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PROBABILISTIC APPROACH TO THE DETERMINATION OF COMMUNICATION PATH IN WIRELESS NETWORK

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Abstract: In MANET or such kind of dynamic wireless networks communication paths between a source and a destination that are moving at random in the sense that forwarding nodes between them go on changing is tried to be estimated using discrete percolation theory in a dense network. Very dynamic nature of the network requires quick adaptation and self reconfiguration so to ensure no breaking of path in a session. A percolation based probabilistic approach is used to give an estimation of the path finding probability and its limit of applicability is verified in a simulation platform replicating a real dynamic network.

Keywords: MANET; node density; transmission range; correlation factor; node disjoint path; multipath routing; discrete percolation model; multi-hop technique.

1. INTRODUCTION

Present day wireless communication systems like IOT (Internet of Things), MANET (Mobile Adhoc Network) and other such networks are basically a collection of data sources and sensors termed as nodes those can move freely in a region while communicating with each other. Help of intermediate nodes are taken to forward data when source and destination are not in direct communication range. It is important that when a source broadcasts some data, it must get some neighbor nodes those are capable of forwarding these data to their neighbor nodes and thereby a path or multiple paths will be established between source and destination throughout the communication session. There are several approaches to estimate the connectivity or data path called routing protocols, some are unipath routing [1,2] and some are multipath routing [3,4]. The usual approach is that the source node creates a communication path by broadcasting a path-finding message which gets forwarded by the cooperative neighbors till it reaches the destination and then the destination replies back to the source through some reverse paths. Paths are established between source and destination by means of some tricky processing of query and response messages. Unipath routing techniques like AODV, DSR, DSDV etc. provides a single path for data delivery. While AOMDV, AODVM, M-DSR, MP-OLSR etc. are used in multipath routing techniques.

Not going through the actual process of message forwarding techniques, a probabilistic approach is used to determine optimum path between a source and a destination in dynamic environment. For this purpose, a dynamic multi-dimensional topological network is used in the sense that every node has sufficient number of neighbour nodes to link with though they are arranged in a two-dimensional physical space. Nodes are assumed as interactive particles moving independently and randomly. Connectivity among the nodes is intermittent or random in nature as the nodes are moving, causing frequent topological changes. The problem of interference or cross correlation between two nodes is taken into consideration by determining the effective power consumptions of the respective nodes. Thus, the very dynamic nature of the network, intermittent connectivity among the nodes, inconsistent end-to-end path and interference among the wireless channels are considered in formulating a mathematical model based on Discrete Percolation Theory. Few articles are available in this context on probabilistic approach to broadcasting in wireless adhoc network [5,6,7] though path finding probability which is one's concern is not exactly discussed.

In the next section the authors have discussed the model and have tried to correlate the network parameters as adjustable variables to determine the probability of paths from source to destination in a multihop environment and it is analysed to determine the threshold density of nodes and the relative dependence of the physical parameters of the network.

2. MODEL DESCRIPTION

These authors consider a wireless network where the nodes are randomly and independently distributed in an area A. Two nodes are neighbors of each other if their introduce Euclidian distance is smaller than or equal to their transmission range or radio range r_0. Motion of the nodes is described by a Random Direction Model (RDM) where each node chooses its direction of movement independently and uniformly with an average speed, 'ν' which is common to all nodes. In this framework the spatial distribution of the nodes always follows a homogeneous Poisson point distribution with intensity λ at any instant. A graph of such interconnected nodes resembles discrete lattice points in a two-dimensional medium and discrete percolation theory is used to describe the upper or lower bound to the transport of information through these points. But, the difference with regular lattice is that in this case there is no regular arrangement of neighbor nodes around a particular node. Rather, the two most important parameters 1) transmission range and 2) node density vary both in time and space. Therefore, to model it, one has considered random distribution of nodes in a plane and have adopted site percolation problem to explain this model. The idea is that if a node at any moment becomes inactive or goes out of transmission range of a particular node, link with it will automatically be broken and it has the effect on the variation of node density in the region around the node of consideration. The authors are modeling it for a finite dimensional network in a small region; the same can be scaled up to the global network by considering each cluster as node and investigating the connectivity among them. Another consideration is the adaptive selection of transmission power of a node depending on the node density, thereby every time it is adjusting its transmission range. Thus, these two parameters are intertwined and one is dependent on the other. Therefore, any of them may be chosen as variable parameter; if one thinks of adaptive selection of transmission power, one should choose node density as variable which is considered in the model here.

Beside the problem of link-failure and power adaptation another important aspect the authors have considered in this article is the problem of cross-linking or interference effect or jamming. If in the region of consideration node density is too high this kind of problem may arise. Discrete percolation model may give a solution to this. So in this model, within this framework, these authors have tried to determine the best percolation region or critical node density for which the probability of path link is higher as well as the effect of interference is low.

3. PERCOLATION THEORY AND ROUTING

In routing scheme, source node tries to find the optimum path with the help of cooperative neighbors those relay route request data packets sent by source towards the destination and then relay back the reply packet from the destination. During this session some or other nodes may go out of transmission range of its neighbor nodes thereby severing the path by them, therefore, path optimization is required for no link failure during a particular session. To calculate the path the authors have considered a network of semi infinite lattice of $\mathcal{N}$ nodes between source and destination. The number of paths at any instant is obtained by calculating the percolation limit of a tree of nodes or Bethe lattice [8] where each of the nodes is assumed to have equal number of independent neighbors and out of this the shortest path is determined. A node is said to be a neighbor to a particular node when their Euclidian distance $r_{ij} = |r_i - r_j| \leq r_0$, where r_0 is the transmission range of that node. Let at any instant n=number of nodes per unit area=$\frac{A}{N}$ be the density of active neighbours around a particular node and in a dynamic environment there is no loss of generality in assuming it to be equal for all nodes in a cluster containing the source node. Simulation on the number of minimum neighbours with 2,3,4 number of neighbour nodes to sustain percolation shows that 3 minimum neighbours gives the best result which is evident from Figure 1.

Let

$$x = \frac{No.\ of\ nodes\ per\ unit\ area\ having\ 3\ min.neighbours}{n}$$

is the probability of finding such a node and is termed as the probability of forwarding node. Then considering hopping propagation among the nodes the probability, $\mathcal{P}_{path}(x)$ that the path to the destination can be found is represented by [9]

$$\mathcal{P}_{path}(x) = x - x\mathcal{F}_{path}(x) \tag{1}$$

where $\mathcal{F}_{path}(x)$ is the probability that the path will lead to a dead node at some later stage and must be equal to

$$\mathcal{F}_{path}(x) = \left(1 - \mathcal{P}_{path}(x)\right)^{n} \tag{2}$$

$\mathcal{F}_{path}(x)$ may be different for different paths.

It results in a nonlinear dependence of path finding probability on *x*

$$x\left(1 - \mathcal{P}_{path}(x)\right)^{n} + \mathcal{P}_{path}(x) - x = 0 \tag{3}$$

The solution of this equation will give the probability of finding the path to the destination in a multi-hop scheme through the nodes. In the vicinity of percolation threshold $\mathcal{P}_{path}(x) \ll 1$, expanding $\left(1 - \mathcal{P}_{path}(x)\right)^{n}$ one can obtain a closed form expression for $\mathcal{P}_{path}(x)$

$$\mathcal{P}_{path}(x) = \frac{2(x - 1/n)}{x(n-1)} \tag{4}$$

It is evident from the above expression that $\mathcal{P}_{path}(x) = 0$ when $x = x_c = 1/n$. This indicates that all the paths will lead to dead node before reaching destination as $x \to 1/n$ and this can be thought of as percolation threshold. Therefore, for $x > 1/n$ a path to the destination may be obtained.

But all the neighbour nodes in a practical network are not completely independent due to cross correlation in a dense network and it is often expressed in terms of interference effect. Interference effect is indirectly obtained by calculating the power transmitted to a neighbour node by a particular node in view of the total power received by that neighbour node from it's all other neighbours and is expressed as [10]

$$\mathbb{P}_r = \frac{\mathbb{P}_{ref} \times \exp(-\alpha r_{ij})}{\mathbb{P}_0 + \sum_{k \neq i,j} \gamma_{kj} \mathbb{P}_{ref} \times \exp(-\alpha r_{kj})} \tag{5}$$

where $\mathbb{P}_0$ is the additive white Gaussian noise (AWGN), $\mathbb{P}_{ref}$ is the average power exchanged between any two neighbours, γ_{kj} is the relative weighting factor and α is the attenuation coefficient.

To incorporate the effect of interference authors have determined average power consumption in the network as a function of the total number of nodes in the network. From the plot of this in Figure 2 it is observed that average power consumption is appreciably low within a small range of intermediate node density ($\mathcal{N}$ between 200 to 500) and is termed as width of the critical percolation region within which the effect of cross correlation is minimum

$$D(n) = \frac{C}{n^{1/\nu d}} \qquad (6)$$

where C is a typical numerical constant and is $C = 1$ for perfectly homogeneous distribution of nodes with all the nodes having equal strength and transmission range; deviation from this ideal condition results in C to be a function of x and C < 1. d is the network dimension and for planar distribution of nodes $d \approx \pi.\nu$ is the correlation exponent indicating the extent of dependence of D on n.

Therefore, probability of finding correlation free optimum path within the correlation width D(n) is required to be determined. Outside this region probability of cross correlation is pretty larger and has to be avoided. Hence, the probability of optimum path in the network will be

$$P_{path} = nD(n)P_{path}(x) \qquad (7)$$

4. RESULTS

To envisage the application of percolation theory in modeling dense wireless network authors have designed a simulation platform in MATLAB - R2009b of a network of nodes distributed randomly over a region of 100m×100m. Figure 7 shows an instantaneous snap of such a distribution of nodes those are distributed on the plane with Euclidian separation ≤20m, considered as the maximum transmission range of a node. The nodes which are in the transmission range of a particular node are its neighbours. The experiment is performed over considerably large session time of 80sec and is tested for different node density with total number of nodes varying between 50 to 500. To introduce dynamicity of a real wireless network the position of nodes during experiment is varied randomly in every second thereby changing the positions of the destination node and the other intermediate nodes with respect to the source. The as-determined time average of the probability of forwarding nodes has been plotted as a function of session time in Figure 3 and it is observed that the probability decreases very slowly with increasing session time indicating increasing interference effect, run-away of power of nodes and other detrimental effects those should appear as time elapsed. As node density in the network is increased by a large extent it shows almost no effect on the average number of engaged nodes and is shown in Figure 4. So, there is no requirement of increasing node density to increase path finding probability, rather it has the detrimental effect of increasing interference effect causing higher rate of power consumption in the network as is evident from the latter half of Figure 2. As almost all the nodes are always engaged at lower node density there is higher rate of power consumption which is observed in the first half of Figure 2. In the determination of power consumption, reference received power at a distance of 1m from a forwarding node is taken as P_{ref} = 5 units with attenuation coefficient α=2 while background noise AWGN power is taken as 7 units. Authors have also estimated P_0 average power consumption per active node which shows an increasing trend as the node density is increased. This behavior is against the normal speculation and is plotted in Figure 5. This may be due to added interference effect at higher node density. Considering all these aspects of a wireless network average value of path finding probability has been determined and is then plotted against node density in Figure 6. It is observed that the path finding probability falls of sharply as node density in the network increases and becomes appreciably low beyond total number of nodes 300 in the work space of 100m×100m indicating the dominance of interference effect beyond it.

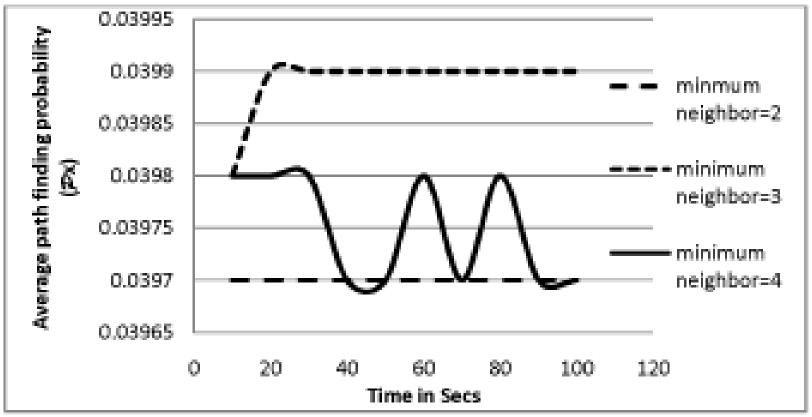

Figure 1: Plot of average path finding probability between a source and a destination that is changing its position at random with the assumptions that any intermediate node must have 2, 3 or 4 nodes as nearest neighbours to sustain percolation. The behavior is observed in time with random changes of position of the nodes in every second.

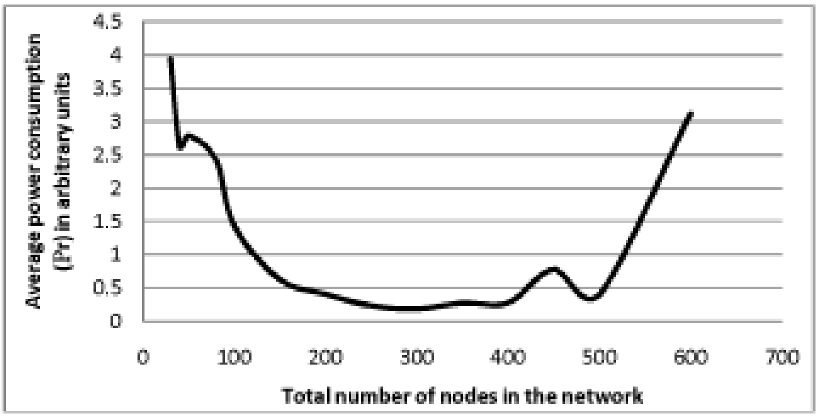

Figure 2: Plot of average power consumption in the network having different node density shows a plateau at the intermediate node density indicating percolation zone. The averaging is done over 80sec with random changes of position of the nodes in every second.

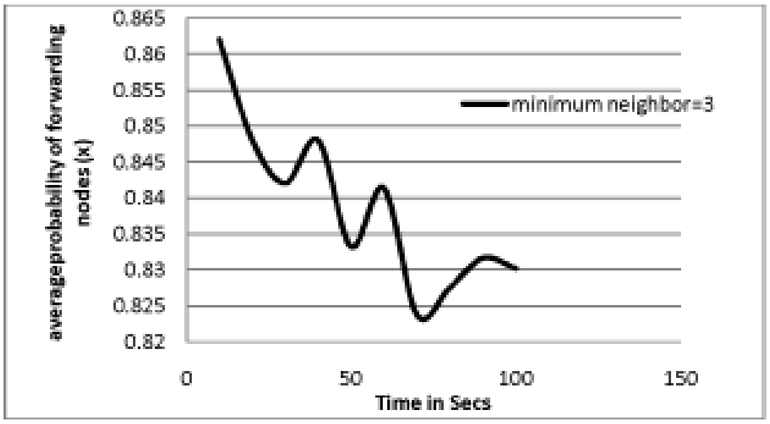

Figure 3: Average probability of forwarding nodes plotted as a function of session time shows little decrease. The behavior is observed in time with random changes of position of the nodes in every second. Oscillating behaviour is the indication of inherent randomness of the network.

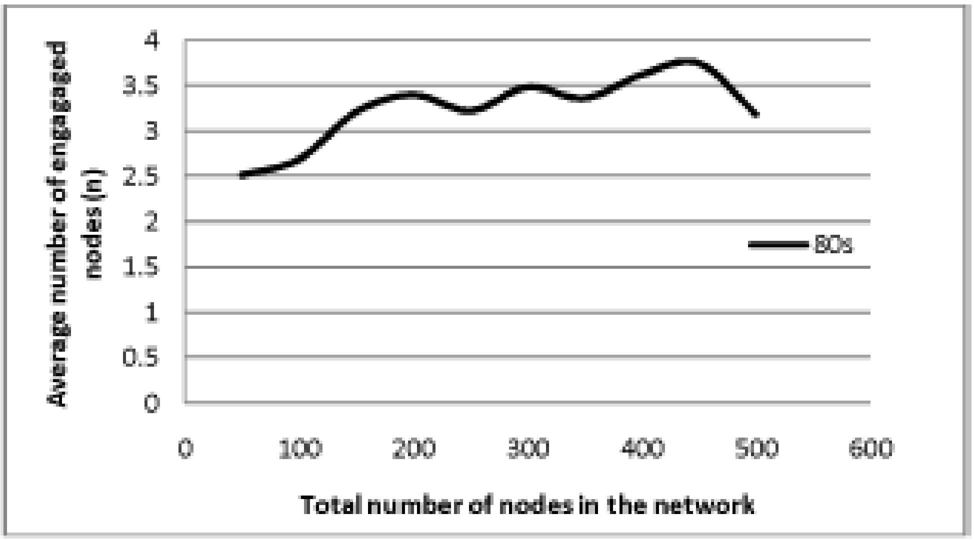

Figure 4: Plot of average number of engaged nodes shows almost no change though node density in the network is increased by an appreciable amount. The behavior is observed in a session of duration 80sec with random changes of position of the nodes in every second. Oscillating behaviour is the indication of inherent randomness of the network.

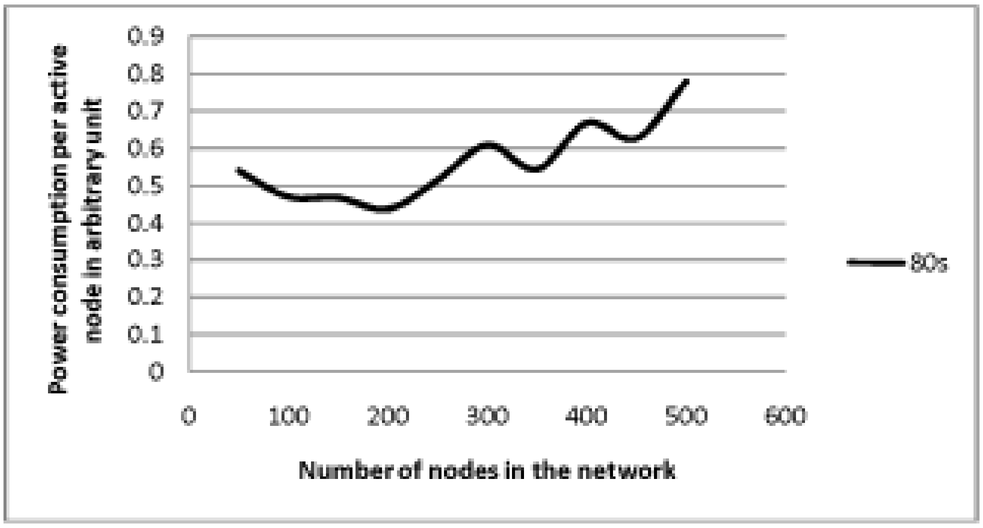

Figure 5: Plot of power consumption per engaged nodes as the node density is increased in the network shows an increasing trend. The behavior is observed in a session of duration 80sec with random changes of position of the nodes in every second.

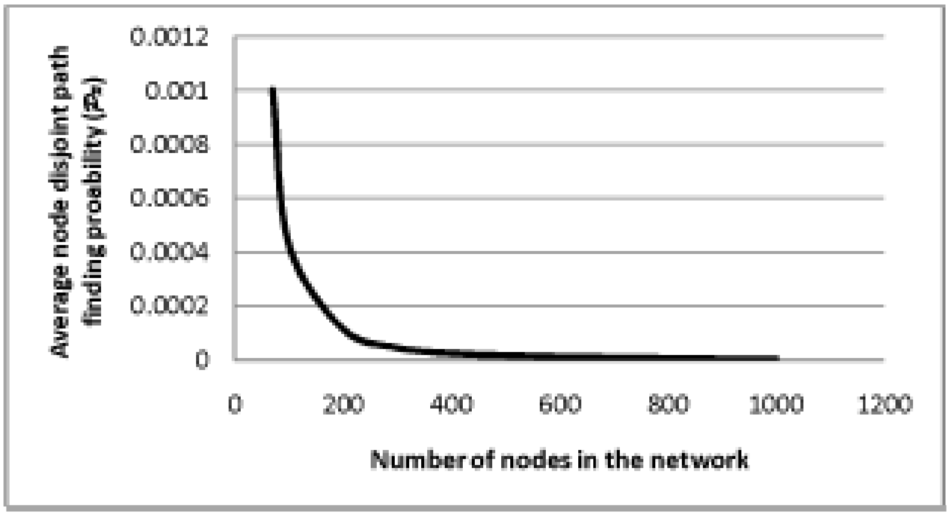

Figure 6: Average path finding probability is plotted as a function of node density in the network. The behavior is observed in a session of duration 80sec with random changes of position of the nodes in every second.

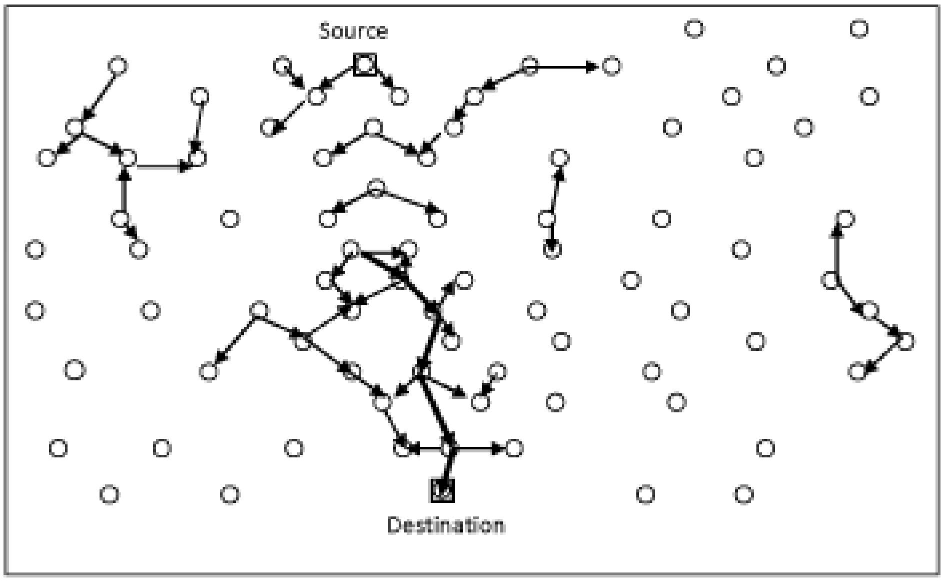

Figure 7: Plot of randomly distributed nodes simulated in MATLAB - R2009b platform in a 100m X 100m planar area. Positions of the nodes change in every second. At any moment, single headed thick arrow shows the shortest path between a pair of source and destination and the double headed arrows are the other neighbours of a particular node. Nodes present within 20m Euclidian distance have been considered as neighbor of a node.

5. CONCLUSION

Application of discrete percolation theory on routing scheme has been estimated with respect to the network parameters such as node density, average transmission range of the nodes and cross correlation exponent. The path finding probability shows that the theory is applicable to a network having not too high density of nodes with minimum number of neighbours of a node being 3 to sustain percolation. By tuning these parameters in a real network it is possible to minimize link failure and the possibility of cross linkage. In an actual network the transmission range and node density varies substantially from one region to the other, so it has the scope to introduce the effect of distribution of these parameters for more accurate estimation of network connectivity.

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