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SAGRA: A Spectrum Aware Geographic Routing Algorithm Proposal for Multi-hop Cognitive Radio Networks

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Abstract:-*In the recent years Cognitive Radio (CR) technology imposed itself like a very good solution to the increasing spectrum utilization. This technology recommends the development of a new radio type – a cognitive radio – endowed with intelligence that shall sense, share, and use the spectrum opportunities (SOP) of the preexisting wireless networks, that is the channels that are not used by the licensed users.A new routing algorithm for CR networks (CRN): SAGRA – Spectrum Aware Geographic based Routing Protocol is presented in the paper. As suggested by the name, the geographic, and the spectrum aware routing concepts were used together in the protocol's design. The dynamism and flexibility, characteristic to both CR and IP networks, made us compare the CR concept with the IP concept (a wireless versus wired flexible environment comparison); thus we assumed the IP routing approach for CRN. The proposed strategy is based on hop-by-hop routing, local decisions being taken by nodes according to both local information (CR node's neighborhood) and global information (the entire topology of CRN), channels availability, and destination location.*

Keywords – *cognitive radio network, routing protocol, geographic routing, spectrum aware routing, routing metric, performance*

I. INTRODUCTION

The CR domain [1] began to be largely approached by the researchers in the last years, especially regarding the sensing and channel allocation schemes. As for the routing in CR, we bounded four main directions based on the already completed work: 1) The development of new CRN (Cognitive Radio Network) specific routing protocols which are based on **adhoc on-demand routing protocols**, such as AODV (Ad Hoc On Demand Distance Vector). One of the main on-demand routing features is represented by the signaling and data transmission phases separation in time: on one hand, for the signaling phase, the request to create the source to destination path RREQ – route request, and the route request response RREP – route reply (RREP is following the RREQ reverse path, and is accompanied by the resources allocation), and, on the other hand, the data transmission along the previously determined route. In the available literature we identified several ways to use the ad-hoc on demand routing characteristics inside the cognitive radio networks:

• The RREQ is broadcasted across the entire CR network (the main disadvantage is given by the network flooding with signaling messages);

• the weaving of on demand routing protocols operation modality with geographic routing; two possibilities are more relevant: 1., the RREQ is broadcasted only in a specific area of the CR network, area which is found based on the destination geographical location [2] (in this way, the flooding area is reduced to a specific part of the network, obvious smaller), and 2., the greedy RREQ forwarding, using a node focus region, which was determined by each CR node on the path using the destination position (no flooding) [3];

• the change of the classic RREQ AODV broadcasting process by taking into account the spectral opportunities: RREQ re-broadcasting on all available channels [4], the RREQ is transmitted further to a node only if the current node and next-hop node have common spectral opportunities [5];

2) The **Dijkstra algorithm** use: based on this algorithm and on the CR network topology, each node (tree root) will have a proper shortest path graph towards the all other CR nodes, the probable destinations; for this algorithm, the usual cost used to calculate the graph is the minimum hops number, but in CR case, the minimum hops number is replaced or adjusted with other metrics, some of them specific to the CR technology, e.g. the combination bandwidth-delay [6];

3) Some **original algorithms** dictated by the network CR characteristics (one of the most interesting algorithms [7]: extracting a portion of CR network, as a route mesh, centered on the shortest source-destination path, and then choosing from this mesh the final route, using a second criteria, such as band);
4) **Large variety of CR routing metrics**, used along with the routing protocol types mentioned above (*1st*, *2nd*, and *3rd* paragraphs): interference to primary user, intra-flux interference, secondary user throughput maximization, channels availability, condition and utilization, number of channel switching along the way, end-to-end delay, minimum route maintenance cost, etc.

II. CR NETWORK MODEL

A. Multi-hop CRN routing model

The CRN based on which SAGRA presents *two components* (Fig 1): the pre-existing wireless systems (WiMAX, WiFi, etc.), and the CR nodes (represented by white circles), operating in the free channels of those systems [1].
Also, the network model that we used is based on *multi-hop* CRN: this means that we can have more CR nodes on the route between source and destination.
SAGAR – the routing algorithm that we propose – concerns exclusively the routing between CR nodes, without mention to the routing in the pre-existing wireless system areas. We assume that on the route to the destination, if a packet encounters a preexisting system, it will be routed according to the system's way of routing, based on the tunneling routing approach.
Thus, the CRN will present two ways of routing: outside the pre-existing wireless systems – IPSAG algorithm based routing, and inside the pre-existing system – routing according to the already existing protocols.
Note: In case of CR nodes located inside of a pre-existing system, we assume that the CR node will behave like a pre-existing system's node.

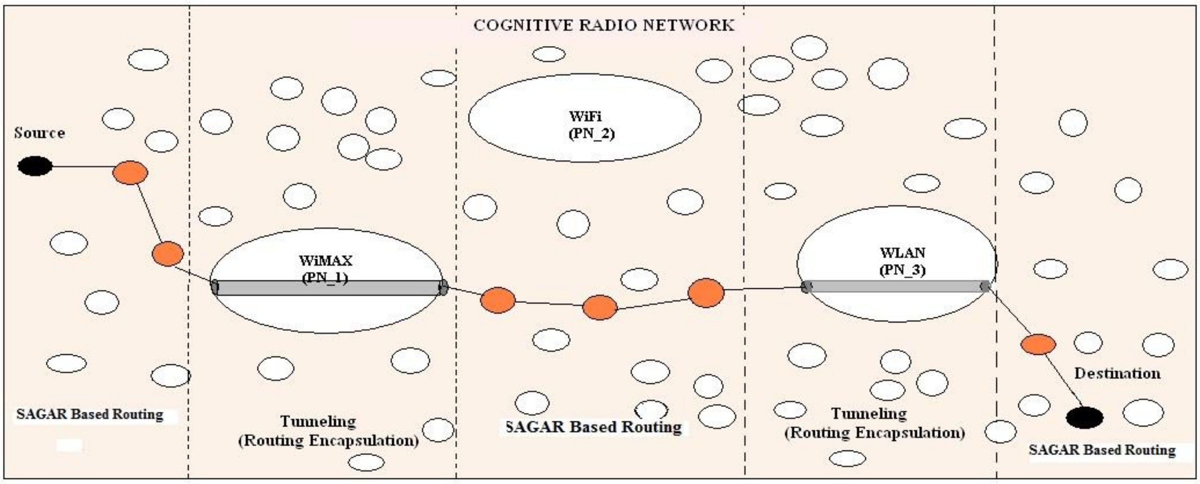

Fig 1. CRN routing network model

B. Ideal Sensing and Sharing

Alongside the CRN multi-hop routing model (paragraph A), we assume that the sensing and sharing models of the lower layers (Physical and Medium Access layers) are ideal; this implies that the third layer (on which the routing is made) receives all the necessary information to take the routing decisions: spectrum opportunities sensing, location sensing, channel negotiation and allocation between different CR nodes, etc.
This paper regards only the CRN layer – routing – making the assumption that the other OSI layers are properly working.

C. Common Control channel

In order to facilitate the signaling part in CRN routing, we will utilize a common control channel (initial information flood, CRN changes report, etc.), instead of propagating the signaling information from neighbor to neighbor.
The control channel will be sensed by each CR node, and each CR node will be able to receive and send information using this channel.
Note: We assume that, for the general signaling information (with respect to the whole CRN), the CR nodes will use the common control channel, and, for the signaling information exchanged in a neighborhood (a more detailed information – see paragraph III.C.2) the information is transmitted directly (neighbor_by_neighbor) between the core node and CR neighborhood's nodes.

III. ROUTING PROTOCOL

A. The Routing Protocol Concept

The idea of the CR routing protocol proposed in this paper is mainly based on three different approaches: the IP hop-by-hop, the geographic, and the spectrum aware routing concepts. The available channels fickleness, the excessive nodes mobility, the frequent change of the network's geographical topology, imposed to choose this heterogeneous combination of factors in designing this protocol.

1) Spectrum aware routing

In order to allocate resources (i.e. channels that are not used by the primary users) for data transmission, the nodes must know the number of available channels, identity, and offered quality. With this aim mostly in view, in CR exist the function of sensing the environment; here we will only use the sensing results (offered by the first two OSI layers) to design and model our routing protocol. The conjecture used for IPSAG, with a view to allocate a channel between two nodes, is to compare the channels sensed by both nodes (current node and next-hop node), find the joint sensed channels, and there from choose for assignation a channel with a good quality of service (QoS).

2) Geographic routing

The CRN is faced with an advanced nodes mobility, additionally to the channel's instability, which makes almost impossible to use proactive routing protocols, which imply a prior route discovery. IPSAG uses the local information (positions and channels opportunities over a neighborhood) and takes a hop-by-hop routing decision. The source and every intermediate node along the path will forward the message by using in the decision process the destination geographical location. This way of routing is the essence of geographic routing (position based routing), more precisely of the "greedy forwarding" strategy [8]: the next hop must be the closest current node's neighbor to the destination. A node running IPSAG forwards the packet to the closest neighbor node, but considering also the quality of the channel to allocate, i.e. using a hop-by-hop geographic routing with QoS. Thus, it cannot be elected the closest node to the destination, if no QoS channel to allocate is available. *Note*: In order to ensure IPSAG functioning, all the CR nodes must know their location (location sensing), and be aware about the destination geographical position (signaling procedure).

B. The Proposed Routing Metric

Taking into account the variable character of the spectrum channels availability, the first parameter to consider when developing a CR routing metric (additionally to the old routing parameters, used in a wireless environment) shall be the common spectrum opportunities (SOP), between the current node and the next node to choose on the selected path. Thus, the routing metric proposed in this paper is influenced by the following conditions:

***1)* The available channels over a link** (the intersection between current node's SOP and next hop's SOP); the available channels are offered to each CR by the Sensing function.

2)* The channels characteristics*; here we will consider only the bandwidth – Bw (the maximum bit rate that can be transmitted over the given channel in a time unit, measured in b/s) and the channel quality given by the bit error ratio – BER (the ratio between the number of information bits with error and the total number of information bits; BER is showing how correct is the information transmitted),

***3)* The destination location** (more precisely, the distance between the current node's neighbor – possible next hop – and destination)

These influences are translated in a mathematical form (1), the next hop being elected according to location ($D_{j\text{-}d}$), joint spectrum opportunities ($SOP_i \cap SOP_j$), and basic QoS characteristics ($CAR_{sopi \cap sopj}$).

We will detail the f1 and local decision regarding the next hop in IV.C.

RM – the routing metric;

$SOP_i = \cup_k\{ch_k|ch_k$ is an available channel sensed by node i$\}$ (the spectrum opportunities sensed by the CR node i);

$SOP_i \cap SOP_j = \cup_k\{ch_k|ch_k$ is an available channel sensed by both I and j nodes$\}$ (the spectrum opportunities for the link (i,j));

$CARch_k= f_2(b_k,q_k)$ (the channel k characteristics are here represented by a scalar returned by function f2, which depends on bandwidth and BER);

$CAR_{SOPi} \cap_{SOPj} = \cup_k\{CARch_k|chk \in SOP_i \cap SOP_j\}$;

$D_{j\text{-}d} = ((xd\text{-}xj)^2+(yd\text{-}yj)^2+(zd\text{-}zj)^2)^{-2}$, x_j, y_j, z_j – the Cartesian coordinates of node j, defining the spatial location

C. Main steps in route setup

SAGRA routing algorithm is opportune for small CRN, where the entire geographical topology of the network (node's ID and location) can be obtained in real-time by each node.
Attention: In this paper we will not investigate what "real-time" means, given the fact that this concept is very much influenced by the CR sensing function. (As we said before, sensing in CRN is not the concern of this paper and we assume to have the perfect sensing)

For large CRN we are going to propose two possible cluster based algorithms, with SAGRA inside each cluster.

1) Obtaining the CRN global topology

In order to obtain the entire geographical topology of the CRN (nodes IDs and locations), we propose the flooding idea used by OSPF (Open Shortest Path First) at the network forming [9]:
Each node will broadcast its ID and location, and will rebroadcast the received information; hereby every CR node will build step-by-step the network topology. (At the end of this process, only the network's changes will be announced.)
It worth mentioning that (by involving each CR node in broadcasting the information) the flooding process is very resources costly, and can prevent the proper network functionality when many changes occur. In order to solve this problem, we opted for the common control channel utilization: each node will send on this channel its ID and location and the others nodes will receive this information – thus, the destination position will be known.
Note: A performant algorithm for colleting the network topologies information is proposed in [10].

2) Creating the neighborhoods

The reason of creating the neighborhoods is to have for each CR node a "knowledge" area: *node IDs, positions, SOPs, and SOPs QoS characteristics*. The node will stock this information in a local table, and, based on this information, will choose the next hop to forward the packet.
The criterion used here to create the neighborhood is the *Euclidian distance*: the neighborhood will be represented by a *circle*, with the *core* given by the corresponding node, and the *radius* given by the chosen maximum Euclidian distance between the core and a CR node.
The radius will be elected by making a compromise between the maximum core node's sensing area, the SAGRA protocol's real-time functionality, and the existence of other CR nodes inside the neighborhood, beside the core.
Note: If inside the initial chosen neighborhood is no CR node – except the core, the radius will be increased until a proper number of CR nodes will be in the neighborhood, and, thus making possible the process of next-hop election).

3) Global and Local Tables

a) Global Table – is used to store the entire CR network topology information: *node ID (IDi) and positions* $\{x_i, y_i, z_i\}$, where i represents a CR node index in the CRN (i = 1…n, where n is the CR nodes number).
The table is completed and modified according to the process described in III.C.1 paragraph. Each CR node will have such a "global table", in order to know the destination position needed to perform SAGRA routing.
Note: The existence of the global table while working with a real-time SAGRA, imposes not to have a very large CR network.
b) Local Table – is used to store more detailed information than the global table (this time regarding only the CR nodes inside current node's neighborhood, not within the entire network); *beside node IDs and positions, the current node will stock also the neighbors' spectrum opportunities and characteristics –* SOP_i, CAR_{SOPi}.
Possessing the knowledge of spectrum opportunities and characteristics, alongside destination position, a node will have all the information necessary to perform IPSAG routing: next hop selection, resource allocation, and packet forwarding.
Note: We chose neighborhoods because it is practically impossible for each node to know all the CRN node SOPs and characteristics.

4) Local Decision Process

It will determine the next-hop to forward the packet within the current neighborhood, toward the destination.
We will present below how the next-hop is elected, following the two steps of the decision process together with the afferent pseudo-code (Assumption: the current node on the path is i):
Step I (Fig 2)*:* Taken into consideration all the jointly sensed channels (between node i and its neighbors), node i selects only the nodes with channels that are satisfying a QoS threshold (resulting a new neighborhood $V_i' \subseteq V_i$):


```
Vi' = Ø;
for each j ∈ Vi do {
SOPi,j' = Ø;
for each chk ∈ (SOPi,j = SOPi ∩ SOPj) do {
compute CARchk = f2(bk,qk)
if (f2(bk,qk) ≥ threshold)
{ Vi' = Vi' ∪{k};
SOPi,j' = SOPi,j' ∪ {chk};}
else go to the next channel;
}
return SOPi,j';
}
```

Fig 2. The first step of next-hop election process – pseudo-code

Step II (Figure 3): *Among the new vicinity Vi ', node i is choosing the next hop to be the closest node to the destination:*

```
next_hop = i;
ch_to _allocate = Ø;
D = a big number;
For each j ∈ Vi' do{
Dj-d = ((xd-xj)2+(yd-yj)2+(zd-zj)^2)^-2;
if (Dj-d<D) {D = Dj-d; next_hop = j;
ch_to allocate = first ch ∈ SOPi,j';
}
else {go to the next node;}
}
return( (next_hop) & (ch_to_allocate));
```

Fig 3. The second step of next-hop election process – pseudo-code

D. The routing protocol functionality

1) General view over the IPSAG functionality

Based on two state diagram we will try to present the SAGRA functionality i.e.: how the previously described algorithm parts integrate and work together:

a) After the general CR information procurement (CR node IDs and positions) and *global table completion*, the CR node starts building its neighborhood: first, the *neighborhood* is built with a small radius d; if no CR neighbors inside the initial neighborhood, the radius range is increased by Δd, until the current CR node will have an appropriate number of CR neighbors. Then, the CR node will complete its *local table*, by gathering the CR neighbor's SOPs .Corresponding with the network changes outside/inside its neighborhood, the CR node will update the global table/both global and local tables (Figure 4).

2) IPSAG algorithm exemplification

A short exemplification of the IPSAG routing algorithm is presented in Figure 6:

- The CR source node will choose the next-hop to forward the packet within its neighborhood; the next hop In_1 is elected according to IPSAG algorithm (this means by taking into consideration SOPs, CARSOP, and distance towards the destination);
- Using the same SAGRA algorithm procedure In_1 will choose within its own neighborhood the next-hop, In_2; Similar, node In_2 will select node In_3;
- In_3 will discover that the destination is inside its neighborhood, and will forward the packet to the destination (no need to run the procedure for the next hop selection within the neighborhood).

IV. IPSAG ALGORITHM VS. OTHER CR ROUTING PROTOCOL ALGORITHMS

In order to have a more constructive vision over our algorithm, as compared to all the previously proposed routing algorithms, we chose for comparison two of them, which are the most related to IPSAG: *ACK Signal Based On-Demand Routing Algorithm* [2], and *SpEctrum Aware Routing for Cognitive ad-Hoc networks* (SEARCH) protocol [3]. Both algorithms are based on the AODV protocol (using RREQ and RREP to determine the route), and at the same time on the geographic location of the destination.

A. ACK Signal Based On-Demand Routing Algorithm: the routing region is determined by a chosen maximum angle, with the segment that connects the source location to the destination location being the angle's bisector; only in this region the RREQ will be broadcasted*;*

B. SEARCH protocol: separately, on each source's available channel, the RREQ is forwarded to a next hop having the biggest advance towards the destination, in a certain region – fusion region ; so, if we have n available channels at the source, we can find maximum n individual routes to the destination. The final route will be, most likely, a combination of fragments belonging to the routes discovered for each channel separately. After the final route computing (signaling phase), the data can be transmitted.

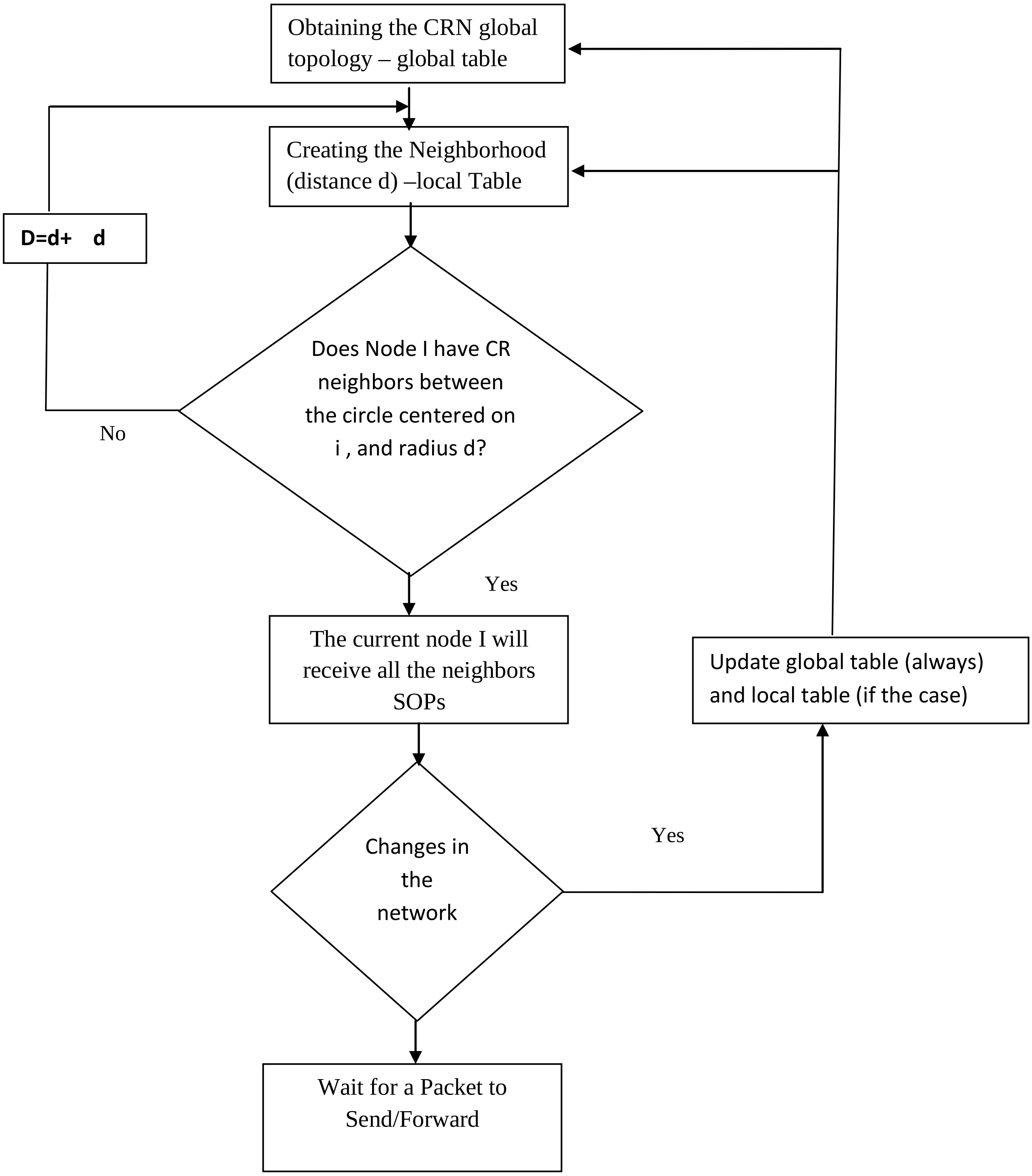

Fig 4. SAGRA functionality: creating the neighborhood

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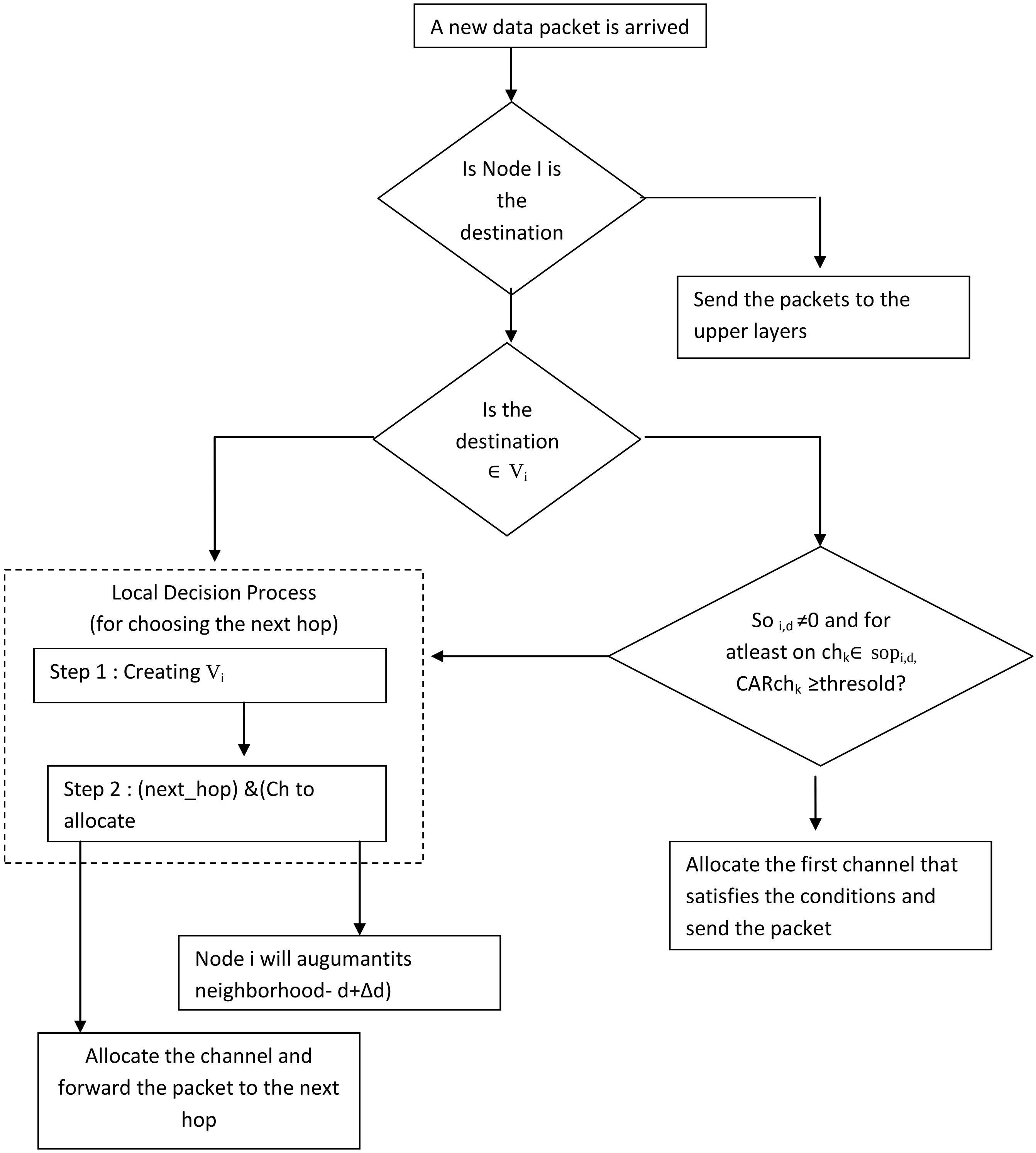

Fig 5. SAGRA functionality: packet forwarding process

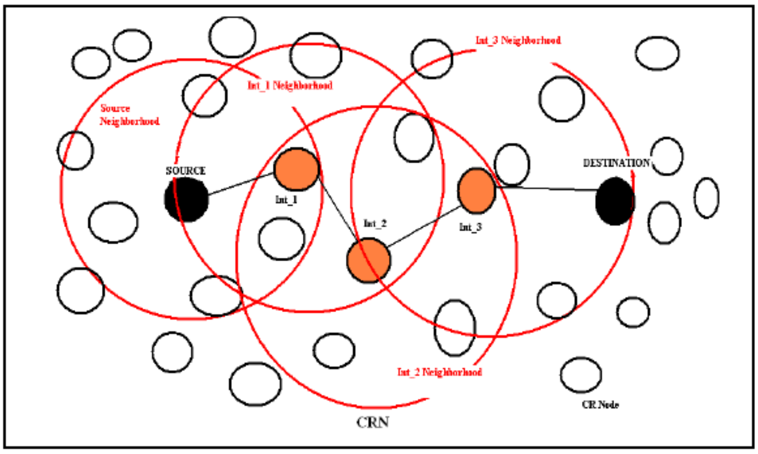

Fig 6. Routing with SAGRA – exemplification

As common characteristics of the two mentioned protocols and IPSAG, we outline on one hand the geographic destination position utilization in determining the route, and on the other hand the neighborhood concept that is somehow similar to the fusion region concept.

More apparent are the differences in our view, which make IPSAG a very good solution for routing in CRN

- SAGRA does not use a separate signaling phase: RREQ from source to destination, and RREP together with resources allocation, from destination to source; the IPSAG's route discovery phase is interwoven with the data forwarding phase, and both data and signaling information are carried out in the same packet, in the same time, similar to IP. SAGRA presents an unicast combined modality to determine the route and transmitting the packet (noRREQ broadcast or multicast);
- consecutive packets, with the same CR source and destination, can follow different routes, according to the network dynamics (the flexibility is IP's advantage versus a predefined route discovery protocol, in case of a path failure);
- SAGRA does not impose to have the same spectral opportunities for all the CR nodes, (each link on the path has an independent channel allocation possibility, which can be or not the same with the other link's possibilities, links that are on the same source-todestination path), the difference being available only for the SEARCH protocol;
- the neighborhood concept utilization makes IPSAG quickly adaptable to the CRN changes, given the factsthat the neighborhood can be dynamically updated in order to make IPSAG properly function and the information can be real-time exchanged in a small area vs. the whole CR network.

Thus, the most important IPSAG advantage is the similarity with the IP's operating mode, that makes it very flexible to the network's changes and nodes mobility.

V. CONCLUSIONS

In this paper we proposed a very complex CR routing algorithm (IPSAG), which gathers more possibilities to achieve a real time routing in CRN. IPSAG offers the flexibility of hopby- hop IP routing, the real-time information exchange inside the neighborhoods, the adaptation to the CR very dynamic spectrum opportunities, and the geographic routing advantages in a high node mobility network. In this respect, we advanced a new routing metric together with a neighborhood based next-hop decision process. The proposed routing metric integrates the spectrum opportunities, the channels quality, and the current nodes position towards the destination. The local next-hop decision process presents two steps: first, the current node chooses from its neighborhood only the nodes which present common spectral opportunities, under QoS restrictions, and second, selects from these nodes the next hop based on a geographic issue. Very original to this algorithm is the IP routing influence: each packet presents a header containing signaling information, and is separately routed according to the network's current topology, without the use of a pre-established route, and without regard to the previously routed packets. This is an important advantage for IPSAG as compared to the other CR routing algorithm, that are proposing the use of a single route
established in a signaling separate phase; because of the very frequent changes in the CR nodes mobility and because of the primary user's priority regarding the CR user, the spectrum opportunities sensed at a given time may totally or

partially disappear in terms of availability. In other words, IPSAG is our original way of viewing the IP working in a wireless The next step will be to show a good functional CR routing protocol implementation, based on this algorithm.

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