Assignment #3
Availability Performance of Multi-Hop Wireless Networkds with Mobile Terminals

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Simulator

InitialzeCounter and UpdateCounter

Matlab Code

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

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

Code Analysis

These functions are the simplest of the entire code. The first initializes an array of N elements all with 0. The second increments the values of the 'counter' positions of the mobile nodes that have Internet access.

ConnectedList

Matlab Code

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

Code Analysis

This function returns a matrix with two columns in which are listed every pair of directly connected nodes (mobile nodes or AP nodes).
It goes through every possible combination (pair) of nodes and checks if their linear distance is equal or inferior to the radio range using Pythagoras Theorem. If so, the pair is added to the return variable.

ConnectedNodes

Matlab Code

```
function C = ConnectedNodes(L,N,AP)
    % Initialize return array with falses
    C = false(1,N);
    % Turn mobile_nodes+APs to graph
    firstColumn = [L(:,1);N+size(AP, 1)];
    secondColumn = [L(:,2);N+size(AP, 1)];
    g = graph(firstColumn, secondColumn);
    % Calculate distances between mobile nodes and APs
    mobileNodesIDs = 1:N;
    accessPointsIDs = N+1:N+size(AP, 1);
    dist = distances(g, mobileNodesIDs, accessPointsIDs);
    for i=1:size(dist,1)
        for j=1:size(AP,1)
            % If distance isn't infinite (if there is connection)
            if dist(i,j)~=inf
                % i node has connection to the internet
                C(1,i) = true;
            end
        end
    end
end
```

Code Analysis

This function returns an array with the size equal to the number of mobile nodes. In each position, the array contains a boolean value that indicates if that mobile node has (direct or indirect) connection to an Access Point.
This is done using a graph made from the array (list) returned from the function *ConnectedList* and checking if that node's (graph) distance to at least one Access Point is not infinite.

Results

Matlab Code

```
function [AverageAvailability, MinimumAvailability]= results(T,counter)
    AverageAvailability = mean(counter)/T;
    MinimumAvailability = min(counter)/T;
end
```

Code Analysis

This function computes the average and the minimum availability (values between 0 and 1) based on array *counter* and on the total number of time slots T.

Tasks

1 Access Point

Case	N	S (km/h)	W (meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	7.70e-02	1.32e-02	4.94e-03	3.40e-03
2	40	3	40	1.34e-01	1.00e-02	8.87e-03	7.33e-03
3	60	3	40	2.49e-01	1.18e-02	5.94e-02	2.02e-02
4	80	3	40	4.07e-01	1.55e-02	1.66e-01	1.83e-02
5	20	6	40	7.60e-02	2.87e-03	1.65e-02	7.33e-03
6	40	6	40	1.37e-01	7.47e-03	1.76e-02	1.13e-02
7	60	6	40	2.48e-01	1.28e-02	8.21e-02	2.03e-02
8	80	6	40	4.26e-01	1.41e-02	1.90e-01	2.14e-02
9	20	3	60	2.89e-01	1.34e-02	1.06e-01	2.93e-02
10	40	3	60	6.24e-01	1.47e-02	3.71e-01	3.16e-02
11	60	3	60	8.77e-01	9.59e-03	7.44e-01	2.01e-02
12	80	3	60	9.75e-01	2.84e-03	9.17e-01	1.07e-02
13	20	6	60	2.64e-01	1.09e-02	1.14e-01	2.86e-02
14	40	6	60	6.00e-01	1.47e-02	4.03e-01	3.65e-02
15	60	6	60	8.79e-01	5.46e-03	7.94e-01	1.54e-02
16	80	6	60	9.73e-01	1.67e-03	9.31e-01	6.59e-03
17	20	3	80	6.03e-01	1.87e-02	3.82e-01	4.43e-02
18	40	3	80	9.39e-01	4.80e-03	8.41e-01	1.97e-02
19	60	3	80	9.94e-01	1.38e-03	9.70e-01	6.87e-03
20	80	3	80	9.99e-01	2.22e-04	9.91e-01	2.20e-03
21	20	6	80	6.12e-01	1.26e-02	4.54e-01	3.59e-02
22	40	6	80	9.33e-01	4.82e-03	8.53e-01	1.61e-02
23	60	6	80	9.93e-01	1.20e-03	9.74e-01	4.91e-03
24	80	6	80	9.99e-01	2.75e-04	9.92e-01	1.55e-03

2 Access Points

Case	N	S (km/h)	W (meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	1.61e-01	2.09e-02	1.82e-02	1.40e-02
2	40	3	40	2.57e-01	1.34e-02	1.01e-01	3.18e-02
3	60	3	40	4.27e-01	1.19e-02	1.80e-01	3.01e-02
4	80	3	40	6.39e-01	1.69e-02	4.08e-01	5.97e-02
5	20	6	40	1.56e-01	1.09e-02	5.16e-02	2.21e-02
6	40	6	40	2.64e-01	9.12e-03	1.38e-01	2.32e-02
7	60	6	40	4.25e-01	7.85e-03	2.21e-01	4.81e-02
8	80	6	40	6.26e-01	8.96e-03	4.45e-01	3.31e-02
9	20	3	60	5.08e-01	2.17e-02	3.65e-01	5.68e-02
10	40	3	60	7.95e-01	9.58e-03	5.70e-01	5.75e-02
11	60	3	60	9.43e-01	4.14e-03	8.36e-01	2.39e-02
12	80	3	60	9.89e-01	1.29e-03	9.46e-01	6.76e-03
13	20	6	60	5.01e-01	1.08e-02	3.40e-01	5.67e-02
14	40	6	60	8.00e-01	7.20e-03	5.96e-01	5.96e-02
15	60	6	60	9.45e-01	3.31e-03	8.73e-01	1.31e-02
16	80	6	60	9.88e-01	9.94e-04	9.61e-01	4.99e-03

17	20	3	80	8.37e-01	1.55e-02	6.62e-01	5.91e-02
18	40	3	80	9.71e-01	2.71e-03	8.81e-01	2.02e-02
19	60	3	80	9.97e-01	7.38e-04	9.71e-01	5.22e-03
20	80	3	80	1.00e+00	7.93e-05	9.87e-01	4.87e-03
21	20	6	80	8.35e-01	1.06e-02	6.92e-01	4.28e-02
22	40	6	80	9.76e-01	2.66e-03	9.35e-01	8.07e-03
23	60	6	80	9.97e-01	7.25e-04	9.84e-01	2.52e-03
24	80	6	80	9.99e-01	1.43e-04	9.91e-01	1.82e-03

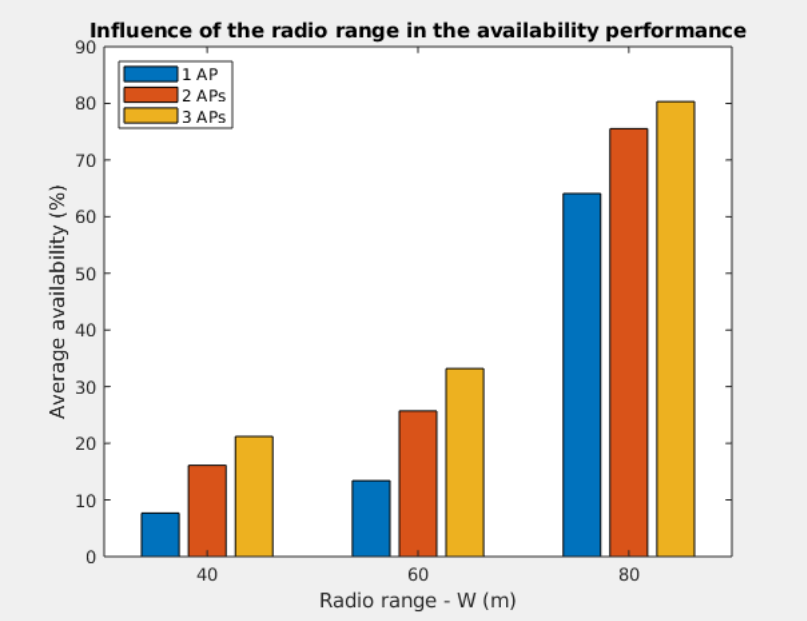
3 Access Points

Case	N	S (km/h)	W (meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	2.12e-01	1.26e-02	7.13e-02	3.13e-02
2	40	3	40	3.32e-01	9.04e-03	1.29e-01	3.97e-02
3	60	3	40	5.20e-01	5.27e-03	3.08e-01	4.12e-02
4	80	3	40	7.00e-01	9.39e-03	4.68e-01	4.04e-02
5	20	6	40	2.19e-01	1.23e-02	8.82e-02	3.34e-02
6	40	6	40	3.29e-01	7.65e-03	1.66e-01	2.55e-02
7	60	6	40	5.10e-01	9.72e-03	3.39e-01	2.92e-02
8	80	6	40	7.18e-01	7.67e-03	5.48e-01	2.78e-02
9	20	3	60	5.97e-01	2.20e-02	3.86e-01	7.20e-02
10	40	3	60	8.81e-01	6.61e-03	7.65e-01	1.10e-02
11	60	3	60	9.75e-01	2.27e-03	9.07e-01	1.56e-02
12	80	3	60	9.94e-01	6.78e-04	9.56e-01	1.17e-02
13	20	6	60	5.95e-01	1.49e-02	4.23e-01	6.24e-02
14	40	6	60	8.81e-01	4.07e-03	4.23e-01	6.24e-02
15	60	6	60	9.72e-01	1.67e-03	7.84e-01	2.06e-02
16	80	6	60	9.94e-01	6.61e-04	9.74e-01	7.62e-03
17	20	3	80	9.01e-01	9.08e-03	7.82e-01	5.11e-02
18	40	3	80	9.88e-01	1.47e-03	9.31e-01	1.49e-02
19	60	3	80	9.99e-01	4.00e-04	9.88e-01	4.15e-03
20	80	3	80	1.00e+00	1.35e-04	9.94e-01	4.28e-03
21	20	6	80	9.06e-01	4.86e-03	8.15e-01	2.56e-02
22	40	6	80	9.90e-01	1.21e-03	9.61e-01	6.52e-03
23	60	6	80	9.99e-01	2.07e-04	9.89e-01	2.54e-03
24	80	6	80	1.00e+00	9.82e-05	9.93e-01	2.11e-03

Task a

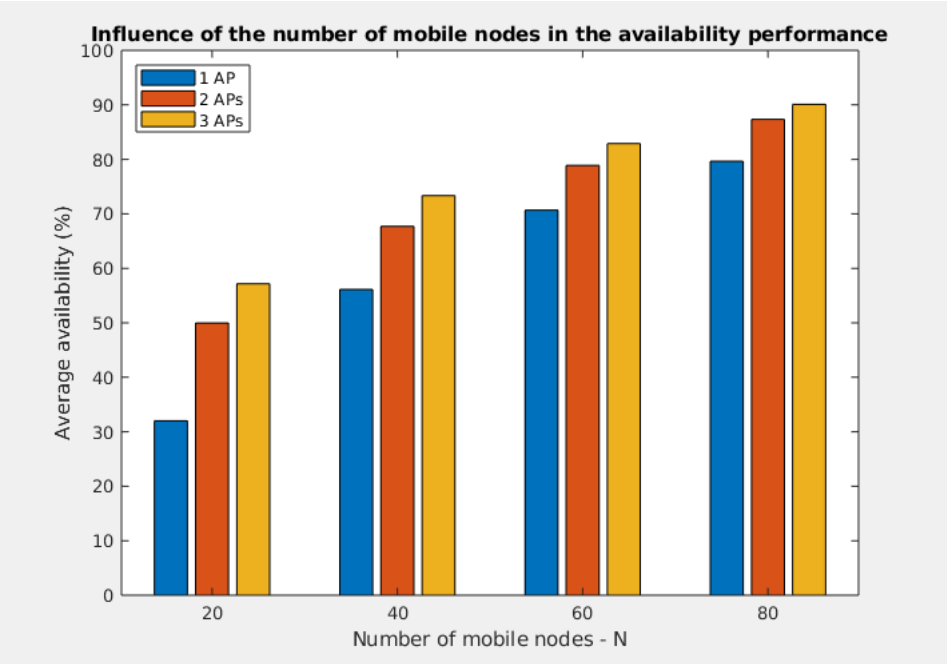
After analysis of the obtained results, it's possible to conclude that that the speed at which the mobile nodes are moving **does not affect** the availability performance of the network. The result variations obtained are not constant (when the velocity increases, the availability of the network doesn't always increase nor decrease) and are so small they should be considered irrelevant.

Task b



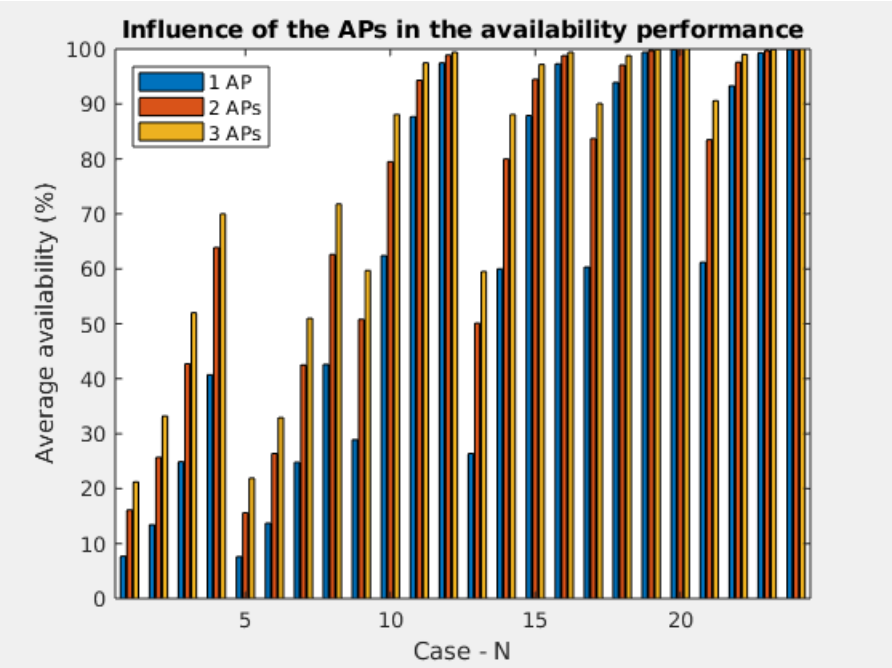
After analysis of the obtained results, it's possible to conclude that that the radio range **affects** the availability performance of the network. The result variations show that with the increase of the radio range, there's also an increase in the availability of the network. With the increase of the radio range, there are more connections between nodes (mobile nodes and AP nodes) being established. Therefore, the probability of a node being directly or indirectly connected to an Access Point will increase.

Task c



After analysis of the obtained results, it's possible to conclude that that the number of mobile nodes **affects** the availability performance of the network. The result variations show that with the increase of the number of mobile nodes, there's also an increase in the availability of the network. The reason for that is the same as for the considerations presented for the variation of the radio range. However, this time there's only an increase of the probability of indirect connection to an Access Point. The probability of a direct connection being established between an Access Point and a mobile node isn't affected.

Task d



After analysis of the obtained results, it's possible to conclude that that the number of AP (Access Point) nodes **affects** the availability performance of the network. The result variations show that with the increase of the number of AP nodes, there's also an increase in the availability of the network. With the increase of the number of AP nodes, there's an increase of the probability of a direct connection to an AP.

Task e

The 90% confidence interval shows variance according to the input parameters. This interval decreases (increase of confidence) with the increase of the number of mobile nodes, the velocity of the mobile nodes and the radio range.
The increase in the number of mobile nodes and radio range allow for more connections to be established, which increases the confidence (decreases the interval).
On the other hand, the increase in the speed of the mobile nodes allows for more connections and disconnections to happen in the same period of time. This acts like if the simulation would run with the same input parameters regarding number of mobile nodes and radio range but for longer. Therefore, there's an increase in the results' confidence.

Task f

Regarding the configurations with 1 and 2 AP nodes, it's intuitive that those are the best configurations. After attempting other location configurations for 3 AP nodes (triangle shaped disposition, for example), it was possible to conclude that there isn't a considerable gain in the change of AP positions.

3 Access Points

Locations: (250,140) (80,70) (420,70)

Case	N	S (km/h)	W (meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	20	3	40	2.45e-01	1.07e-02	1.10e-01	3.19e-02
2	40	3	40	3.41e-01	8.35e-03	1.95e-01	4.36e-02
3	60	3	40	5.38e-01	4.35e-02	2.80e-01	3.20e-01
4	80	3	40	7.28e-01	4.78e-02	5.14e-01	3.54e-02
5	40	6	40	2.15e-01	9.08e-03	8.86e-02	0.00e+00
6	60	6	40	3.50e-01	1.22e-02	2.18e-01	5.57e-02
7	80	6	40	5.48e-01	1.20e-02	3.40e-01	2.54e-02
8	20	3	60	7.54e-01	1.33e-03	6.64e-01	7.54e-03
9	20	3	60	6.18e-01	4.43e-03	4.16e-01	9.96e-02
10	40	3	60	9.00e-01	2.01e-02	7.75e-01	1.88e-02
11	60	3	60	9.74e-01	2.47e-03	8.98e-01	4.72e-02
12	80	3	60	9.90e-01	3.55e-03	9.46e-01	2.44e-02
13	20	6	60	6.38e-01	2.72e-03	5.53e-01	4.99e-02
14	40	6	60	8.92e-01	6.89e-03	7.98e-01	1.75e-02
15	60	6	60	9.72e-01	2.03e-03	8.88e-01	2.89e-02
16	80	6	60	9.93e-01	1.33e-04	9.58e-01	1.51e-02
17	20	3	80	9.19e-01	8.10e-03	8.26e-01	5.97e-02
18	40	3	80	9.92e-01	7.42e-04	9.57e-01	2.40e-03
19	60	3	80	9.99e-01	6.57e-04	9.84e-01	1.71e-03
20	80	3	80	1.00e+00	2.71e-04	9.94e-01	1.03e-02
21	20	6	80	9.11e-01	6.44e-03	8.47e-01	1.10e-02
22	40	6	80	9.90e-01	1.32e-03	9.58e-01	2.40e-02
23	60	6	80	9.98e-01	7.01e-04	9.89e-01	2.74e-03
24	80	6	80	1.00e+00	9.57e-05	9.89e-01	6.28e-03

Task g

According to what is stated above, from the 3 configurations needed for this problem, the one which will report the lower availability rates will be the one with 40 mobile nodes.
After a lot of testing with 14 AP nodes, the following locations:

- (40,150) (140,170) (250,170) (360,170) (460,150)
- (100,100) (200,100) (300,100) (400,100)
- (40,50) (140,30) (250,30) (360,30) (460,50)

Produced the best results. However, these never exceeded a minimum availability rate of 92%. Therefore, no configuration with 14 APs was found adequate.
After conforming with the idea that 14 APs were not enough, it was possible to find a configuration using 15 APs that complied with the problem requirements. The chosen configuration was the following:

- (20,175) (130,175) (240,175) (350,175) (460,175)

- (100,100) (200,100) (300,100) (400,100) (470,100)
- (20,25) (130,25) (240,25) (350,25) (460,25)

With this configuration, it was possible to achieve the following results:

Case	N	S (km/h)	W (meters)	Average availability	90% confidence interval	Minimum availability	90% confidence interval
1	40	3	40	1.00e+00	1.20e-05	1.00e+00	2.71e-04
2	60	3	40	1.00e+00	3.10e-06	1.00e+00	1.22e-04
3	80	3	40	1.00e+00	0.00e+00	1.00e+00	0.00e+00