IPSAG Cognitive Radio Routing Protocol: Models and Performance

Cornelia-Ionela Bădoi, Victor Croitoru
Faculty of Electronics, Telecommunications and Information Technology
"POLITEHNICA" University of Bucharest
Bucharest, Romania
e-mails: cbadoi@elcom.pub.ro, croitoru@adcomm.pub.ro

Adrian Popescu
School of Computing
Blekinge Institute of Technology
Karlskrona, Sweden
e-mail: adrian.popescu@bth.se

***Abstract*—The paper is about performance evaluation of the 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 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 cases, especially when the network is highly populated.**

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

I. INTRODUCTION

Cognitive Radios (CR) have been suggested as a solution to the problem of scarce spectrum resource, by giving the possibility for the secondary users to use 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. The most representative functions 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 channel 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 node mobility and channel availability in time, a very dynamic routing protocol is needed. In this direction, especially when the channel availability period is much lower than the CR transmission duration, there is need for a totally opportunistic routing [1].

Today, a large number of suggested CR routing are based on existing routing algorithms for ad-hoc networks, adjusted to respond to CR demands. Most of the solutions are based on the Ad Hoc On-Demand Distance Vector protocol (AODV), while limiting the broadcast area of the Route Request (RREQ) message [2].

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

Along with the traditional factors (delay, interference, throughput), the routing metrics also include the fluctuation of the link availability. The vacant channels are selected based on probabilistic information [3] or by considering the switching frequency from one channel to another [4].

Within this context, the IP Spectrum Aware Geographic routing protocol (IPSAG) was advanced as a solution to routing in CRNs [5]. IPSAG uses the IP principle of step-by-step forwarding with respect to the channel availability status, QoS features and CR node 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 as follows. Section II describes the IPSAG protocol functionality. Section III presents the advanced CRN model to test IPSAG correctness. Sections IV and V provide the obtained results of IPSAG simulation in a one-cell and a seven-cells CRN, respectively. Section VI concludes the paper.

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 according to a position-based approach, which also considers the channels availability 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 basic concept of IP.
- The spectrum opportunities of CR nodes are considered when constructing the step-by-step path: a link between two CR nodes can be part of the source-destination route if the corresponding CR nodes have at least one joint channel sensed to be free; i.e., IPSAG is a spectrum aware routing protocol.

 ISBN: 978-1-61208-131-1

- QoS elements in the form of signal-to-noise ratio (SNR) are considered in determination of a channel between two arbitrary nodes. Hereby, a channel sensed to be free is allocated only if the channel has the SNR above a given threshold.
- Geographical routing principles are used to reach the CR destination node. Given the CR neighbors with common spectrum opportunities (SOP) with QoS, the CR node selects the next-hop to be the one closest to the destination.

The local decision process regarding the next-hop election is as follows (see Figure 1):

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

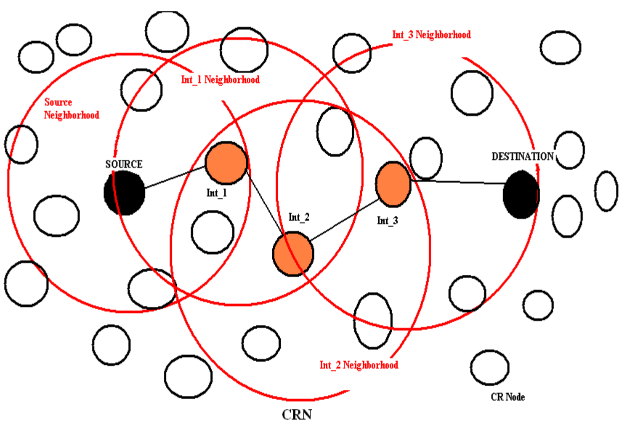

Figure 1. IPSAG routing example [5]

For instance, in Figure 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-hops. 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 variable SNR. 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 node discovers its neighbors can be varied. The CR node can determine the cell in which it is located at a given time. 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 in a discrete manner [6]. At each IPSAG iteration, the CR node has the possibility to move with a probability of 0.5 at left/right and up/down, respectively. The random walk implementation avoids the CR nodes exceeding the CRN perimeter. The case when a CR node crosses the border is not considered.
- *Network class,* which models the CRN. The user can set the simulation parameters. These are: total number of CR nodes, number of cells that form the CRN, number of radio channels per cell, geographical dimensions of the radio cell, 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 one cell CRN and seven cells CRN (see Figure 2).

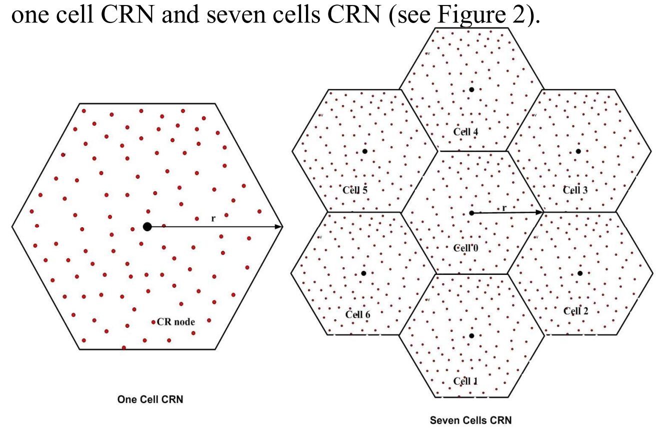

Figure 2. The CRN models used in simulations

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 simulation cases we consider a number of 120 radio channels per cell. This 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.

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 to a step value around the transmission range of 533 m [9];
- The *number of CR nodes*, which gives 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 Figure 3, the average number of intermediary nodes grows with the random walk step.

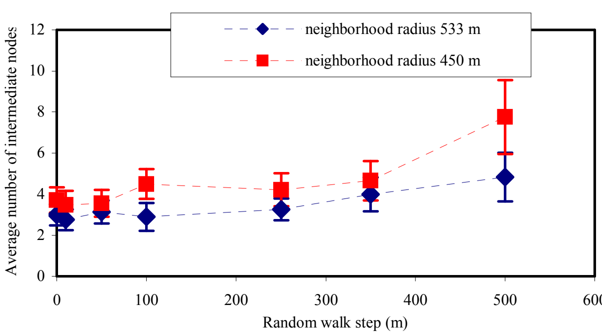

Figure 3. The CR nodes random walk step influence on the number of intermediate nodes

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, influencing thus the optimum next-hop selection.

We compare our protocol with two other CR protocols. These are Cognitive On-Demand Distance Vector (CAODV), which is an improvement of AODV protocol for CRN [10], and Opportunistic Service Differentiation Routing Protocol (OSDRP), which chooses the "minimum delay-maximum stability" route based on the channels availability issues [11]. The performance of these protocols has been observed to be similar to the IPSAG one cell case, for 100 CR nodes. Thus, if IPSAG gives an average hop count number of 2.5, respectively of 4 [see Figure 3], COADV offers an average hop count of 3.5/4 (see Figure 8 in [10]) while OSDRP gives a total number of 3 to 8 intermediary CR nodes (see Figure 4 in [11]), depending on the particular simulations parameters.

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

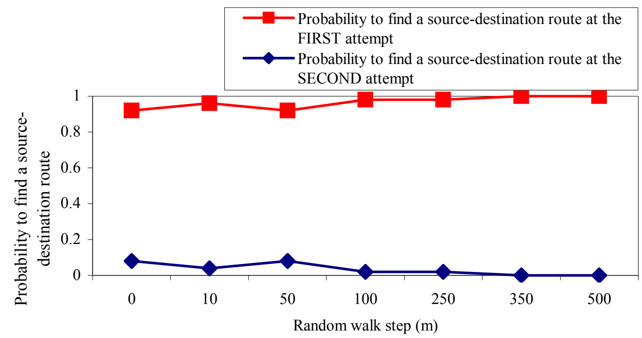

Figure 4. Probability to find the source-destination route (533 m neighborhood radius)

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 (see Figure 5).

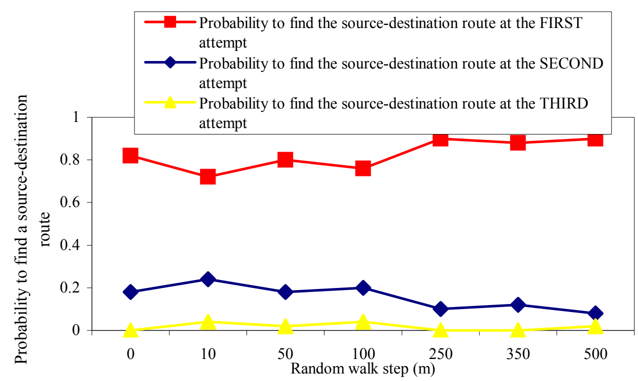

Figure 5. Probability to find the source-destination route (450 m neighborhood radius)

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 range.

B. *Experiments regarding the number of CR nodes*

These experiments focus on the number of CR nodes and the influence on the IPSAG behavior. In the previous simulations the number of CR nodes 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 observed in Figure 6, the average number of intermediary nodes is bigger when there are only few CR nodes inside CRN. The simulation results confirm the previous results according to which the average number increases with the random walk step (see Figure 2).

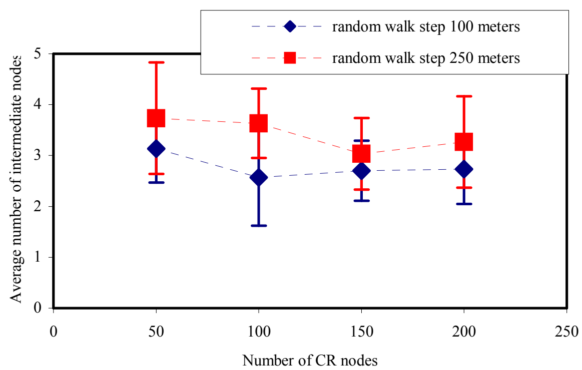

Figure 6. The number of CR nodes influence on the average number of intermediate nodes in the source-destination path

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

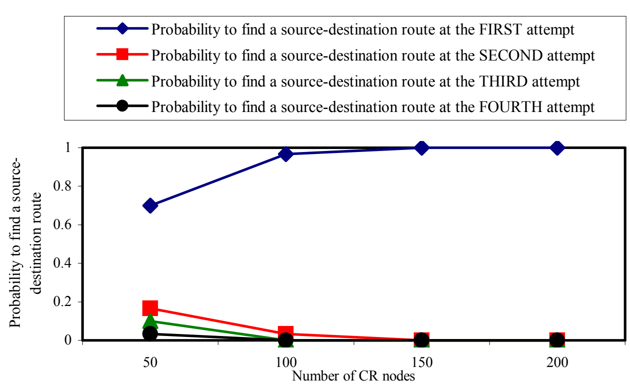

Figure 7. Probability of finding the source-destination route (random walk step 100 m)

The probability of successfully finding the route is considerably low when the CR numbers and the random walk step have small values. The worse case scenario is considered for 50 CR nodes and a random walk step of 100 m, when this probability is going to be approximately 0.6 (see Figure 7). When the CR nodes are stationary, this probability becomes lower than 0.6.

This decrease is however improved in a highly mobile environment (see Figure 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.

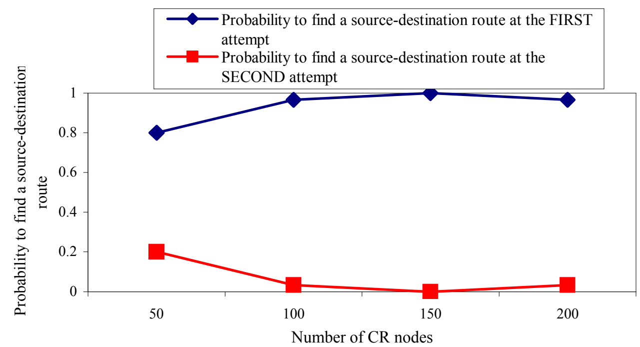

Figure 8. Probability of finding the source-destination route (random walk step 250 m)

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

V. SIMULATIONS RESULTS – SEVEN CELLS CLUSTER

The conditions considered in Section 4 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 IPSAG. In addition, the average number of inter-cells routing is analyzed.

A. *Experiments regarding the random walk step*

The average number of 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 (see Figure 9). This is because, 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.

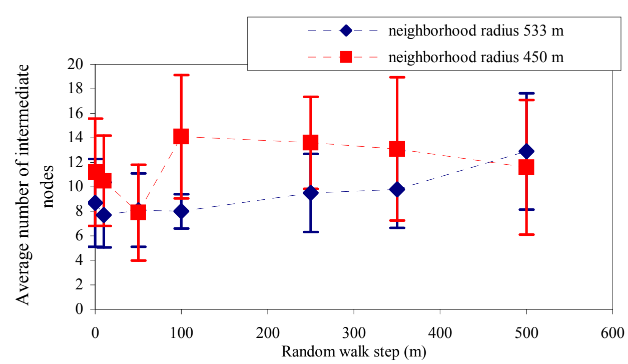

Figure 9. The influence of the step of random walk on the average number of intermediate nodes

At the same time, the average number of inter-cell routing steps has a similar behavior as in the case of average

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-131-1

number of intermediary nodes on the path, but with a smaller dependence (see Figure 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.

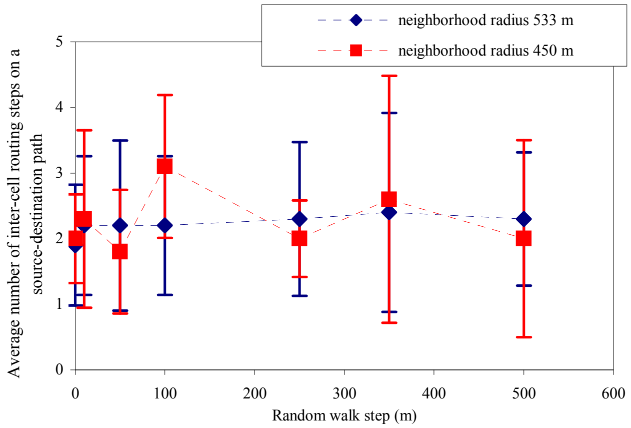

Figure 10. The influence of the step of random walk on the average number of inter-cell routing steps

As it can be observed in Figure 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 always has 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 (see Figure 12).

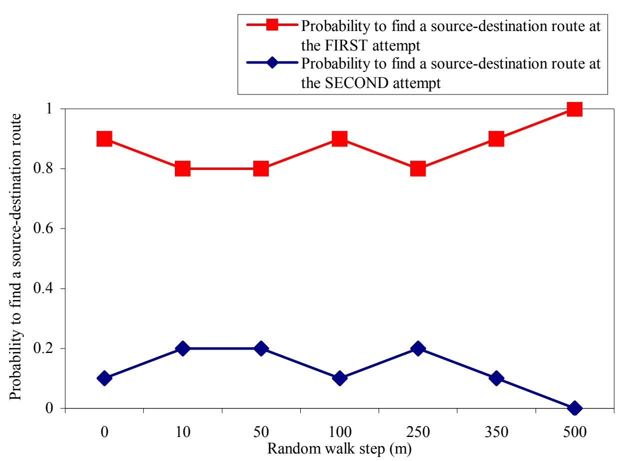

Figure 11. Probability to find the source-destination route (533 m neighborhood radius)

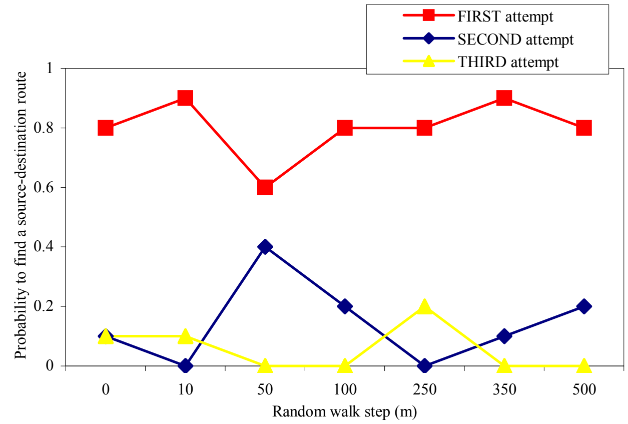

Figure 12. Probability to find the source-destination route (450 m neighborhood radius)

The simulations show 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 (see Figure 13).

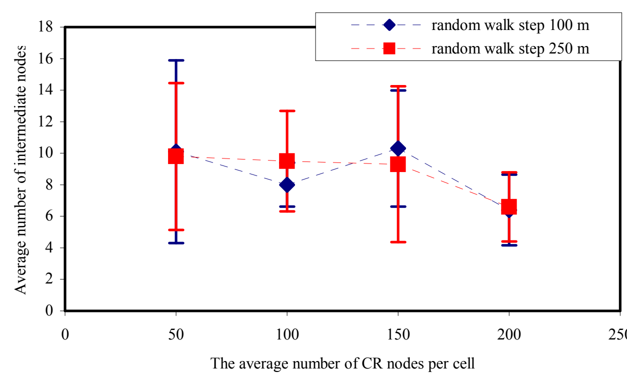

Figure 13. The influence of the number of CR nodes on the average number of intermediate nodes on the source-destination path

Note. Given 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 parameter "average number of CR nodes per cell".

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

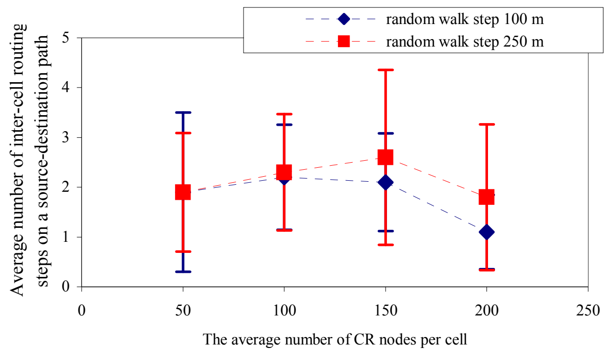

Figure 14. The influence of the number of CR nodes on the average number of inter-cell routing steps on the source-destination path

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

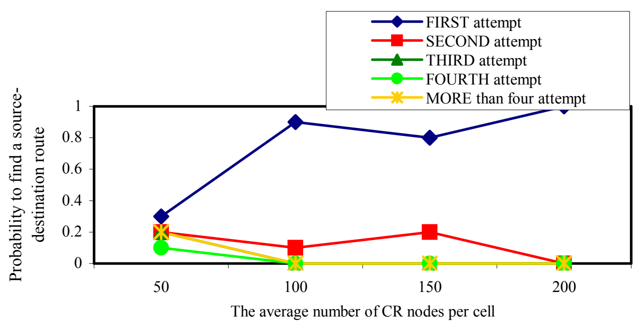

Figure 15. Probability of finding the source-destination route (random walk step 100 m)

Also, there are no major differences for a random walk step variation from 100 m to 250 m (see Figure 16).

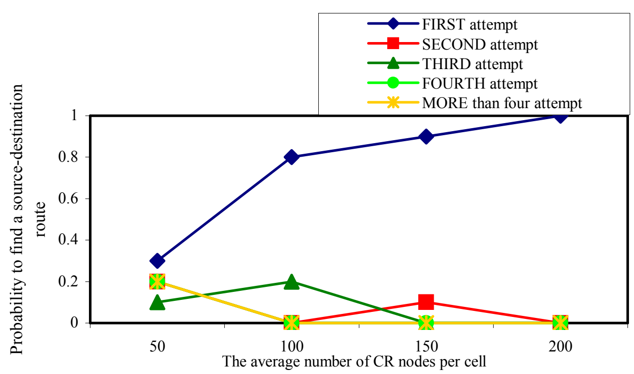

Figure 16. Probability of finding the source-destination route (random walk step 250 m)

Therefore, IPSAG has been proved to perform well even when the CRN area increases.

VI. Conclusion and Future Work

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

A simple CRN simulator has been developed in Java. The experiments 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 to 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.

Acknowledgment

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/6/1.5/S/16.

References

[1] H. Khalife, N. Malouch, and S. Fdida, “Multihop cognitive radio networks: to route or not to route”, IEEE Network, vol. 23, pp. 20—25.

[2] X. Zhou, D. Zhou, X. Kong, and Q. Sheng, “ACK Signal Based On-Demand Routing Algorithm in Cognitive Radio Networks”**,** PacRim 2009**,** August 2009, pp. 774 – 779.

[3] H. Khalife, S. Ahuja, N. Malouch, and M. Krunz, “Probabilistic Path Selection in Opportunistic Cognitive Radio Networks”, IEEE Global Telecommunications Conference, 2008, pp. 1-5.

[4] S. Krishnamurthy, M. Thoppian, S. Venkatesan, and R. Prakash, “Control channel based MAC-layer configuration, routing and situation awareness for cognitive radio networks”, MILCOM 2005, pp. 455 – 460.

[5] C. I. Bădoi, V. Croitoru, and R. Prasad, “IPSAG: An IP Spectrum Aware Geographic Routing Algorithm Proposal for Multi-hop Cognitive Radio Networks”, COMM 2010, June 2010, pp. 491-496.

[6] W. Wang, “Modeling and Management of Location and Mobility”, in Wireless Information Hayways, D. Katsaros, A. Nanopoulos, and Y. Manolopoulos, IRM Press, 2005, pp. 177-212.

[7] T. Rappaport, “Wireless Communications: Principles and Practice”, Prentice Hall Communications Engineering and Emering Technologies Series, 2nd Edition, 2001.

[8] C. Siva Ram Murthy and B. S. Manoj, “Ad Hoc Wireless Networks – Architectures and Protocols”, Prentice Hall Communications Engineering and Emering Technologies Series, 2004, pp. 191-226.

[9] T. Ohta, K. Ogasawara, and Y. Kakuda,“End-to-End Transfer Rate Adjustment Mechanism for VANET”, IEEE Third International Conference on Dependability, July 2010, pp. 1-6.

[10] A. S. Cacciapuoti, C. Calcagno, M. Caleffi, and L. Paura, “CAODV: Routing in mobile ad-hoc cognitive radio networks”, Wireless Days (WD), October 2010, pp. 1-5.

[11] K. C. How, M. Ma, and Y. Qin, “An Opportunistic Service Differentiation Routing Protocol for Cognitive Radio Networks”, GLOBECOM 2010, December 2010, pp. 1-5.

 ISBN: 978-1-61208-131-1