Study of Connection Patterns in Opportunistic Networks

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Abstract. A mobile ad hoc network (MANET) is a continuously self-configuring, infrastructure-less network of mobile devices connected without wires. Each device/node in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. The main problem in a MANET is to maintain connectivity. A simulation model has been implemented in NetLogo to analyze the behavior of the network according to certain varying properties, the results comprehend some common evaluation metrics calculated on many experiments in which different strategies for handling connections have been used.

1 The Model

1.1 Base Model

The model which has been used defines a type of agent : a node, every node moves independently and randomly. Two nodes can communicate when there is a link between them, this link gets created only if the distance between the two nodes is less or equal than r which is the coverage area of a node. Obviously when two connected nodes move beyond their coverage area, the link between them is removed.

In addition to the coverage area of a node there is another constraint to be satisfied in order for a link to be established, both nodes must have a degree which is less than the maximum possible degree.

A node also has a defined speed of movement, according to this parameter we know how many steps the node can move forward in just a unit of time.

The last property of the model is the strategy the nodes adopt for handling connection, which defines the behavior when events such as "establish new connection" or "replace a connection" occur.

The area on which this simulation model has been deployed is a torus of variable size.

1.2 Extensions to the Base Model

The base model which has just been described has been extended with few properties.

- **Node speed** : every node can have its own speed parameter. When the global parameter s (node speed) is set a node set its own speed parameter which is chosen randomly and uniformly between 1 and s;

- **Node maximum degree** : every node can have its own maximum degree parameter. When the global parameter D_m (maximum degree) is set a node set its own maximum degree parameter which is chosen randomly and uniformly between 1 and D_m.

1.3 Connection Handling Strategies

The base rule is that every node establish a new connection when possible, therefore the different strategies define how a node behaves when it has reached the maximum number of connections and a new node gets discovered (it means that the new node enters in its coverage area), this implies that some decision has to be made about whether removing an older connection in order to establish the new one and according to what criterion this must be done.

These are the different connection handling strategies present in the NetLogo implementation of the model and which are therefore available for the simulation experiments.

The following strategies define whether to remove a connection and how a node decides which connection to remove before establishing a new one:

1. **Random-kill** : this strategy always removes an existing random connection when a new node gets discovered;

2. **Max-degree-kill** : When a new node gets discovered this strategy always removes the connection with the node having the maximum degree among a node's neighbors;

3. **No-bridge-kill (random)** : this strategy tries to remove a random connection which is not a bridge, this implies that removing this connection the connected component to which the node belongs is not broken in 2 smaller components. When a node only has bridge-connections it removes a random connection;

4. **No-bridge-kill (max-degree)** : this strategy tries to remove a random connection which is not a bridge, when a node only has bridge-connections it removes the connection with the node with the maximum degree;

5. **No-bridge-kill (most-distant)** : this strategy tries to remove a random connection which is not a bridge, when a node only has bridge-connections it removes the connection with the node which is the most distant;

6. **No-bridge-kill** : this strategy tries to remove a random connection which is not a bridge, if all connections are bridges the new connection is not established;

7. **Most-distant-kill** : this strategy always removes the connection with the most distant node in order to be able to connect to a new node;

8. **Most-distant-no-bridge-kill** : this strategy tries to remove a non-bridge connection with the most distant node, if every connection is a bridge then the new connection is not established;

9. **Max-degree-no-bridge-kill** : this strategy tries to remove a non-bridge connection with the node with the maximum degree, if every connection is a bridge then the new connection is not established;

All the "no-bridge" strategies are <u>theoretical</u> strategies because in a MANET there's no centralized vision of what is happening, therefore these kind of strategies in reality are not possible, nevertheless I included them as being "optimal" strategies because they were of interest to me.

All the connection handling strategies which have just been described will be used in the following experiments which have been performed with the NetLogo software.

2   Evaluation Metrics

For the purpose of evaluating the simulation results of the implementation of the model some metrics have been considered and computed on each performed experiment.

2.1   Connectivity

One of the evaluation metric which has been taken into account is the growth over time of the biggest connected component, this has a strong meaning for the network we obtain because what it basically means is how many node is the giant component made of and therefore how many nodes are at a given time

reachable in terms of communication.

As a matter of fact the size of the biggest component present in the network has been defined as being the value of **connectivity** of the network, which defines the probability that if we randomly pick two nodes of the network there exists a path between them through which they are capable of communicating with each other.

Given this definition of connectivity this is the metric of the network we obtain which we most care and pursue to maximize (the greater this value is the better the connectivity is).

2.2 Edge Density

This evaluation metric takes into consideration how many edges are present over the possible number of edges.
This metric is computed a bit differently from the standard one because in this model we have a constraint on the number of edges which each node can have (the maximum degree).

The edge density E_D is computed as follows:

$$E_D = \frac{2 * E_c}{N_c * D_m}$$

where E_c is the number of edges present in the network and N_c is the number of nodes present in the network.

2.3 Bridges

An edge in a graph is a bridge if deleting it increases the number of components of the graph.

In this evaluation metric the number of bridges over the number of edges is taken into account (to normalize the value between 0-1), for the purpose of examining the network we obtain during the experiments we are only interested in calculating the percentage of bridges present in the giant component.

This metric is computed as follows :

$$B_{gc} = \frac{Bn_{gc}}{E_{gc}}$$

where Bn_{gc} is the number of bridges present in the giant component.

The percentage of bridges is defined as the fault-tolerance of the network, the lower the number of bridges is the higher is the resilience of the network, as a matter of fact the metric B_{gc} represents the probability of breaking the giant component in two distinct components removing a connection picked randomly, so as stated before the lower this probability is the better is the network.

2.4 Degree Distribution

The last metric which is the degree distribution doesn't help us in evaluating how good is the network we obtain with a certain configuration, but it is still of interest because we may want to know to what law the degree distribution obeys.

As a matter of fact it may be curious to find out that the degree distribution when the network is fully connected might obey either a power law, therefore there are some nodes which are hubs, or a normal distribution.

3 Experiments

In this section there are the results of the experiments with different configurations of the parameters of the model we have described so far.

Since the range of the parameters which characterize the model is too wide we will make some assumptions on the value of some them as to study the parameters which are more of interest with the objective to find relations between them and if possible to find the tipping points of these properties to have a fully connected network.

Throughout the experiments the following parameters will be set to the following values :

- r (radius) = 15
- s (node speed) = 5

and the extensions to the model are enabled, therefore the radius and the node speed for each node are chosen randomly.

These values are relative to the dimension of the torus on which the simulation model is deployed.

All the plots shown in this section have been made with the software R using the library ggplot2 and a smoothing algorithm has been applied to all the datasets used for the graphs (except for the degree distribution plot).

During the following sections not all the strategies will be shown, in fact there are

only the main ones (No-bridge-kill, Most-distant-kill, Max-degree-kill, Random-kill), this has been done because all the "hybrid" strategies perform almost the same as their "pure" version and don't exhibit therefore interesting behaviors.

3.1 Connectivity experiments

In these experiments the values of the number of nodes in the system and their maximum degree has been varied to observe how it affects the connectivity of the network we obtain.
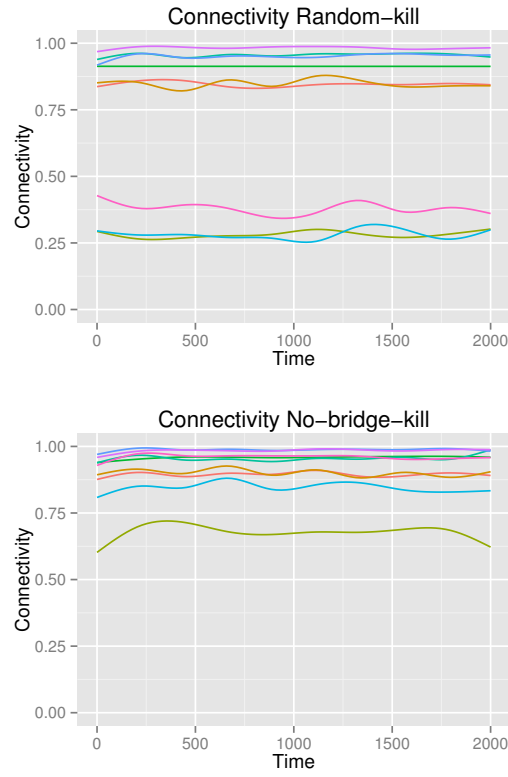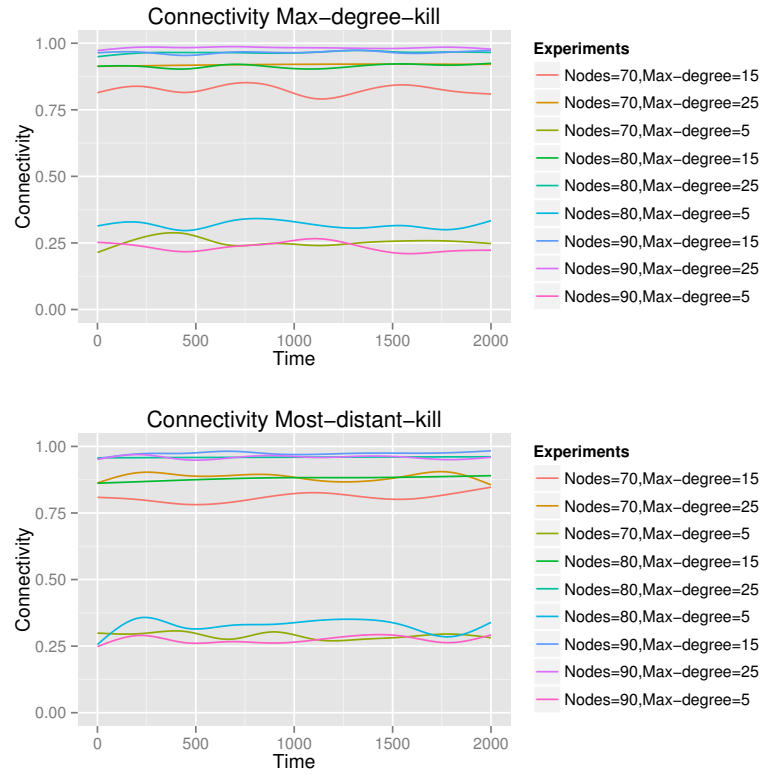

Fig. 1. Connectivity experiment - 1/2   **Fig. 2.** Connectivity experiment - 3/4

In Fig. 1 and Fig 2 there are the first four experiments in which we compare the performance of the following strategies:

– Random-kill;
– Max-degree-kill;
– No-bridge-kill (theoretical);
– Most-distant-kill;

We can observe that all the strategies apart from the "No-bridge-kill" one behave similarly.

In fact we can deduce from the plots that the amount of nodes is almost irrelevant for the connectivity, as a matter of fact in all the strategies when the maximum degree is set to the five the connectivity doesn't go beyond the 45-50%, but when we go from $D_m = 5$ to $D_m = 15$ we have a sudden change, in fact we can say that between 5 and 15 (D_m) there's a tipping point value for the connectivity metric.

From the plots we can observe that increasing D_m up to 15 or more the connectivity goes up to 80% and the more we increase this value the higher the connectivity is, until reaching almost 100% for the whole simulation time.

These results are quite predictable because even if the radius is fixed and equals to 15% when we increase the number of nodes they end up in filling up the whole area on which they are deployed and if the number of possible connection per node (the maximum degree) is sufficient then we can achieve full connectivity. From these results we can see that this last parameter is the most relevant (compared to the nodes number, because the others are fixed) because independently of the handling connection strategy adopted (even the "Random-kill" performs quite well) the networks we obtain are all quite good in terms of connectivity when the maximum degree value is set to 15.

The "No-bridge-kill" obviously stands out in terms of connectivity performance because is an optimal behavior, as a matter of fact adopting this strategy the nodes remove a connection in order to replace it with another one only if this connection doesn't break the connected component to which the node belongs in more components, therefore it clearly performs really well, in fact it achieves a value of connectivity higher than the 80% in most cases (all of them actually, apart from when the nodes are 70) even when $D_m = 5$.

Unfortunately we have to point out again that this strategy is only theoretical and not implementable in reality, because in a MANET network every node is independent and there is no central authority having the information required to be capable of computing whether a connection is a bridge or not.

3.2   Edge density experiments

In these experiments the values of the number of nodes in the system and their maximum degree has been varied to observe how it affects the edge density of
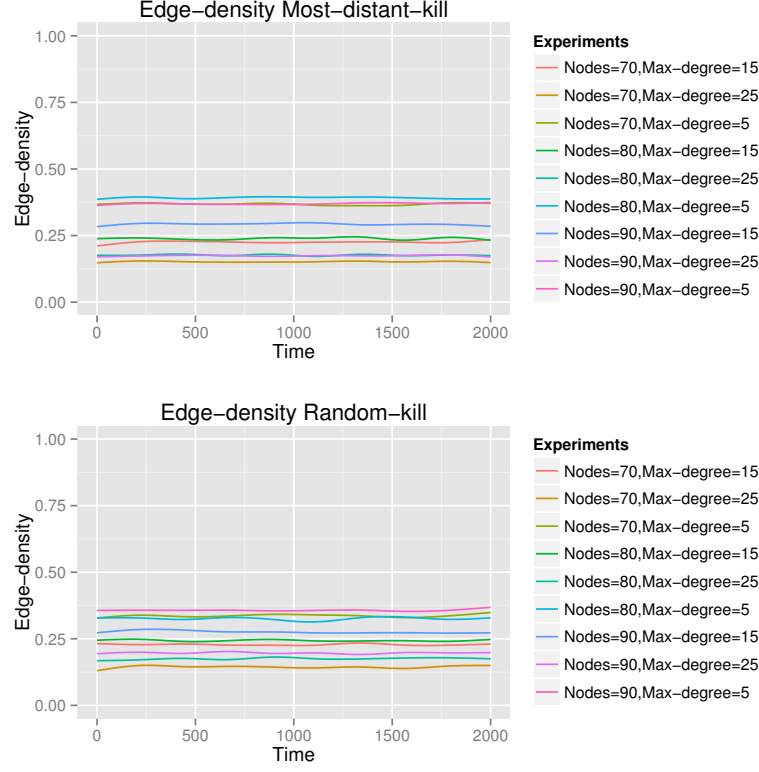
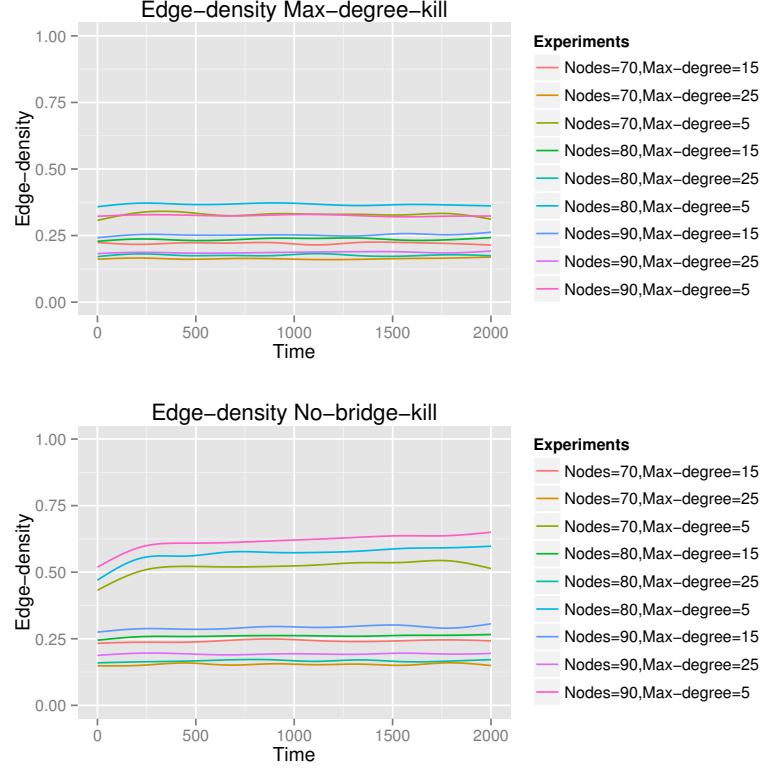**Fig. 3.** Edge density experiment - 1/2   **Fig. 4.** Edge density experiment - 3/4

the network we obtain.

From the plots in Fig 3 and Fig 4 we can observe that no strategy is really effective in increasing the density of the network, apart from the "No-bridge-kill" one which increases this value (compared to the other strategies) when the nodes in the system are 70 and $D_m = 5$, this is understandable because of the goodness of the "No-bridge-kill" at keeping bridge connections intact and for the fact that we roughly have the same number of connections over all the experiments, therefore the lower D_m is the higher the edge density is, this is a direct consequence of the how the metric is computed.

3.3 Bridges experiments

In these experiments the values of the number of nodes in the system and their maximum degree has been varied to observe how it affects the value of B_{gc} of the network we obtain.
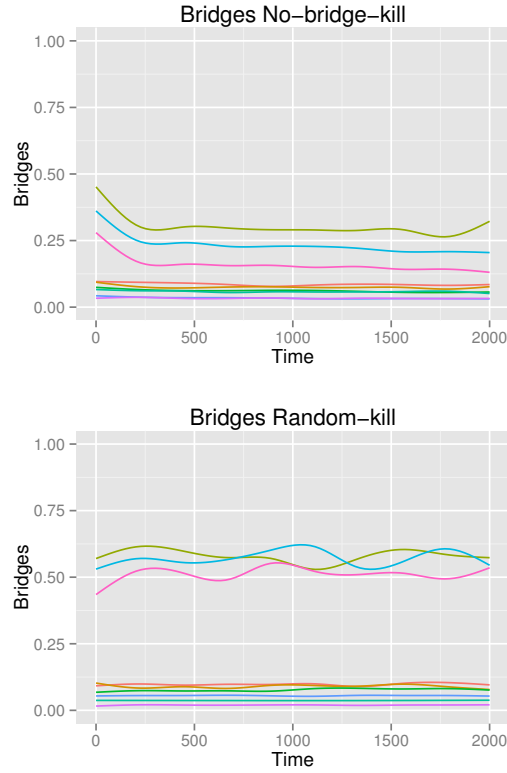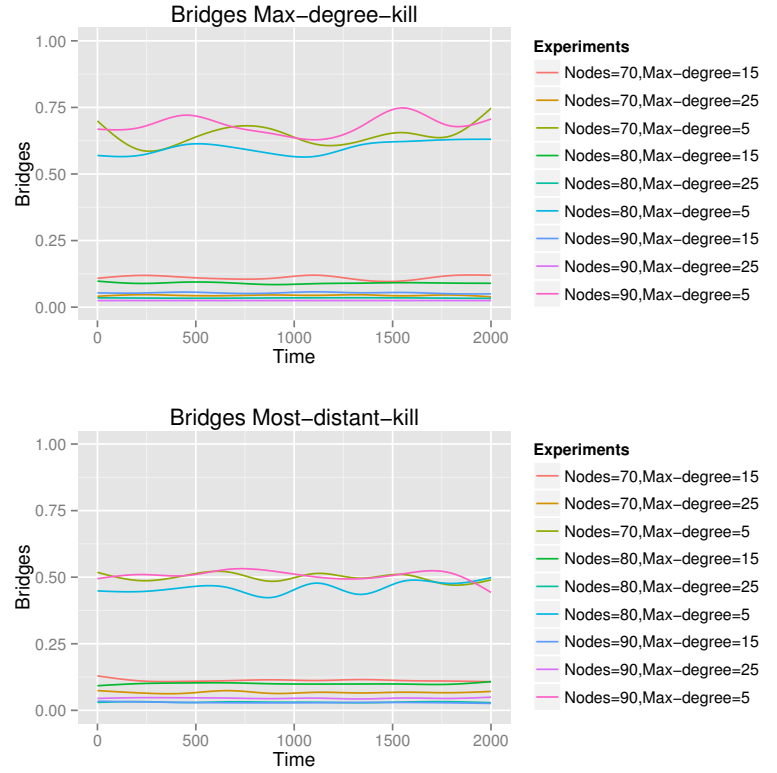
Fig. 5. Bridge percentage - 1/2   **Fig. 6.** Bridge percentage experiment - 3/4

The plots in Fig. 5 and Fig. 6 show the percentage of bridges in the different networks obtained during the experiments, to recap the value of this metric has been defined as the fault-tolerance of network since B_{gc} is the probability to break the giant component in more components if we remove a random connection from it, therefore the lower it is the more resilient the network is.

Obviously the best handling connection strategy at minimizing this value is the "No-bridge-kill", but since it is so obvious is not interesting.
What is actually interesting is the behavior of the network independently of the strategy adopted, as a matter of fact we can observe that if we increase D_m up to 15 then all the strategies keep the value of B_{gc} below the 12-13%, therefore we might deduce that there is a tipping point between 5% and 15%, and in fact the tipping, as we can see from Fig. 7 is actually the value 6%.

Other interesting things emerging from these plots to point out are that in terms of minimizing the number of bridges the "Random-kill" strategy performs
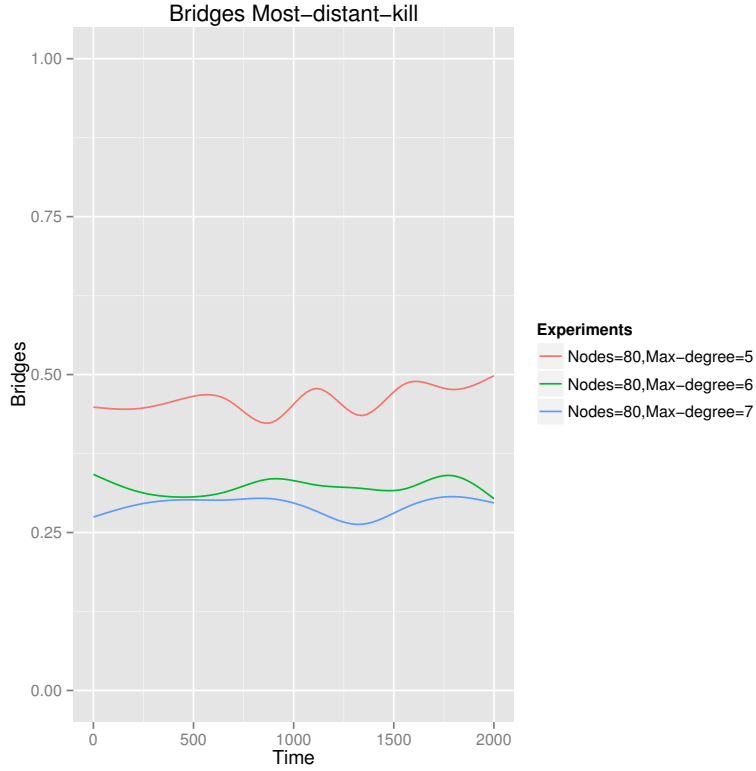
Fig. 7. tipping point value - Bridges

better than the "Max-degree-kill" but not as good as the "Most-distant-kill" which seems to be a best-option for a real MANET deployment.

Lastly we have to say that these values are not really encouraging, it is quite easy to deduce that any kind of MANET obtained with any of the configurations in which $D_m = 5$ (that are really plausible as real configurations) would be highly subject to frequent disconnections in the giant component, but still just by increasing the maximum degree of the nodes by a little the number of bridges can be kept to an acceptable minimum.

3.4 Degree distribution experiments

In these experiments the values of the number of nodes in the system and their maximum degree has been varied to observe how it affects the degree distribution of the network we obtain.
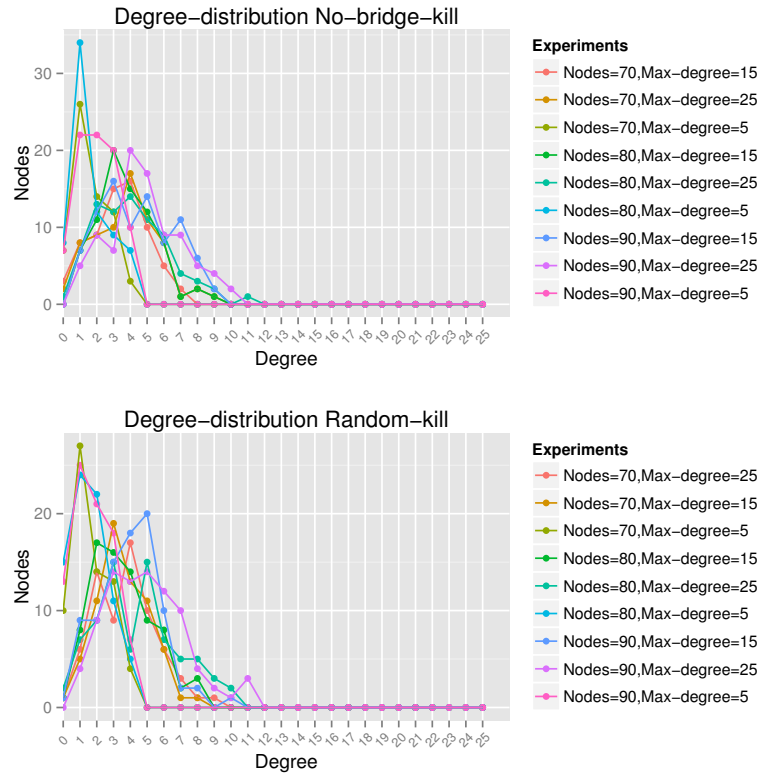
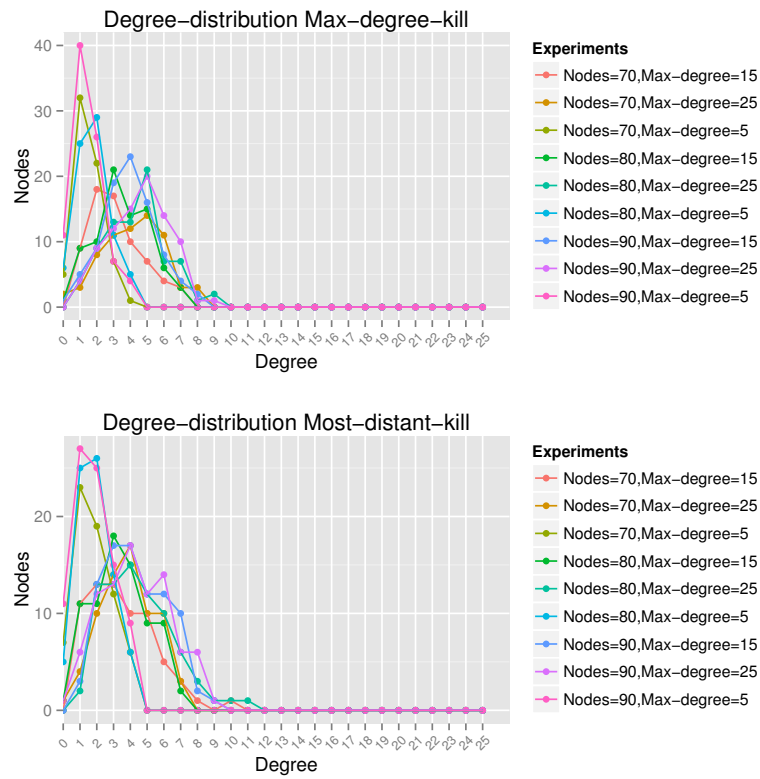**Fig. 8.** Degree distribution - 1/2

Fig. 9. Degree distribution - 3/4

From the plots in Fig. 8 and Fig. 9 we might conclude that the law which the degree distribution obeys is a binomial law, but in order to be sure (and for curiosity) we inspect the plots in Fig. 10 and Fig. 11 which are the same graphs but plotted in a Log-Log scale (this is useful for inspecting the decay rate of the curves). Indeed we can conclude that the degree distribution of the nodes in the
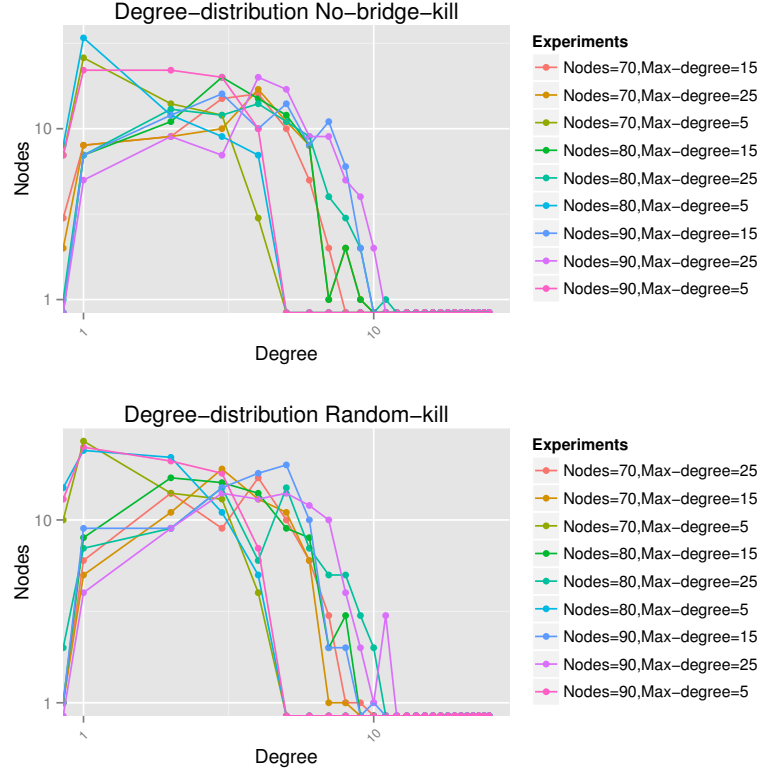

Fig. 10. Degree distribution - 1/2

MANET of these simulations appears to obey a binomial law [3].

4 Conclusions

Finally we can say that MANETs are really delicate networks in which any little parameter change (radius, maximum degree...) can completely modify the properties of the network we obtain.

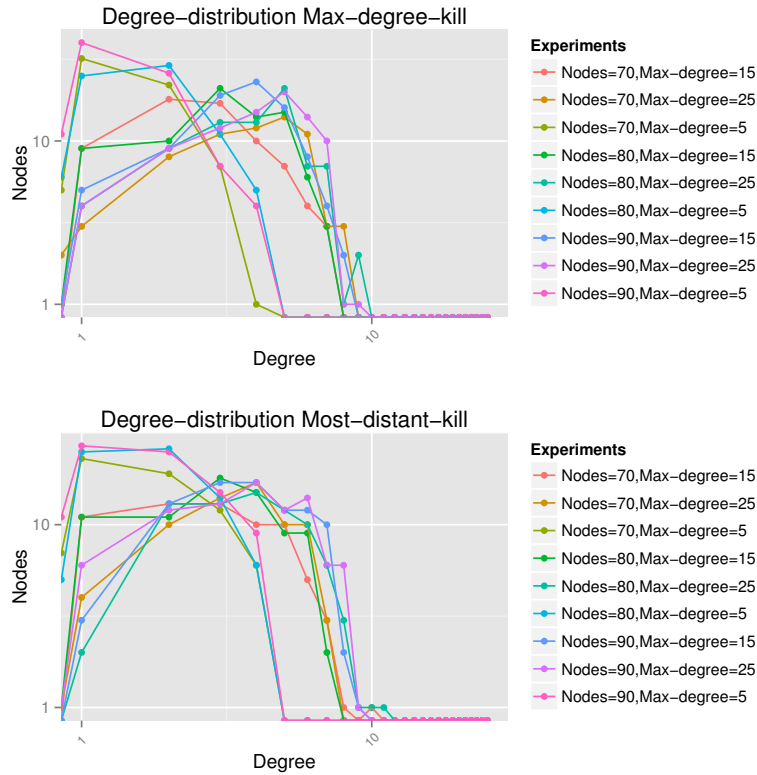As a personal choice if I were to deploy a connection handling strategy I would

Fig. 11. Degree distribution - 3/4

choose the "Most-distant-kill" because it appears to have little better performance than the other ones.

During this report many simulation results have been shown in which different strategies have been used, nevertheless in the NetLogo implementation of the model there are many more "hybrid" strategies which can used and tested, lastly I would like to point out the importance of the presence of the "No-bridge-kill" strategy which can be used for comparison, since it is an optimal strategy.

References

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