IPSAG Cognitive Radio Routing Protocol: Models and Performance

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***Abstract*—The paper is about performance evaluation of IP Spectrum Aware Geographic routing protocol (IPSAG). IPSAG is an opportunistic cognitive routing protocol which determines a source-destination route in a hop by hop manner, based on both global and local information. Simulation results are reported for a particular case of IPSAG, where the cognitive radio (CR) nodes are uniformly distributed inside the cognitive radio network (CRN), and a two-dimensional random walk model is used to model the mobility of CR nodes. The results show that the IPSAG protocol is performing well in the case of a highly mobile CRN and that the source-destination path is successfully found in the majority of the cases, especially when the network is highly populated.**

Keywords-Cognitive Radio Network (CRN); IP Spectrum Aware (IPSAG) routing; random walk

I. INTRODUCTION

Cognitive Radios (CR) have been suggested as a good solution to the problem of scarce spectrum resource, by giving the possibility for the secondary users to utilize the licensed users channels sensed to be free.

In relation to the existing wireless technologies, the CR technology has a revolutionary character by providing new functions, of which the most representative are:

- *Sensing function*: the CR terminal is able to sense the entire environment and accordingly change the behavior;
- *Sharing function*: the CR users must respect the primary users priority regarding the channels access and, at the same time, must be able to share the free channels with other CR users.

The new features have a strong impact on the routing function. Due to the unstable nature of CRNs, regarding both nodes mobility and channels availability in time, a very dynamic routing protocol is needed. In this direction, especially when the channels availability period is much lower than the CR transmission duration, there is need of a totally opportunistic routing [1].

In the literature, an important number of the suggested CR routing are based on existing routing algorithms of the ad-hoc networks, which are adjusted to respond to the CR demands. Most likely, the proposed solutions are based on the Ad Hoc On-Demand Distance Vector (AODV) protocol, with some limitations regarding the broadcast area of the Route Request (RREQ) message [2].

Also, in order to avoid the network flooding with control information, source/destination based routing solutions are advanced. In this case the needed information is obtained through the medium of Common Control Channel (CCC) [1].

Along with the traditional factors (delay, interference, throughput, etc.), in the routing metrics is now included also the fluctuation of the links availability. Thus, the vacant channels to build the path are selected based on probabilistic information [3] or by tacking into consideration the switching frequency from one channel to another along the path [4].

Within this context, the IP Spectrum Aware Geographic routing protocol (IPSAG) was advanced [5]. IPSAG uses the IP principle of step-by-step forwarding, with respect to the channels availability status, QoS features, and CR nodes geographic positions.

The paper evaluates the IPSAG behavior in different mobility conditions, from stationary to high CR mobile nodes. The CRN model is implemented and tested in Java.

The rest of the paper is structured as follows. Chapter 2 describes the IPSAG protocol functionality. Chapter 3 presents the CRN model created and used to test IPSAG correctness. Chapters 4 and 5 provide the obtained results of IPSAG simulation in a one-cell and a seven-cells CRN, respectively. Chapter 6 concludes the paper by underlying the IPSAG good performance and future work to be achieved.

II. IPSAG PROTOCOL DESCRIPTION

The IPSAG protocol is a highly opportunistic protocol for CRN routing. IPSAG is inspired by the IP flexibility regarding the route selection process. The path is determined step by step based on a position-based approach which also considers the channels availability status and the Quality of Service (QoS) features.

The characteristics of the protocol are as follows [5]:

- The next-hop decision process is an individual one, taken by each CR node on the source-destination path. No previous determined route is used when forwarding the data packet. This is the concept according to which IP is functioning in the data networks.

- The spectrum opportunities of CR nodes are considered when constructing the step-by-step path: a link between two CR nodes can be a part of the source-destination route if the corresponding CR nodes have at least one joint channel sensed to be free. In other words, IPSAG is a spectrum aware routing protocol.
- When considering the channel to allocate between two CR nodes, QoS issues are considered in the form of signal-to-noise ratio (SNR) parameter. Hereby, a channel sensed to be free is allocated only if the channel has the SNR above a given threshold.
- Finally, geographical routing principles are used to reach the CR destination node. Between the CR neighbors whereby it has common spectrum opportunities (SOP) with QoS, the current CR node chooses the next-hop to be the one closest to the destination.

The steps of the local decision process regarding the next-hop election are (Fig. 1):

- Each CR node determines its geographical neighbors inside a circle (with the node as the center and variable radius, usually selected to be equal with the transmission range).
- Inside the neighborhood, the CR node must determine the neighbors with which it has common SOP (that also satisfy the QoS demands);
- The next-hop is the closest node to the destination between the pre-determined neighbors.

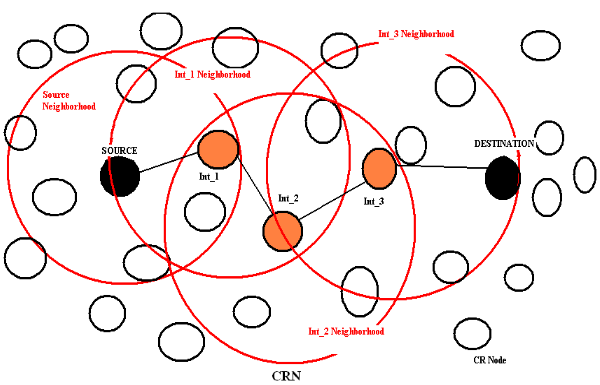

Figure 1. IPSAG routing example

In Fig. 1, the Source is running IPSAG inside its neighborhood and chooses node Int_1 as the next hop to forward the packet. Similarly, node Int_1 selects node Int_2, and Int_2 selects Int_3 to be the next-hop. Finally, node Int_3 determines that the destination is located in its neighborhood and forwards the packet [5].

III. SIMULATIONS MODELS

In order to analyze the IPSAG performance for mobile CR nodes, a CRN model has been created in Java. The elements that provide the CRN simulation environment are:

- *Channel class*, which models the primary radio channel. The channel is characterized by an availability status and a SNR variable. It also has an index based on which it is identified in the corresponding cell. In our simulations the channel status is considered to vary between "available/unavailable" with a probability of 0.5 at each IPSAG iteration.
- *Cell class,* which models the radio cell. This class extends the Polygon Java class and it is described by the set of radio channels that can be utilized on its area. Also, in each cell, the available radio channels at a given time, which correspond to a required SNR threshold, can be determined.
- *Node class*, which models the CR node. Each node is able to determine and maintain a table with its neighbors, and it can choose the next-hop when running IPSAG The neighborhood radius along which the nodes discovers its neighbors can be varied. The CR node can determine the cell in which it is located at a given time, and it is identified by a global index in the CRN. Initially, the CR nodes are uniformly distributed along the network and each CR node moves across CRN according to the two-dimensional random walk model [6] in a discrete manner. At each IPSAG iteration, the CR node has the possibility to move at left/right and up/down, respectively, with a probability of 0.5. The random walk implementation avoids the CR nodes exceeding the CRN perimeter, and, in the extreme case when a CR node does cross the border, the case is not considered.
- *Network class,* which models the CRN. The user can set the simulations parameter. These are: the total number of CR nodes, the number of cells that form the CRN, the number of radio channels per cell, the geographical dimensions of the radio cell, the number of the channels belonging to the Industrial, Scientific and Medical (ISM) band used for inter-cells routing and the random-walk step where the nodes are moving.

Two CRN models are used in our simulations, namely: a one cell CRN and a seven cells CRN (Fig. 2).

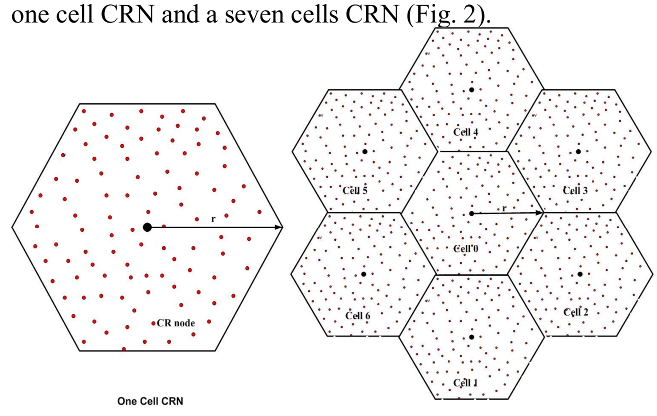

Figure 2. The CRN models used in simulations

In the first case, the IPSAG routing is used inside the cell. In the second case, the IPSAG routing is extended for inter-cells routing, with the difference that the channels are allocated from the ISM band.

In all simulations cases we consider a number of 120 radio channels per cell. This number corresponds to the spectrum reutilization scheme factor of N=3, for the 800 MHz band (62 carriers for each uplink/downlink communications direction) [7]. As mentioned above, the channel availability is varied at each IPSAG iteration with a 0.5 probability.

Furthermore, the cell radius is considered to be 2 000 m, which is a common value used.

IV. Simulations Results – One Cell

The IPSAG simulations focus on the probability to successfully find a source-destination route. Also, the probability of not finding the route from the first attempt is analyzed in different conditions. According to [8], this is the first performance criteria when evaluating a total opportunistic routing protocol. At the same time, the number of intermediary nodes between source and destination is observed. In this case, the results are reported with a confidence interval of 95 %.

The parameters considered in the simulations are:

- the *random walk step*, from the stationary case till a step value around the transmission range of 533 m [9];
- the *number of CR nodes*, which provides information about the manner in which IPSAG is performing in a poorly/highly populated CRN;
- the *neighborhood radius value* of the circle inside which a CR node determines its neighbors.

Our results are as follows.

A. Experiments regarding the random walk step

For this simulation type, different movement situations are considered (random walk step values of 50, 100, 250, 350 and 500 m, respectively) such as to analyze the influence on the IPSAG behavior. The number of CR nodes is maintained constant (100 nodes), a value that is very close to the number of radio channels (120).

As we observe in Fig. 3, the average number of intermediary nodes grows with the random walk step.

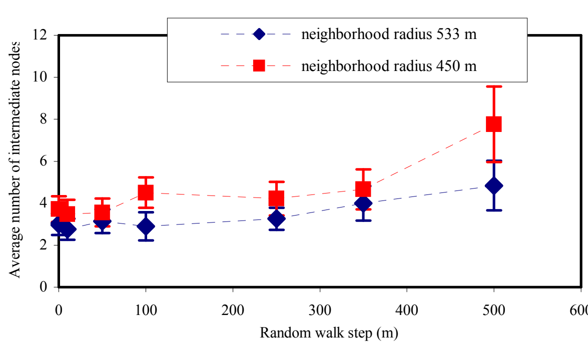

Figure 3. The CR nodes random walk step influence on the number of intermediate nodes

At the same time it can be observed that a higher value for the neighborhood radius decreases the number of intermediary nodes along the path. This is because a higher number of CR nodes means a higher number of next-hop candidates, and thus the optimum next-hop selection is influenced.

An important advantage is given by the fact that, in a highly mobile CRN, IPSAG has a longer probability to find the source-destination route from the first attempt compared with the stationary case (Fig. 4). In other words, regarding the path determination, IPSAG is performing better in a mobile environment than in a stationary case.

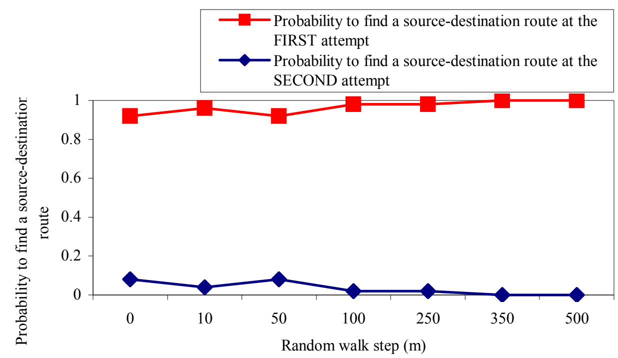

Figure 4. Probability to find the source-destiantion route (533 m neighborhood radius)

A small degradation in finding the path at the first attempt is observed when decreasing the neighborhood radius. However, this still has a better behavior at a high random-walk steps (Fig. 5).

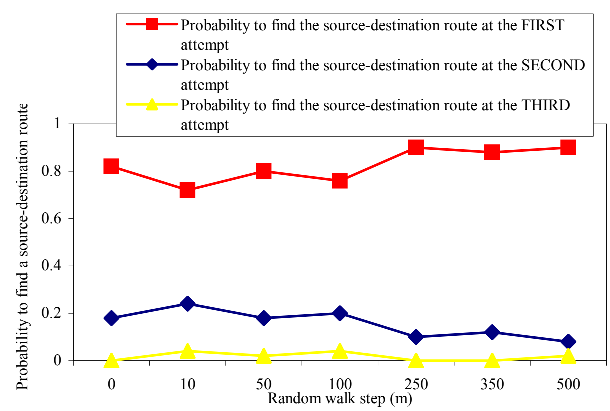

Figure 5. Probability to find the source-destiantion route (450 m neighborhood radius)

These results show therefore that IPSAG is performing very well in the case of mobile CR nodes. The neighborhood radius value can however diminish the performance at lower values or improve it at higher values, which are approaching the transmission rage.

B. *Experiments regarding the number of CR nodes*

These simulations focus on the number of CR nodes and its influence on the IPSAG behavior. In the previous simulations set the CR nodes number was maintained constant, but in this case it varies between 50 and 200. Also, the neighborhood radius is preserved at an optimum value, represented by the transmission range (533 m).

The simulation results show that, in a highly populated network, IPSAG is behaving better than in a poorly populated CRN. As it can be seen in Fig. 6, the average number of intermediary nodes is bigger when there are only few CR nodes inside CRN. The simulation results confirm the previous conclusion according to which the average number increase with the random walk step (Fig. 2).

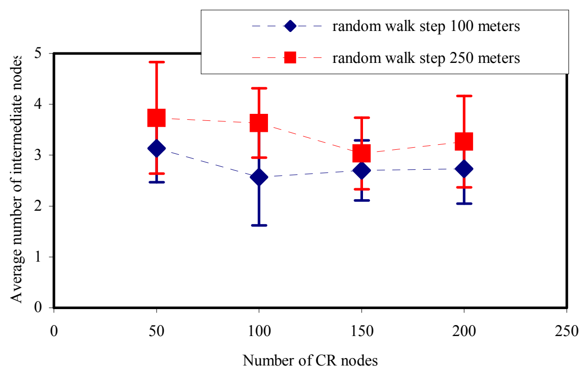

Figure 6. The number of CR nodes influence on the average number of intermediate nodes in the source-destination path

The probability of finding the route from the first attempt is approximate maximum when the CRN is very populated, and significantly decreases (0.7) for a lower number of CR nodes (Fig. 7).

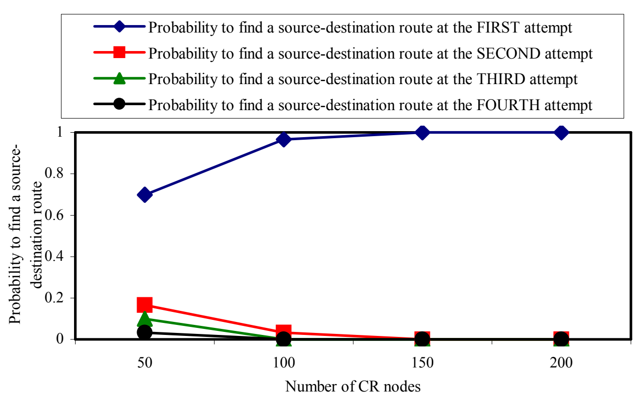

Figure 7. Probability of finding the source-destination route (random walk step 100 m)

This decrease is however improved in a highly mobile environment (Fig. 8). If, at a 100 m value for the random walk step, the probability to find the route at the first attempt is around 0.7, for a 250 m step this probability increases at 0.8. This result confirms the good performance of IPSAG in a highly mobile network.

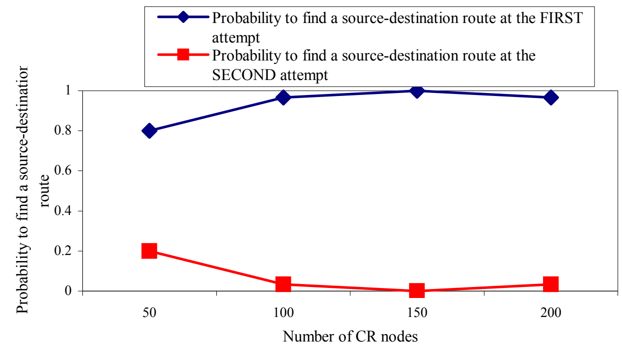

Figure 8. Probability of finding the source-destination route (random walk step 250 m)

Thus, the results clearly show that a populated CRN improves the IPSAG performance.

V. SIMULATIONS RESULTS – SEVEN CELLS CLUSTER

The conditions made in Section 4 for one cell remain valid. A number of 120 radio channels and a cell radius of 2000 m, respectively, are maintained for each cell. Also, the average number of intermediary nodes along the path and the probability to successfully find the route are considered in evaluating the IPSAG performance.

In addition, the average number of inter-cells routing is analyzed.

A. *Experiments regarding the random walk step*

As in the case of an one cell CRN, the average number of the intermediary nodes between the source and destination increases with the growth of the random walk step. A lower neighborhood radius value also increases this parameter (Fig. 9). The explanation is that, in a highly mobile environment, the IPSAG geographical selection of the next-hop (closest neighbor to the destination) does not have the accuracy of the stationary case.

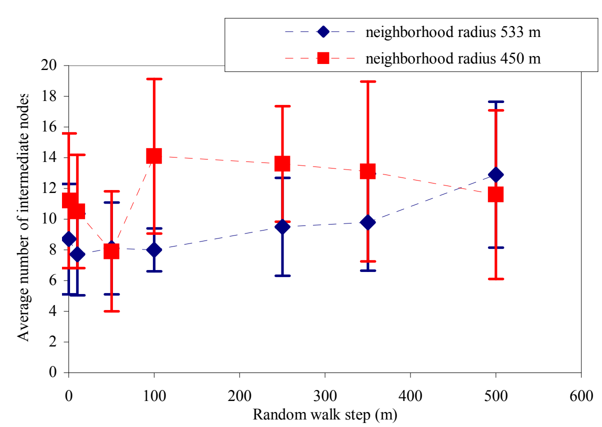

Figure 9. The influence of the step of random walk on the average number of intermediate nodes

At the same time, the average number of inter-cell routing steps has a similar behavior as in the case of average number of intermediary nodes on the path, but with a more slight dependence (Fig. 10). The low dependence can be explained by the fact that the next-hop is determined at each IPSAG iteration while an inter-cell routing step is done only when the destination is located in another cell.

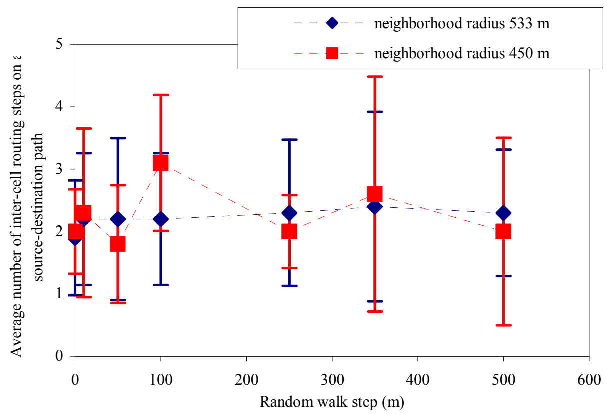

Figure 10. The influence of the step of random walk on the average number of inter-cell routing steps

As it can be observed in Fig. 11, the probability of finding the route from the first attempt is good, with the remark that, relative to the one-cell CRN instance, it presents a higher variability. Also, the good behavior of IPSAG for high mobility is maintained. This is because, when CRN is very dynamic, the current node has always neighbors that satisfy the IPSAG conditions. The price is in form of a longer route, given that the number of intermediary nodes increases with the mobility degree.

When the neighborhood radius is reduced, the number of neighbors for a given CR node is also reduced, and, thus, the probability of finding the route at the first attempt decreases. Furthermore, the tentative number for successfully finding the route increases (Fig. 12).

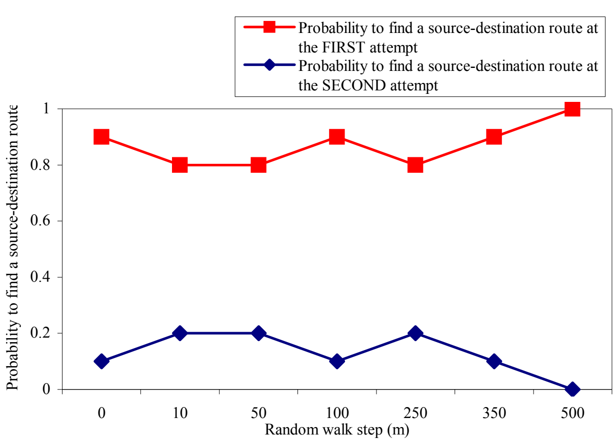

Figure 11. Probability to find the source-destiantion route (533 m neighborhood radius)

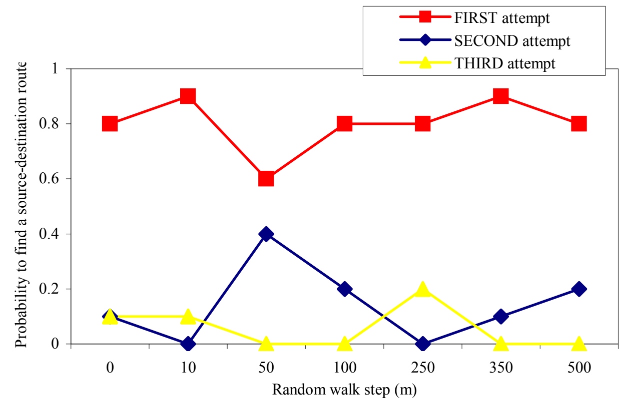

Figure 12. Probability to find the source-destiantion route (450 m neighborhood radius)

The simulations showed therefore that IPSAG is performing well in a high mobility environment, even when the CRN area is broader, with a perceptible deterioration when the neighborhood radius is decreased.

B. Experiments regarding the number of CR nodes

In this experiments set the neighborhood radius is maintained constant (533 m).

As showed in the one-cell CRN case, the increase of the CR nodes number inside the CRN improves the IPSAG performance. When the CRN grows from one cell to a seven cells area, the number of intermediary nodes suffers a 2/3 orders increase (Fig. 13).

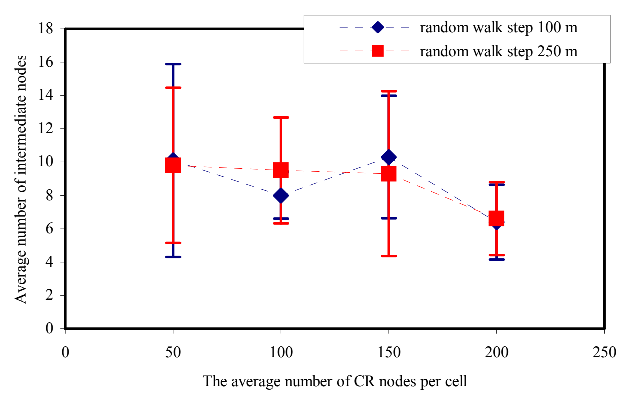

Figure 13. The influence of the number of CR nodes on the average number of intermediate nodes on the source-destination path

Note. Given the fact that the CR nodes are uniformly distributed along the CRN area and they are moving according to the random walk model, the number of CR nodes may be different from one cell to another. This is the reason of using the “average number of CR nodes per cell” expression.

As expected, a similar behavior presents the average number of inter-cell routing steps at the CR nodes density growth. As shown in Fig. 14, this parameter decreases with the increase of the random walk step, which implies a short path.

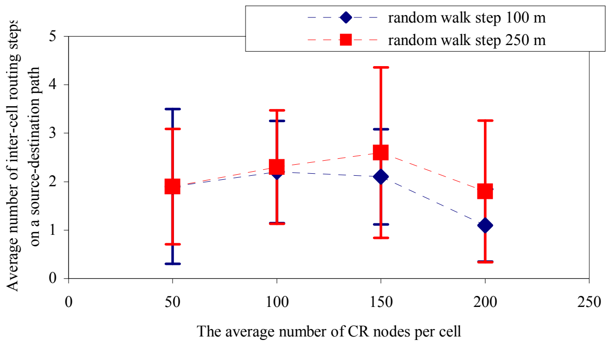

Figure 14. The influence of the number of CR nodes on the average number of inter-cell routing steps on the source-destination path

Similar to the case of a one cell CRN, the probability of finding the path has a high value in a populated CRN (Fig. 15).

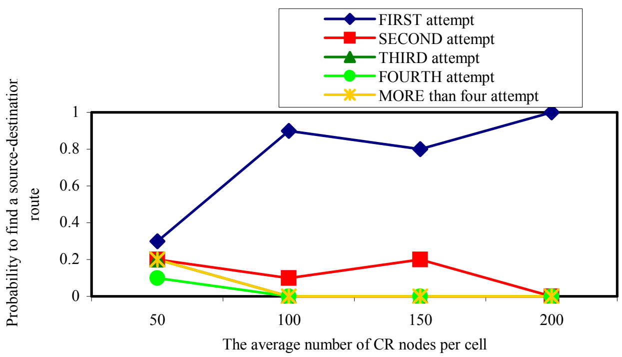

Figure 15. Probability of finding the source-destination route (random walk step 100 m)

There are no major differences for a random walk step variation from 100 m to 250 m (Fig. 16).

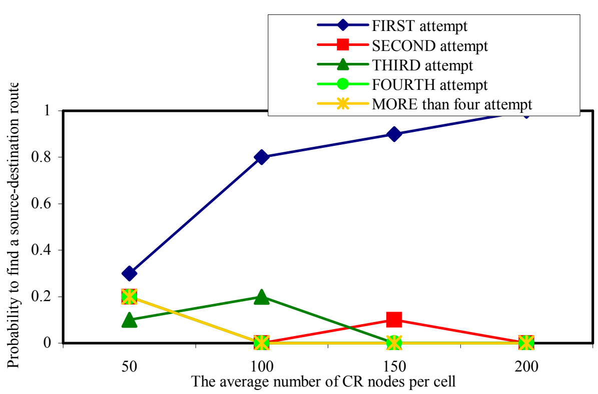

Figure 16. Probability of finding the source-destination route (random walk step 250 m).

Therefore, IPSAG proved to perform well also when the CRN area increases.

VI. Conclusion and Future Work

The paper has focused on evaluating the performance of IPSAG – a new CR routing protocol.

A simple CRN simulator has been developed in Java. The tests have focused on the IPSAG performance in different mobility conditions. In this respect, a two dimensional random walk model was implemented for the CR nodes.

The simulation results showed that IPSAG is well performing at high random walk steps. The path was successfully found in the majority of cases from the first attempt, with the drawback of a longer route in terms of intermediary nodes between source and destination.

Also, it was observed that the IPSAG performance improves in a high populated network, and diminishes through the neighborhood radius decrease below the transmission range.

The conclusion is therefore that IPSAG responds very well at the CRN highly dynamism. This good behavior can be explained by the total opportunistic character of the protocol in finding the path.

The future work will focus on the IPSAG performance in large areas, by splitting the network into clusters.

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