	3	80	9,89E-01	1,70E-03	9,46E-01	1,28E-02
19	60	3	80	9,98E-01	6,00E-04	9,84E-01	4,10E-03
20	80	3	80	1,00E+00	1,00E-04	9,95E-01	2,60E-03
21	20	6	80	9,03E-01	6,50E-03	8,34E-01	1,61E-02
22	40	6	80	9,91E-01	8,00E-04	9,69E-01	4,10E-03
23	60	6	80	9,99E-01	3,00E-04	9,90E-01	3,20E-03
24	80	6	80	9,99E-01	1,00E-04	9,95E-01	2,60E-03

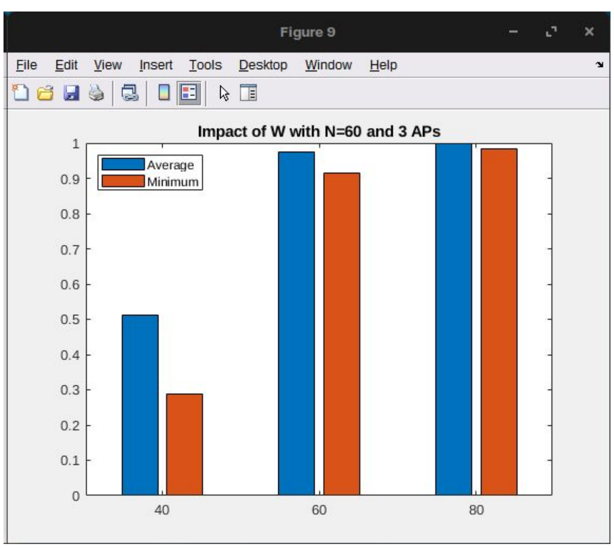
a) Impact of maximum speed S on availability performance

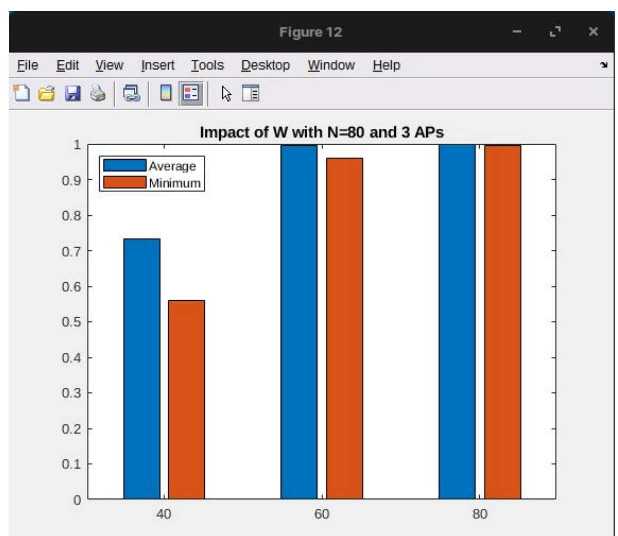
By looking at the results, we can conclude that S (the maximum speed of the mobile nodes) has no influence in the availability performance of the network, because the availability percentages (both for maximum and minimum) have very small variations when changing S (particularly small if we compare them to changes that N, W and AP configurations make).

b) Impact of radio range W on availability performance





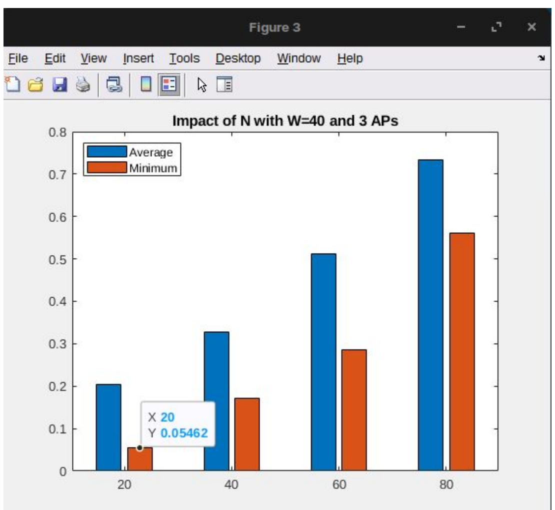


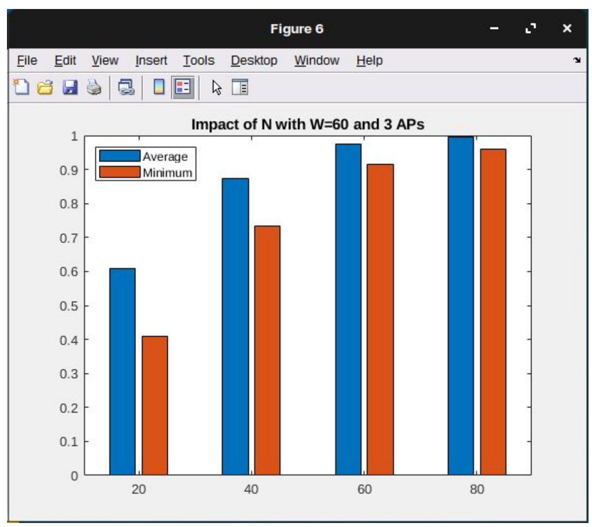


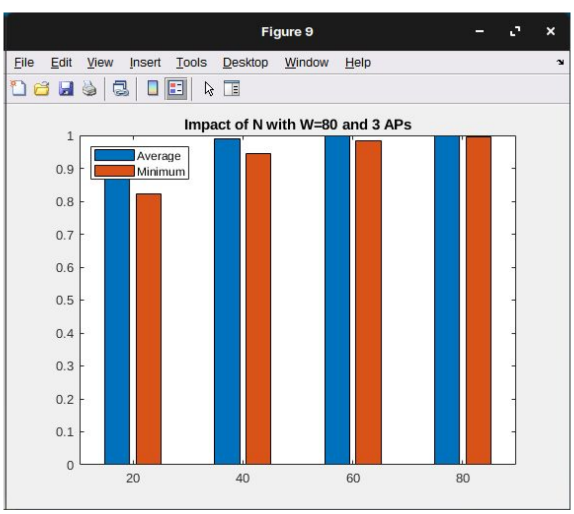
These plots show us 4 different situations: the change in availability (both maximum [in red] and minimum [in blue]; the Y axis) given W (the X axis) for 20, 40, 60 and 80 mobile nodes (N) with 3 AP's with the [50, 50; 250, 100; 450 ,150] configuration. We don't show plots for different amounts of AP's because that variation doesn't affect the impact of changing W in the availability performance much.

In all cases, we notice increases in availability, although for the last two situations (high number of mobile nodes) the increase in availability from W=60 to W=80 is not too significant. Still, we can see that for small values of N (mobile nodes) the value of W has a big impact in the availability performance, even when going from W=60 to W=80, and more importantly, the increase in availability is always very significant when going from W=40 to W=60, regardless of the amount of mobile nodes and, although not shown here, the amount of AP's as well. Thus, we can conclude that the radio range plays a massive role in availability performance, since having low radio ranges injures the availability a lot while having medium to high radio ranges allows for much better availability performances.

c) Impact of number of mobile nodes N on availability performance



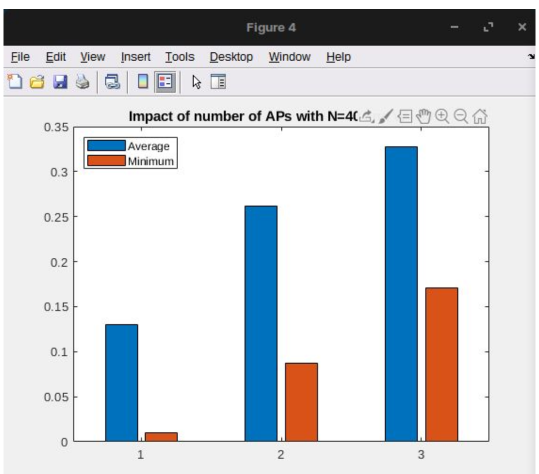


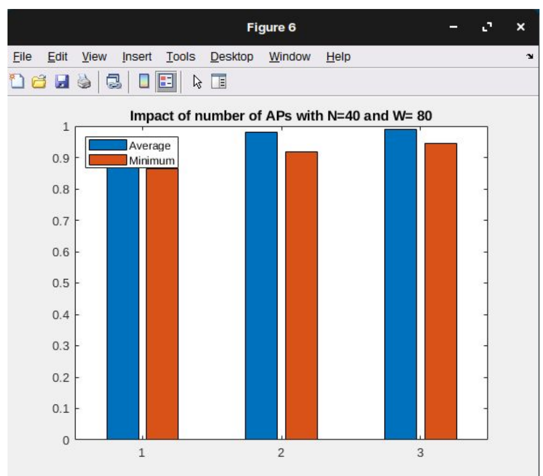


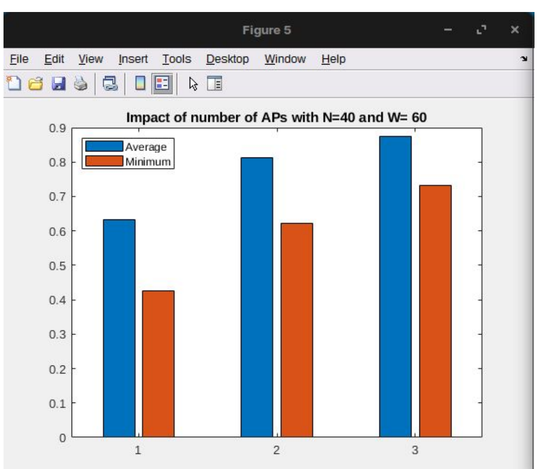
These plots shows us 3 different situations: the change in availability (both maximum [in red] and minimum [in blue]; the Y axis) given N (the X axis) for 40, 60 and 80 radio range (W) with 3 AP's with the [50, 50; 250, 100; 450 ,150] configuration. Again, we don't show plots for different amounts of AP's because that variation doesn't affect the impact of changing N in the availability performance much.

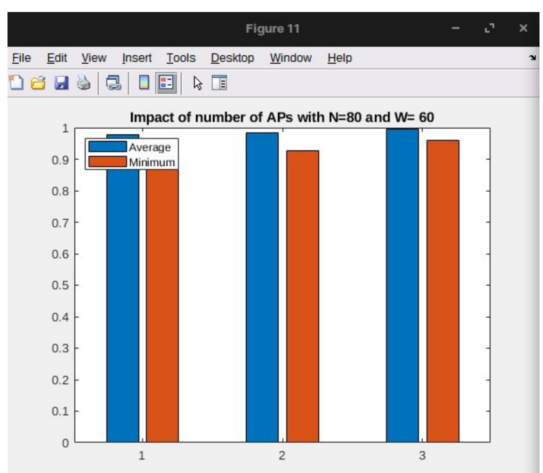
Here can see that as N increases there's a gradual increase in availability, much like it happened with the radio range (W). But whereas the radio range was an important factor for availability for all situations, here we notice that the amount of mobile nodes (N) becomes less and less significant as the radio range(W) increases. So, we can state that the number of mobile nodes is important for situations where the radio range is small, but becomes less important as we increase the radio range.

d) Impact of number of AP nodes on availability performance









In the two plots of the upper side, we see the change in availability when changing the number of AP's for a fixed number of mobile nodes (N=40) but for two different radio ranges (W=40 and W=80). In this case we can see that for small radio ranges the number of AP's does have a good impact, but when we increase W, we practically don't see any change in availability by changing the amount of AP's .

In the plots below, we see the change in availability when changing the number of AP's for a fixed radio range (W=60) but for two different amounts of mobile nodes (N=40 and N=80). The results in this scenario are similar to the ones above, where for small values of N the number of AP's does make a change in availability, but when N increases, the number of AP's becomes almost irrelevant.

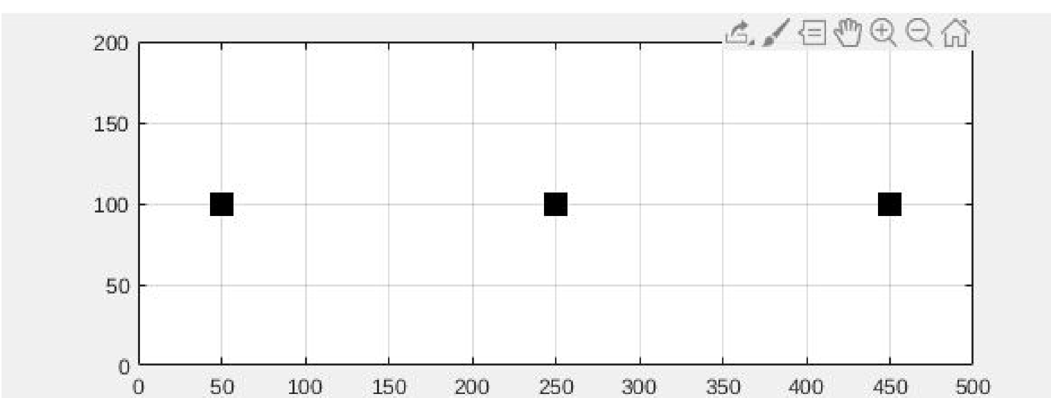
We can then conclude that the amount of AP's is only important for small amounts of mobile nodes and small radio ranges, and has those increase, the amount of AP's becomes more and more irrelevant.

e) Impact of input parameters on confidence intervals

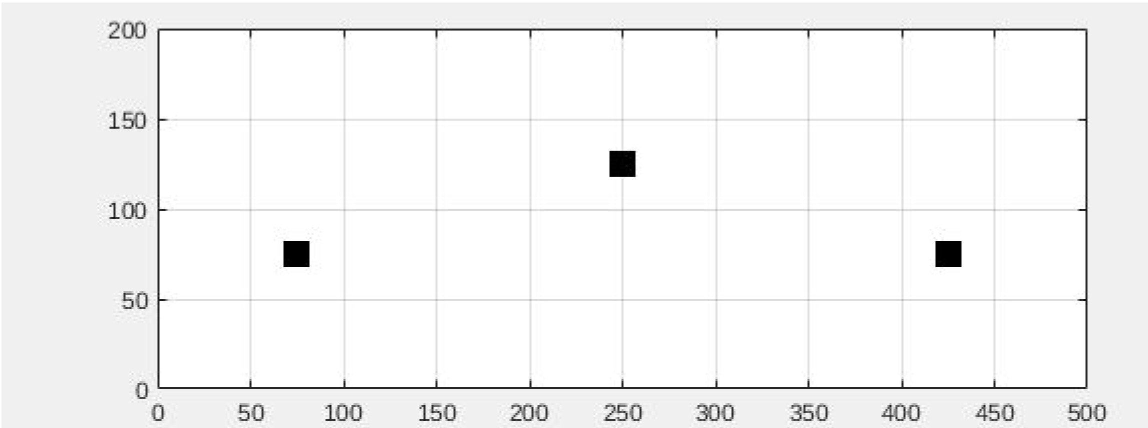
Analysing the values of the confidence interval in the tables with results above, we can observe that the values for the confidence interval become smaller as the availability reaches extremes, this is, either 0% or 100%. The fact that the confidence interval gets smaller when getting closer 0% availability is more noticeable on the minimum availability, since it reaches smaller values than the maximum availability. So, we can conclude that the input parameters decrease the confidence interval when N and W are big or when N, W and the amount of AP's is small (given the prior conclusions).

f) AP nodes location alternatives

Both the configurations for 1 and 2 AP's seem very reasonable. We suggest only configurations for 3 AP's.



Alt1



Alt2

Here we present the results for these new configurations and compare them with the previous configuration with 3 AP's:

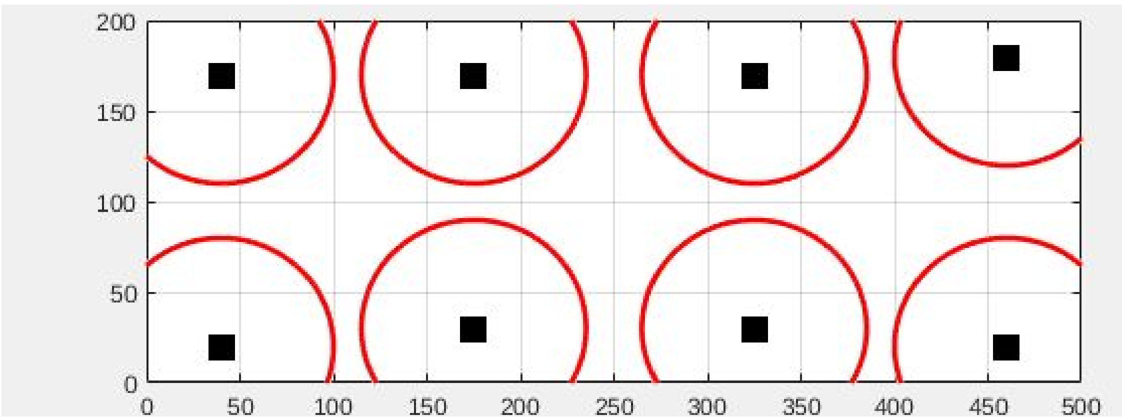
Config	N	W	Average availability	90% confidence interval	Minimum availability	90% confidence interval
Original	40	60	8,75E-01	4,90E-03	7,33E-01	3,06E-02
Alt1	40	60	8,94E-01	4,20E-03	7,95E-01	1,34E-02
Alt2	40	60	8,86E-01	3,60E-03	7,41E-01	3,48E-02
Original	60	60	9,74E-01	1,90E-03	9,14E-01	8,80E-03
Alt1	60	60	9,77E-01	1,80E-03	9,21E-01	1,50E-02
Alt2	60	60	9,71E-01	2,60E-03	8,94E-01	1,85E-02
Original	80	60	9,94E-01	1,10E-03	9,58E-01	8,90E-03
Alt1	80	60	9,94E-01	4,00E-04	9,60E-01	7,80E-03
Alt2	80	60	9,92E-01	5,00E-04	9,56E-01	5,10E-03

In these results we can see that the first alternative is generally better than the original configuration, as it performed better than the original for every example (Note that more examples were tested, but these represent the overall performance for each configuration well enough).

As for the second alternative, it performed a little better on lower performance settings, but became worse for the other settings.

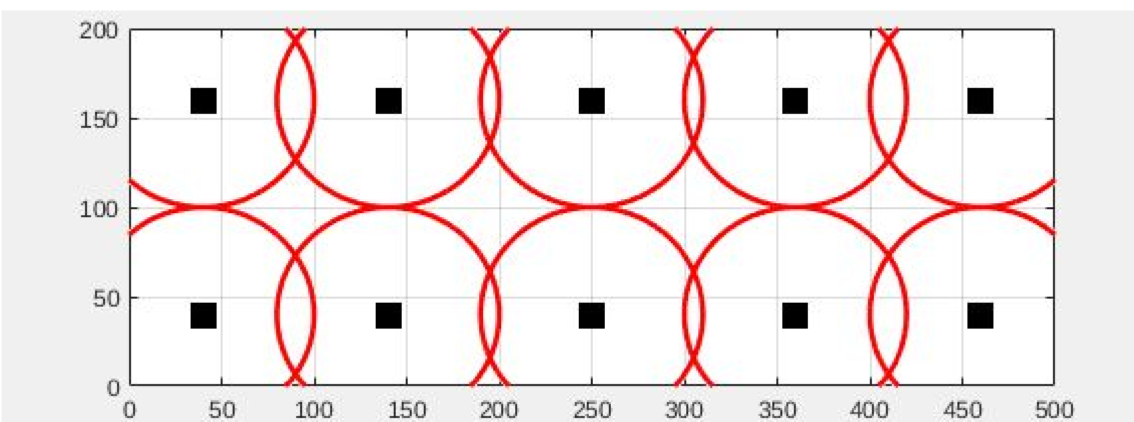
g) Minimum number of APs and their locations to guarantee 99% minimum availability

N = 80 (20 simulations)



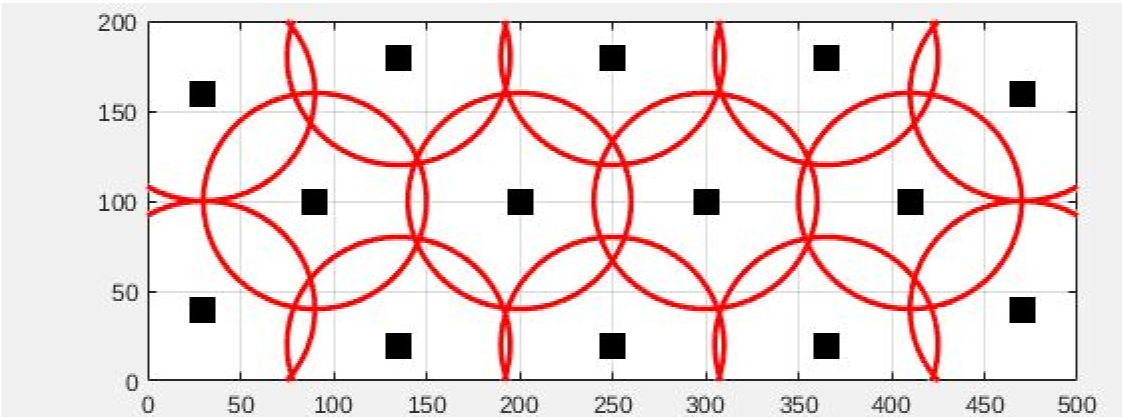
Configuration = [40 20;40 170;175 30;175 170;325 30;325 170;460 20;460 180]
Maximum availability = 0.9996 ∓ 0.0001
Minimum availability = 0.9932 ∓ 0.0018

N = 60 (20 simulations)



Configuration = [40 40; 40 160; 140 40; 140 160; 250 40; 250 160; 360 40; 360 160; 460 40; 460 160]
Maximum availability = 0.9996 ∓ 0.0001
Minimum availability = 0.9926 ∓ 0.0013

N = 40 (20 simulations)



Configuration = [30 40; 30 160; 90 100; 135 20; 135 180; 200 100; 250 20; 250 180; 300 100; 365 20; 365 180; 410 100; 470 40; 470 160]
Maximum availability = 0.9997 ∓ 0.0001
Minimum availability = 0.9948 ∓ 0.0015

The Code

For the Simulation Function

```
function visualize(N,AP,pos,L,C,plotar,W)
    if plotar==0
        return
    end
    nAP= size(AP,1);
    plot(AP(1:nAP,1),AP(1:nAP,2),'s','MarkerEdgeColor','k','MarkerFaceColor','k','MarkerSize',12)

    centers = [AP(1:nAP,1) AP(1:nAP,2)];
    viscircles(centers, W+zeros(nAP,1)); % to show the circles of range around the APs
```

We added the W parameter to the visualize to draw the range around each AP. The viscircles functions is included in the Image Processing Tools Matlab add-on.

```
function counter= InitializeCounter(N)
    counter = zeros(1,N);
end

function [pos,vel]= UpdateState(pos,vel,dlt)
    N= size(pos,1);
    pos = pos + dlt*vel;
    aux= [500*ones(N,1) 200*ones(N,1)];
    vel(pos>aux) = -vel(pos>aux);
    pos(pos>aux)= aux(pos>aux);
    aux= zeros(N,2);
    vel(pos<aux) = -vel(pos<aux);
    pos(pos<aux)= 0;
end

function counter= UpdateCounter(C,counter)
    counter = counter + C;
end

function L= ConnectedList(pos,W,AP)
    nodes_and_aps = [pos;AP];
    len = size(nodes_and_aps,1);
    L = [];
    for i = 1:len-1
        for j = i+1:len
            if sqrt( (nodes_and_aps(i,1)-nodes_and_aps(j,1))^2 + (nodes_and_aps(i,2)-nodes_and_aps(j,2))^2 ) <= W
                L = [L; i j];
            end
        end
    end
end

function C= ConnectedNodes(L,N,AP)
    C = false(1,N);
    if isempty(L)
        return
    end
    s = L(:,1);
    t = L(:,2);
    G = graph(s,t,[],N+size(AP,1));
    d = distances(G, N+1:N+size(AP,1), 1:N);
    if size(d,1) == 1
        C = d<inf;
    else
        C = min(d)<inf;
    end

end

function [AverageAvailability, MinimumAvailability]= results(T,counter)
    AverageAvailability = sum(counter)/(T*size(counter,2));
    MinimumAvailability = min(counter)/T;
end
```

The methods we had to complete.

For the Simulations

```
N = [20; 40; 60; 80;];
S = [3; 6];
W = [40; 60; 80];
AP = {[250 100];[150 100; 350 100];[50 50; 250 100; 450 150] };

numIter = 10;
avg = zeros(numIter,1);
min = avg;
alpha = 0.1;
res = zeros(size(N,1), size(S,1), size(W,1), size(AP,1), 4);

for N_conf = 1:size(N,1)
    for S_conf = 1:size(S,1)
        for W_conf = 1:size(W,1)
            for AP_conf = 1:size(AP,1)
                tic
                fprintf('N --> %d | S --> %d | W --> %d | Nº of APs --> %d\n', N(N_conf), S(S_conf), W(W_conf), AP_conf)
                for i= 1:numIter
                    fprintf('.')
                    [avg(i), min(i)] = simulatorFunction( N(N_conf), S(S_conf), W(W_conf), 1, 7200, AP{AP_conf}, 0 );
                end
                fprintf('\n')
                mean_avg = mean(avg);
                mean_min = mean(min);
                conf_int_avg = norminv(1-alpha/2)*sqrt(var(avg)/numIter);
                conf_int_min = norminv(1-alpha/2)*sqrt(var(min)/numIter);
                tmp = [mean_avg; conf_int_avg; mean_min; conf_int_min];
                for j=1:size(tmp,1)
                    res(N_conf, S_conf, W_conf, AP_conf,j) = tmp(j);
                end
                toc
            end
        end
    end
end

save('res.mat', 'res');
```

How we ran our simulations to obtain the results. The simulations performed for the suggested AP locations follow the same structure.

For the Plots

```
res = load('res.mat').res;
N = [20; 40; 60; 80;];
S = [3; 6];
W = [40; 60; 80];
AP = {[250 100];[150 100; 350 100];[50 50; 250 100; 450 150] };

% plot the impact of the radio range (W) on availability
% here we plot for every amount of N and AP configuration
% we fixate on those values and see how the availability changes with W

count = 1;
for i=1:length(N)
    for j=1:length(AP)
        % only retrieving availability values (no confidence intervals)
        y = res(i, 1, :, j, [2,4]);
        %resize mat to be a 3*2 to have average avail in collumn 1
        %and minimum avail in collumn 2
        y = reshape(y,length(W),2);
        %tranpose y to plot it
        y = y';
        figure(count)
        bar(W, y);
        legend('Average confidence', 'Minimum confidence', 'location', 'northwest')
        title(['Impact of W with N=',num2str(N(i)),' and ',num2str(j), ' APs'])
        hold on
        count = count + 1;
    end
end
```

The way the rest of the plots (for the impact of N and amount of APs) is obtained in a similar way, where we only have to change the for loops and the way we access the ‘res’ matrix accordingly.