SIMULATION OF THE IPSAG COGNITIVE RADIO ROUTING PROTOCOL – STATIONARY CASE

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Reţelele Cognitive Radio (CRNs) au devenit în prezent foarte populare datorită posibilităţii inovatoare de a creşte eficienţa spectrală de către utilizatori secundari dotaţi cu inteligenţă, care pot folosi canalele radio licenţiate atunci când acestea sunt libere. În contextul CRN, am sugerat un nou algoritm de rutare numit IP Spectrum Aware Geographic algoritm (IPSAG) [1]. Această lucrare prezintă validarea corectitudinii pentru algoritmul IPSAG, în cazul unor noduri CR staţionare. Un model CRN este creat prin suprapunerea unei hărţi de canale cu o hartă de noduri, si apoi este demonstrat că în interiorul CRN ruta sursă-destinaţie este găsită cu succes în majoritatea cazurilor.

Cognitive Radio Networks (CRNs) have now become very popular due to their innovative idea of increasing the spectrum efficiency by smart secondary users, which are using the unused licensed channels. In the CRN context we have suggested a new routing algorithm called IP Spectrum Aware Geographic algorithm (IPSAG) [1]. The paper presents the validation of the IPSAG correctness in the case of stationary CR nodes. A CRN model is created by overloading a channel map with a node map, and then, inside the CRN, it is proved that the source–destination path is successfully found in the majority of the cases.

Keywords: Cognitive Radio Network (CRN), IP Spectrum Aware Geographic (IPSAG) routing, stationary case

1. Introduction

The Cognitive Radio (CR) field has experienced a great development in recent years due to the possibility to significantly increase the spectral efficiency. This can be achieved by using smart end-user devices able to sense the available licensed users channels – in the context of observing the environment behavior (*Sensing function*), and use these channels based on different medium access methods (*Sharing function*).

An important challenge is related to the CR routing function, given the highly unstable nature of the channels availability. Many solutions have been

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suggested so far, mainly based on ad-hoc-on-demand routing protocols, in combination with new routing metrics:

- the path construction towards the destination by selecting the vacant radio channels from among "the opportunistically existing channels that have the *best history* regarding the information to be transmitted" [2].
- the path construction towards the destination by selecting the vacant radio channels based on *probabilistic information* [2].
- the link cost is directly influenced by the *channels condition* and *channels utilization* [3] as well as by the time that the channel is expected to be *available* together with the *intra-flow interference* [4].
- route selection based on the *minimum maintenance cost*; the end-to-end source-destination route is very likely to be composed of several sequences (channels); the proper functionality of path's sequences is analyzed so that the end-to-end flow is maintained even when a primary user (PU) requires a sequence (channel) of the source-destination route [5].
- the path construction by choosing the *minimum cumulative delay* as a sum of the delays given by the links along the source-destination route [6].
- the path selection by taking into account the *channel switching frequency* over the path's component links [7].

The presented routing solutions are still in an incipient form and have several important drawbacks:

- the on-demand based routing protocols are implemented with the CRN flooding when the RREQ is broadcasted/re-broadcasted into the network. A solution to this can be the one suggested to limit the flooding process at a delimited area, based on geographical information [8].
- the CRN imposes new and very complex routing metrics, which means that additional information needs to be known and which demand for a greater computing power.
- some of the suggested algorithms do not take into consideration the dynamic nature of the spectrum opportunities (SOP) along the path, and consider the route based only on a single channel. In return, the algorithms that do consider that the source-destination path is created trough the concatenation of more links with different SOPs, must take into account the channel switching number along the path and the corresponding introduced delay.

Based on this, we suggest a more opportunistic algorithm that responds to the CRN flexibility in a similar way that IP does in the wired network context. We therefore propose IP Spectrum Aware Geographic (IPSAG) algorithm to achieve opportunistic routing in CRN [1].

The paper presents the validation of IPSAG correctness. To this end, a CRN model is created and, inside the CRN, a set of simulations are considered for a particular scenario. The principle that guides the simulation experiments is to prove that IPSAG is performing well in a difficult scenario: a low number of CR nodes located in a channel area (which would also confirm that IPASG successfully works in the majority of the situations). Also, the values used for the simulation parameters correspond to the real situations in the wireless environment.

The paper is structured as follows:

Section 2 presents the IPSAG routing principle.

Section 3 describes the IPSAG model implemented in Java.

Section 4 shows the obtained results of our simulations and, finally, section 5 concludes the IPSAG validation and suggests future improvements.

2. IPSAG Routing Protocol

2.1. Routing Concept

IPSAG is an opportunistic routing protocol that was inspired by the Internet Protocol (IP) flexibility and promptitude to respond at network changes. Three main factors have been included in the IPSAG design [1]:

- **IP hop-by-hop routing**: the next-hop decision is taken individually by each tracked node towards the destination. The advantage in this case is the flexibility introduced in the routing process given that the CRN have an architecture that is constantly changing (mobile nodes, links availability, etc.). Consequently, successive packets belonging to the same data stream can follow different paths across the network (similar with IP).
- **Spectrum aware routing**: the fundamental assumption of IPSAG is that the Sensing function (localized at the physical layer) provides information regarding the availability of the licensed users channels for the routing module. Thus, each CR node has knowledge of its own spectral opportunities (SOP).

  If we consider:

  i - the current node; j- a geographical neighbor of i; SOP(i) - $\cup_k\{ch_k|ch_k$ *an available channel sensed by node i}*, then j is elected to be a next-hop candidate for i only if SOP(i) $\cap$ SOP(j) $\neq$ 0.
- **Geographic routing ("greedy" forwarding)**: the geographical positions of the nodes are taken into consideration in order to route the packet towards the destination. That is, between the geographical neighbors that have common SOP with the current node, the next-hop is chosen to be the one closest to the destination.

  In the initial IPSAG design, the routing metric had three characteristics:

1. *the common SOP* between the current node and its neighbors;

2. *the common SOP Quality of Service (QoS) characteristics*;
3. *the geographical CR nodes locations* relative to the destination position.

In the currently implemented Java code, only the 1st and the 3rd factors were maintained while the 2nd (the QoS factor) was excluded so as to not have a non-polynomial (NP) complete next-hop decision process.

2.2. Next-Hop Decision Process

The next-hop selection process, is as follows [Fig. 1]:

- the geographical neighbors are first identified for each CR node;
- the current node, on the source-destination path, will then run the IPSAG algorithm in order to obtain the next-hop:
    1. the channels availability shifts between "available" and "unavailable" status at each IPSAG iteration, according to a varying probability, that gives the unstable nature of the channels used in CRN;
    2. identification of the nodes that have common SOP with the current node between the geographical neighbors;
    3. between the existing neighbors with common SOP, the next-hop is chosen to be the closest node to the destination;
    4. it is checked if the determined next-hop is or not the destination:
        a. positive case: end of algorithm (Success);
        b. negative case: IPSAG rerun with the determined next-hop as current node.

For a detailed IPSAG design presentation it is recommended to consult the information in [1].

3. IPSAG Simulation Model

The idea on which the IPSAG validation is based is to build a CRN inside which the IPSAG must run. With this aim, by using the Java programming language [9], three classes have been created:

1. "Channel" class that models a radio channel. The channel is represented by a circle, with the center given by the two Cartesian coordinates (x and y) and a specified radius. Also, the channel availability is varying at each IPSAG algorithm iteration according to the pseudo-code:

```
for each channel {
        channel.aleator = new Random().nextInt(1000000) + 1;
        if (channel.aleator % a_chosen_number == 0) {
                channel.availability= false;
        } else {channel.availability = true;}
        }
```

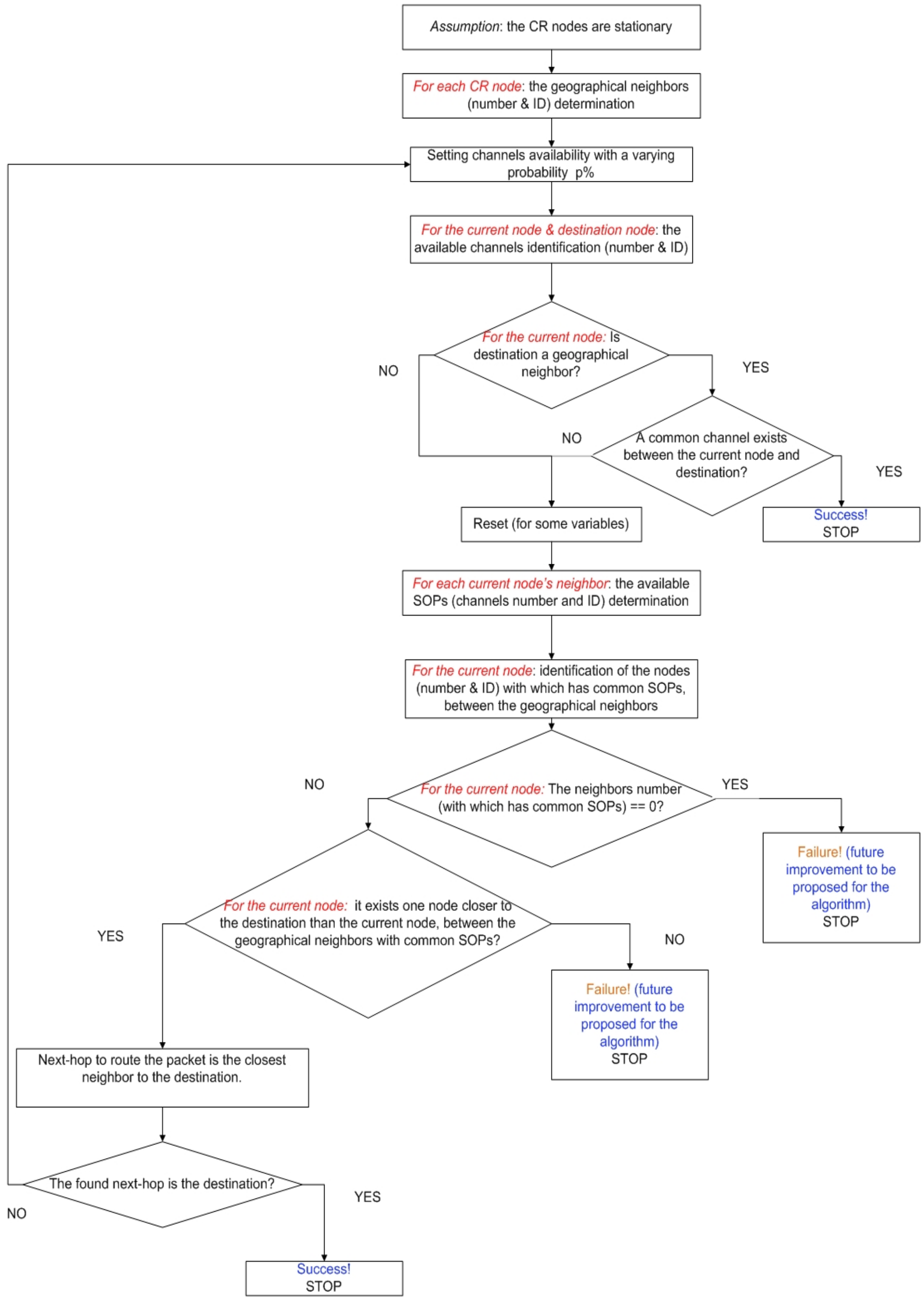

Fig. 1. The next-hop decision process - flowchart

This means that, if a random number is divisible with a user chosen number, then the channel is unavailable. Thus, the availability degree is controlled by the divisibility degree, for each channel separately.

2. “Node” class that models a CR node. Geographically, a CR node is represented by two Cartesian coordinates (x and y) and it is characterized by the set of variables: the neighborhood radius, the available SOP, the geographical neighbors, the neighbors with common SOP, and others.
   Remark. If a CR node is located in a specific channel area (that is, if the node is inside the channel circle), then the node can sense the channel availability condition.
3. “Network” class which, based on the previous two presented classes, models a CRN. This class contains a map of channels and a map of nodes, by whose overlap will results in a CRN basic model.
   Further, all necessary methods for running IPSAG are implemented in this class. Practically, the user chooses the source and destination index in the nodes map, and then IPSAG offers the route (intermediary nodes).

The simulation experiments concentrated on proving the success of IPSAG in finding a source-destination route. The CRN model has been specifically developed for some given parameter values [see 4.1.] and in different situations, namely:

- the number of CR nodes was varied, while the number of radio channels and the neighborhood radius were maintained constant;
- the number of radio channels was varied, while the number of CR nodes and the neighborhood radius were maintained constant;
- the neighborhood radius was varied, while the number of radio channels and CR nodes was maintained constant.

4. Simulation Experiments

4.1. Scenario

Prior to comment some statistical results regarding the IPSAG simulations, an example of finding the source-destination path with IPSAG is presented [Fig. 2]. The example is randomly chosen and its purpose is only to show a step-by-step IPSAG functionality. The parameter values of the CRN model (CR nodes number, the number of sensed channel per node, the channel coverage area and others) are selected for a disadvantaged situation in report with the real ones. By proving that IPSAG is working in a difficult case, the IPSAG good functionality for normal cases is also confirmed.

Thus, the used CRN model [Fig. 2] has the following characteristics:

- the CRN perimeter is a square, with the side of 200 km,
- 50 CR stationary nodes are inside CRN (so that a medium number of 9 nodes are located in a channel area),
- 15 channels are dynamically available, with the circle radius of 40 or 50 km (20% and respectively 25% of the square side).

The chosen values are strongly related to the real wireless environment. Therefore, the maximum cell radius in the case of WiMAX 802.16d is about 50 km at 3.5 MHz (45 km at 5 MHz), depending on the equipment type. Also, the maximum number of supported users is 512, in the case of a performant base station. By choosing a lower number of CR users (9 nodes are located in a channel area) we assure that, if IPSAG finds a route in a poor populated network, then the higher will be the probability to find it in a very populated CRN, i.e. more geographical neighbors, more next-hop candidates.

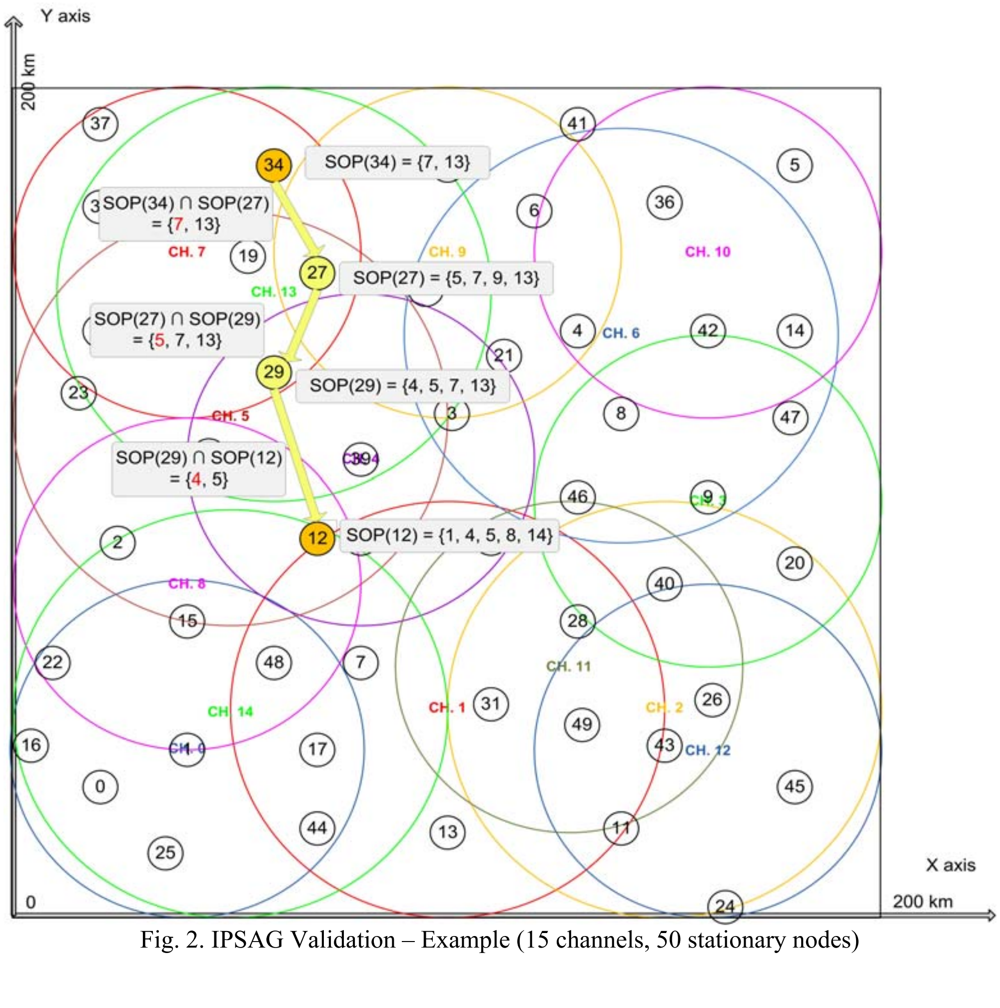

Fig. 2. IPSAG Validation – Example (15 channels, 50 stationary nodes)

In this particular example, the source ID is 34 and the destination ID is 12. According to the IPSAG simulation, the route was determined in three steps [see Fig. 2]:

1. *step I*: Node 34 (the source) senses channels 7 and 13 to be available. After running IPSAG, the node 34 chooses node 27 as the next-hop to forward the packet. The first channel sensed to be free by the both nodes is allocated. So, channel 7 is allocated on the link 34-27, and the packet is forwarded.
2. *step II*: Node 27 senses channels 5, 7, 9 and 13 to be available. After running IPSAG, the node 27 chooses node 29 as the next-hop to forward the packet (node 29 senses that channels 4, 5, 7 and 13 are available). Channel 5 is allocated on the link 27-29, and the packet is forwarded.
3. *step III*: Node 29 discovers that the destination (node 12) is one of his neighbors, and then verifies if they have common SOP. As a result, channel 4 is allocated on the 29-12 link.

Thus, the route from node 32 towards node 12 is containing two intermediary nodes (nodes 27 and 29) and it is created by concatenating three links on which there were allocated the channels 7, 5 and 4.

4.2. Simulations Results

A set of three simulation are reported. The first two experiments are about the IPSAG success/failure probability of finding a random chosen path and the third one gives information about the medium number of intermediary nodes between source-destination, with focus on the neighborhood radius influence.

1. **Experiment one**

   Context: 50 stationary nodes, 15 radio channels, a medium number of 9 CR nodes located in a channel area, with *different* values for the neighborhood radius: 30 km, 40 km, and 50 km, respectively (representing 15%, 20%, and 25%, respectively of the CRN perimeter side). For each neighborhood value a subset of 30 simulations have been done. The success/failure probability of finding a source-destination route is calculated to be the number of simulations that succeeded/failed in finding a path reported to the total number of simulations.

   Results [Fig. 3]: In all cases the success probability of finding the route was very high, namely from 93% (neighborhood radius 30 km) till 100% (neighborhood radius above 40 km). The main observation is that, for a small neighborhood radius value, the risk does appear for not having geographical neighbors, and thereby next-hop candidates. This problem can be solved by increasing the number of CR nodes, from 9 users per channel area up to 512 users, i.e. the maximum users number in a WiMAX cell.

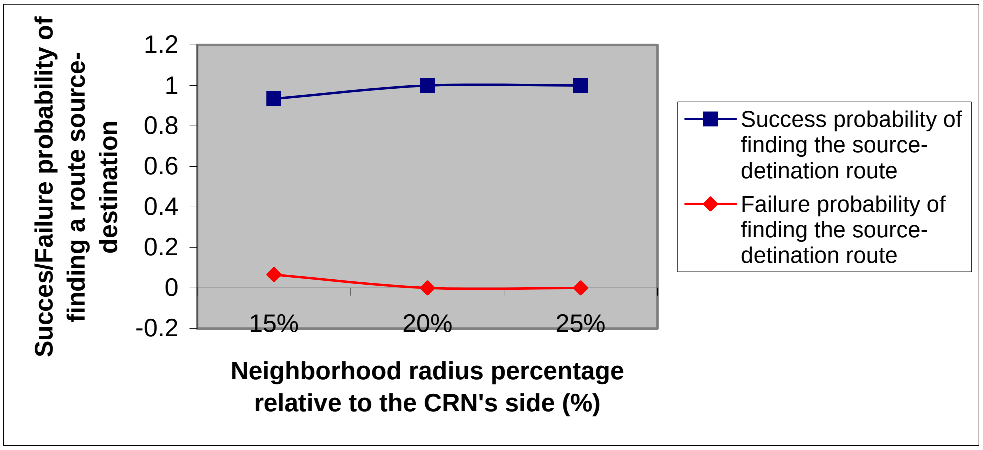

Fig. 3. Neighborhood radius value influences the success/failure probability of finding a source-destination route

2. **Experiment two**
   Context: 15 radio channels, the neighborhood radius is 40 km (representing 20% of the CRN perimeter side), with *different* numbers of CR nodes: 30, 50, and 80, respectively; a medium number of CR nodes in a channel area of 6, 9, and 15, respectively. For each number of CR nodes a subset of 30 simulations was considered.
   Results [Fig. 4]: In all cases, the success probability of finding the route was observed to be high, with the remark that below 30 nodes the IPSAG failure rate is increasing. This means that in a poor populated CRN (an extreme case in the majority of the situations), IPSAG is not performing well.

3. **Experiment three**
   Context: 50 stationary nodes, 15 radio channels, with the neighborhood radius of 40 km (case 1) and 30 km (case 2), representing thus 15% and 20%, respectively, from the CRN perimeter side. For each neighborhood value a subset of 30 simulations was considered.
   Results [Fig. 5]: The purpose was to monitor the number of intermediary nodes between source and destination, with regard to the influence of the neighborhood radius value.
   In the first case (neighborhood radius 40 km), a number between 0 and 6 of intermediary nodes was obtained, with the medium value of 2.466 intermediary nodes per simulation.

In the second case (neighborhood radius 30 km), a number between 1 and 7 of intermediary nodes was obtained, with the medium value of 3.35 intermediary nodes per simulation.

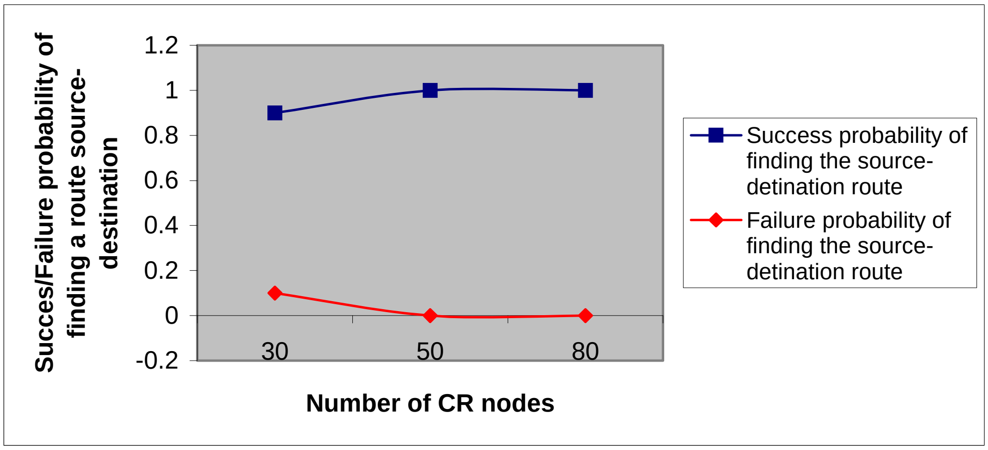

Fig. 4. The CR nodes number influences the success/failure probability of finding a source-destination route

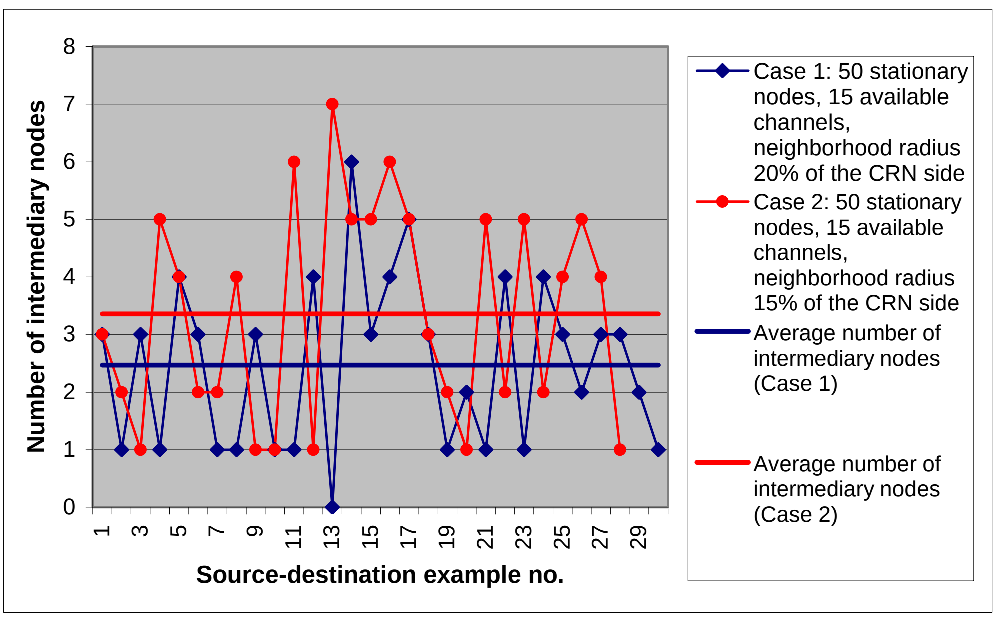

Fig. 5. The number of intermediary nodes between source and destination obtained with IPSAG and neighborhood radius value influence on the results

All these results show that IPSAG is behaving well, with the observation that it is necessary to have a CRN dimensioning function in order to attain strong performance. This function refers, e.g., to the number of nodes, number of channels, neighborhood radius value, etc.

5. Conclusions

IPSAG is an original CR routing protocol developed to offer a high opportunistic facility of determining a route. In this paper we reported on the IPSAG protocol validation, for the case of stationary CR nodes.

First, a simple CRN model was created in Java and second, the IPSAG algorithm was implemented and tested in the CRN. The goal was to test the correctness of IPSAG.

The simulations showed that the protocol has good performance, which leads the authors to improve the simulations in a future work by a high level mathematical approach.

Furthermore, another future work is on developing a mobility model for the CR nodes and to evaluate the performance of IPSAG.

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