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ASSIGNMENT GUIDE NO. 2

CONNECTIVITY PERFORMANCE OF MULTI-HOP WIRELESS NETWORKS WITH MOBILE TERMINALS

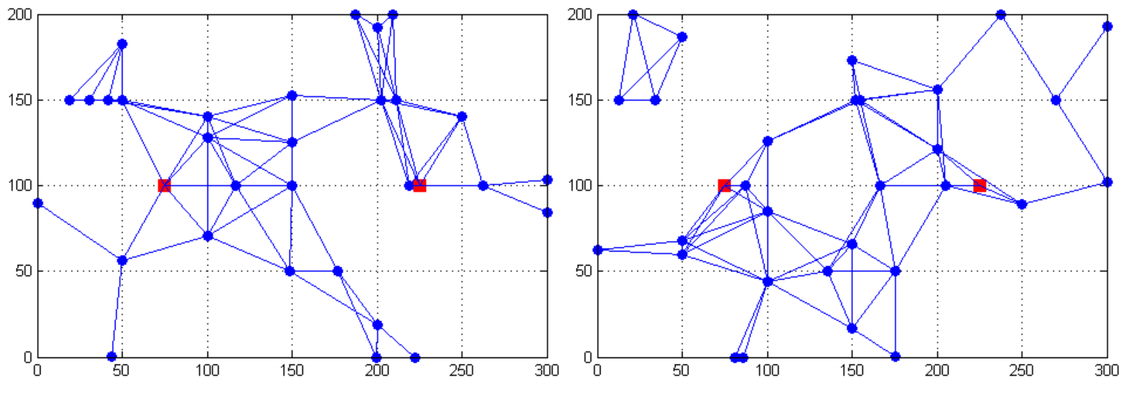
1. General Description

The aim is to conduct a simulation analysis of the connectivity performance of a multi-hop wireless network where mobile nodes are moving on a given geographical area. The wireless network provides mobile nodes with Internet access through AP (Access Point) nodes spread over the geographical area. The network is characterized by a given radio range W such that any mobile node establishes a direct wireless link with each of the other nodes (mobile or AP) whose distance from it is not higher than W. In multi-hop wireless networks, nodes are able to perform routing, i.e., they can forward data packets received from other nodes and destined to other nodes. So, at each time instant, a mobile node has connectivity with the Internet if there is a routing path between it and at least one AP node over the set of established wireless links.

Consider the geographical area of the network given by a rectangle of 300 horizontal meters by 200 vertical meters representing a possible open space campus with 5 horizontal walking paths and 7 vertical walking paths, in both cases separated by 50 meters. Each mobile node moves over one walking path with a constant velocity and turns back in the same walking path when it reaches the limit of the rectangle.

Fig 1 presents two snapshots (taken in two different time instants) of a simulation with 2 AP nodes (represented by red squares) and 30 mobile nodes (represented by blue circles). The inner walking paths are represented by dashed lines and the outer walking paths are represented by solid lines (note that mobile nodes are always located on one of the walking paths). The blue line segments on the snapshots represent established wireless links between nodes. In the snapshot of Fig. 1(a), all mobile nodes have Internet access since there is at least one routing path from every mobile node to at least one AP. In the snapshot of Fig. 1(b), there are only 26 mobile nodes with Internet access because 4 mobile nodes (upper left part of the figure) are disconnected from all the other nodes.

Consider as connectivity metric the average percentage number of mobile nodes with Internet access over all simulated time. In the snapshot of Fig. 1(a) the percentage number of nodes with Internet access is 100% while in the snapshot of Fig. 1(b) the percentage number of nodes with Internet access is 100%×26/30 = 86.(6)%.



(a) (b)

Fig. 1 – Snapshots of the network with two AP nodes (red squares) where: (a) all mobile nodes have Internet access and (b) 4 mobile nodes do not have Internet access.

Note that the network to be simulated is a continuous time systems (i.e., the location of the mobile nodes varies continuously with time). To develop a proper simulator, time is discretized in time instants with equal time difference between consecutive instants. Then, the simulator computes only the state of the system at each discrete time instant (the time difference value between consecutive time instants is a trade-off between simulation running time and results accuracy: for smaller time differences, the simulation running time increases and the results accuracy also increases).

Fig. 2 illustrates the results of a simulation run. The blue plot gives the percentage number of nodes with Internet access on each discrete time instant of the simulation and the red plot gives the evolution of the average percentage number of nodes with Internet access (the result of the simulation is the value of the red plot at the end of the simulation).

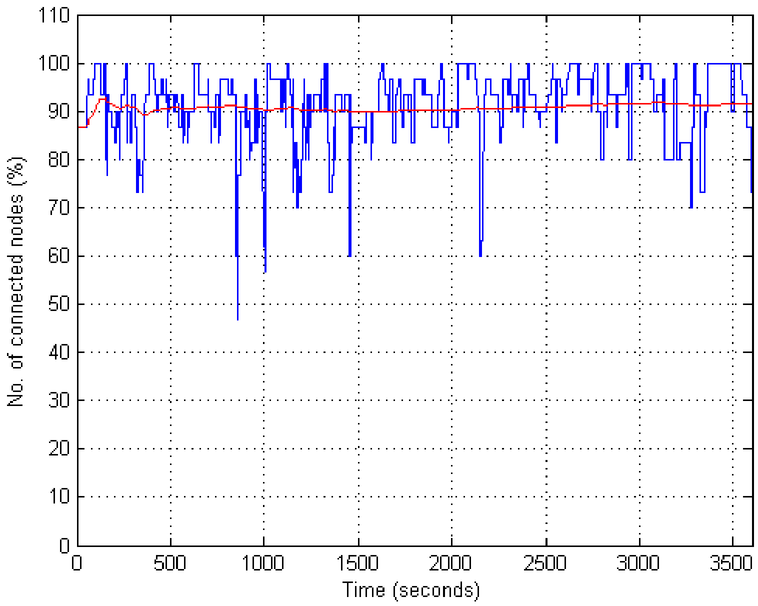


Fig. 4 – Simulation run example.

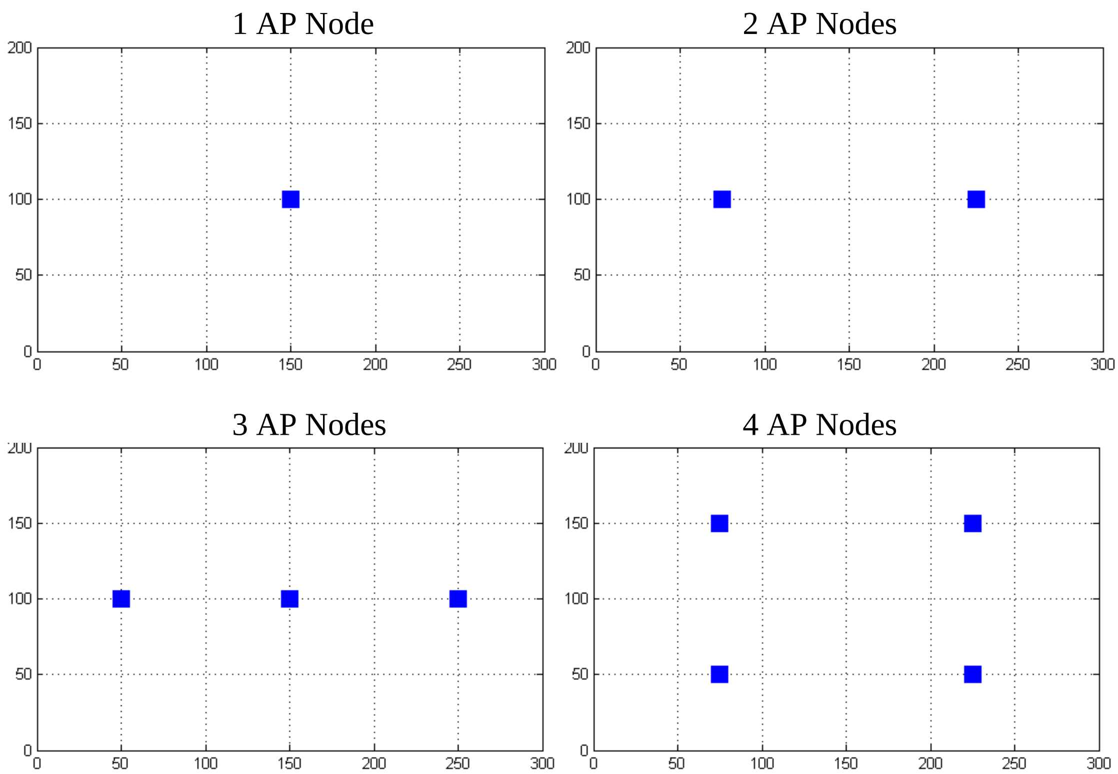
2. Assignment Description

2.1. Simulator Development

Using the MATLAB main script provided in a separate file (named simulator.m), implement the required MATLAB functions to develop a simulator of a multi-hop wireless network as described in the previous section. The aim of the simulator is to estimate the average percentage number of mobile nodes with Internet access.

Section 3.1 describes how to generate the initial horizontal and vertical coordinates of each mobile node position and Section 3.2 describes how to generate the initial horizontal and vertical components of each mobile node speed vector. See Section 4 describing a labelling algorithm to compute the percentage number of connected node pairs with Internet access for each time instant.

Concerning the AP configuration in terms of number of AP nodes and their locations, consider the following 4 AP configurations:



The input parameters of the simulator are:

N	number of mobile nodes
W	radio range (in meters)
S	maximum node speed (in Km/h)
Δ	time difference between simulated time instants (in seconds)
T	number of time instants to be simulated (i.e., the total simulated time is $T \times \Delta$ seconds)
AP	matrix with one row per AP node and 2 columns where the first column has the horizontal coordinates and the second column has the vertical coordinates of the AP nodes

2.2. Results Analysis

a) For each AP configuration, run 10 simulations for all cases defined in the following Table and determine the average number of nodes with Internet access together with the 90% confidence intervals (run each simulation with $\Delta = 1$ second and $T = 3600$).

Case	N	W (meters)	S (km/h)	Avg. no. of nodes with Internet access (%)	90% confidence interval
A	50	40	3		
B	50	60	3		
C	50	80	3		
D	100	40	3		
E	100	60	3		
F	50	40	6		
G	50	60	6		
H	50	80	6		
I	100	40	6		
J	100	60	6		

b) Based on the results of the average number of nodes with Internet access, take conclusions about the influence of the maximum speed S, radio range W, number of mobile nodes N and number of APs on the connectivity performance of the wireless network. Whenever possible, justify your conclusions.

c) By analyzing the obtained 90% confidence intervals, what do you conclude on the influence of the different input parameters on the statistical confidence of the results?

d) Are the suggested AP configurations the best choice for each considered number of APs? Simulate possible alternatives in the cases you think better performance can be obtained.

e) Assume now that the maximum speed of each node is S = 6 Km/h and that the number of mobile nodes is $N = 50$. For each of the 3 radio range values W = 40, 60 and 80 meters, determine the minimum required number of APs (and locations) such that the average number of nodes with Internet access is not lower than 99%. For each of the three cases, run an enough large number of simulations to reach an adequate 90% confidence interval.

3. Generation of Random Values

3.1. Initial Node Coordinates

At the beginning, the initial horizontal and vertical coordinates of each node must be randomly generated within a rectangle area of 300 horizontal meters by 200 vertical meters. Moreover, half of the nodes must be randomly placed in one of the 5 horizontal walking paths and the other half of the nodes must be placed in one of the 7 vertical walking paths. In MATLAB, the function `randi([a b],N,M)` generates a matrix of `N` rows and `M` columns of integer values randomly generated with an uniform distribution between `a` and `b`. To generate the initial coordinates of `N` mobile nodes, you can use the following sequence of MATLAB lines:

```
pos= [50*randi([0 6],N/2,1) 200*rand(N/2,1)];
pos= [pos; 300*rand(N/2,1) 50*randi([0 4],N/2,1)];
```

which generates the matrix `pos` with `N` rows and 2 columns where the first column has the horizontal coordinates and the second column has the vertical coordinates. In the first line, the first `N/2` nodes are randomly placed in the vertical walking paths (i.e., their horizontal coordinates are only 0, 50, 100, 150 or 200 meters). In the second line, the last `N/2` nodes are randomly placed in the horizontal walking paths (i.e., their vertical coordinates are only 0, 50, 100, 150, 200, 250 or 300 meters).

3.2. Initial Node Speed and Direction

At the beginning, the speed value of each node must be randomly generated with a uniform distribution between 0 and a maximum speed value S. Moreover, the speed angle of the nodes placed in vertical walking paths must be selected as either $-\pi/2$ or $\pi/2$ radians (to maintain the nodes on the same walking paths) and the speed angle of the nodes placed in the horizontal walking paths must be selected as either 0 or π radians. To generate the initial speed values and speed angles of all mobile nodes, you can use the following sequence of MATLAB lines:

```
vel_abs= S*rand(N,1);
vel_angle= pi*randi([0 1],N/2,1) - pi/2;
vel_angle= [vel_angle; pi*randi([0 1],N/2,1)];
vel= [vel_abs.*cos(vel_angle) vel_abs.*sin(vel_angle)];
```

The first line generates the speed values of all `N` mobile nodes. The second line generates the speed angles of the first `N/2` nodes. The third line generates the speed angles of the last `N/2` nodes. The last line generates matrix `vel` with `N` rows and 2 columns where the first column has the horizontal component of the speed vector (equal to the speed value multiplied by the cosine of the speed angle) and the second column has the vertical component of the speed vector (equal to the speed value multiplied by the sine of the speed vector).

4. Labelling Algorithm for Connectivity Computation

Consider a set of N mobile nodes (represented by $i = 1, 2, \dots, N$) and a set of A AP nodes (represented by $i = N+1, N+2, \dots, N+A$). At a particular time instant, consider the list of node pairs $(i, j) \in A$ that have established wireless links between them. Consider a Boolean variable *Repeat* and an array of labels $L = [l_1\ l_2 \dots\ l_{N+2}]$ where l_i is the label assigned to node $i = 1, 2, \dots, N + A$. A labelling algorithm to compute the mobile nodes that have at least one routing path to one AP node is as follows:

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1. Assign label $l_i = 0$ to all mobile nodes $i = 1, \dots, N$ and label $l_i = 1$ to all AP nodes $i = N + 1, \dots, N + A$.
2. *Repeat* ← TRUE
3. **While** *Repeat* = TRUE **do:**
4.   *Repeat* ← FALSE
5.   **For** all node pairs $(i, j) \in L$ **do:**
6.   **If** $l_i \neq l_j$ **do:**
7.   Assign 1 to the node (either *i* or *j*) that has label 0
8.   *Repeat* ← TRUE
9.   **EndIf**
10.   **EndFor**
11. **EndWhile**

At the end, all mobile nodes *i* with label $l_i = 1$ have at least one routing path to at least one AP node while mobile nodes with label 0 have no routing path to any AP node. Consider an example with 10 mobile nodes and 2 AP nodes. In Step 1, the assigned labels are:

	Mobile nodes										AP nodes	
Nodes:	1	2	3	4	5	6	7	8	9	10	11	12
Array *L*:	0	0	0	0	0	0	0	0	0	0	1	1

At the end, if the assigned labels are:

	Mobile nodes										AP nodes	
Nodes:	1	2	3	4	5	6	7	8	9	10	11	12
Array *L*:	1	0	1	1	0	0	1	1	1	1	1	1

it means that nodes 1, 3, 4, 7, 8, 9 and 10 have Internet access and the other nodes (2, 5 and 6) don't. In this case, the percentage number of mobile nodes with Internet access is $\frac{7}{10} \times 100\% = 70\%$ (i.e., 70% of the total number of mobile nodes have Internet access).