CORASMA Program on Cognitive Radio for Tactical Networks: High Fidelity Simulator and First Results on Dynamic Frequency Allocation

Luca Rose, Raphael Massin, Luxmiram Vijayandran, Mérouane Debbah, Christophe J. Le Martret

▶ To cite this version:

Luca Rose, Raphael Massin, Luxmiram Vijayandran, Mérouane Debbah, Christophe J. Le Martret. CORASMA Program on Cognitive Radio for Tactical Networks: High Fidelity Simulator and First Results on Dynamic Frequency Allocation. MILCOM 2013, Nov 2013, San Diego, United States. pp.1-9. hal-00923430

HAL Id: hal-00923430
https://hal-centralesupelec.archives-ouvertes.fr/hal-00923430

Submitted on 2 Jan 2014

CORASMA Program on Cognitive Radio for Tactical Networks: High Fidelity Simulator and First Results on Dynamic Frequency Allocation

Luca ROSE
Thales Communications and Security, France.
luca.rose@thalesgroup.com

Raphaël MASSIN
Thales Communications and Security, France.
raphael-a.massin@thalesgroup.com

Luxmiram VIJAYANDRAN
Thales Communications and Security, France.
luxmiram.vijayandran@thalesgroup.com

Mérouane DEBBAH
Alcatel - Lucent Chair in Flexible Radio, Supelec, France.
merouane.debbah@supelec.fr

Christophe J. LE MARTRET
Thales Communications and Security, France.
christophe.le_martret@thalesgroup.com

***Abstract*—This paper reports some preliminary results of the "cognitive radio for dynamic spectrum management" (CORASMA) program that is dedicated to the evaluation of cognitive solutions for tactical wireless networks. It presents two main aspects of the program: the simulator and the cognitive solutions proposed by the authors. The first part is dedicated to the simulator. We explain the rationale used to design its architecture, and how this architecture allows to assess and compare different cognitive solutions in an operational context. The second part addresses the dynamic frequency allocation topic that is part of the cognitive solutions tackled in the program CORASMA. We first give an overview of the challenges attached to this problem in the military context and then we expose the technical solutions studied by the authors for this purpose. Finally, we present some results obtained from the simulator as an illustration.**

I. INTRODUCTION

"Cognitive radio for dynamic spectrum management" (CORASMA) is a category B program managed by the European Defence Agency (EDA) and sponsored by the governments of seven countries: Belgium, France, Germany, Italy, Poland, Portugal, and Sweden. The program started in November 2010 for a three-year duration and aims at studying the capability of cognitive radio (CR) to support communication systems for tactical networks operations.

Among the main outputs of the CORASMA program, we have: 1) the study of cognitive solutions to improve performance of communication systems and 2) the development of a layer 1 to layer 3 high fidelity (HiFi) simulator to evaluate performance at operational level of solutions proposed in 1). The objective of the HiFi simulator is to validate cognitive solutions at a technology readiness level (TRL) of level five. Note that the CORASMA project does not aim to develop one particular cognitive waveform, but rather investigate possible solutions and to assess their pros and cons in an operational context.

This paper reports the latest advancements of the program on these two previous points. We will first explain the simulator's structure and architecture that enables to host the various cognitive solutions to be tested. Then, we will address the dynamic frequency allocation (DFA) and, more specifically, the solutions proposed by the authors within the CORASMA framework.

II. CORASMA SIMULATOR

The purpose of the simulator developed in CORASMA is to allow the evaluation of cognitive solutions at operational level. To this end, a HiFi simulator is developed encompassing the three first layers of the ISO model, namely the physical (PHY) layer (layer 1), the data link layer (layer 2), also often referred to as medium access control (MAC), and the network (NET) layer (layer 3). Here, HiFi means that the detail level of implementation is enough to replicate behavior of real systems for these layers. HiFi simulation is a challenging topic, which is getting increasing interest in the communication community as PHY and MAC layers are becoming more and more sophisticated [1], [2].

At PHY layer, channel coding and decoding is implemented as well as modulation / demodulation in baseband (IQ samples). Transmitted IQ signals are sent through a propagation channel that integrates a digital terrain model including the above ground such as buildings. At the MAC layer, all the protocols are implemented including the signaling messages needed to operate the protocols. This is important in order to assess the extra signaling required by the cognitive solutions and to evaluate their sensitivity to the loss of signaling. At the NET layer true implementation of routing protocols is done transmitting IP datagrams through the network. Here, the interest to implement such detail is that it captures the impact of the lower layers behavior on true datagrams and IP signaling.

In the simulator each receiver receives as input the summation of all the transmitting nodes samples that have a part of their spectrum coinciding with the receive filter bandwidth (after propagation). Note that in order to capture co-channel effects, we have considered the interference bandwidth as two times the bandwidth of the receive filter.

This approach, which is not usually considered in network simulations, was required since we expected to render interference effects with fidelity, thus avoiding developing high-end abstractions that are usually limited to specific conditions. Moreover, the implementation of sensing algorithms, which are usually considering IQ samples as input, calls also for a HiFi PHY simulation. If a conventional network simulator was used instated, it would have been necessary to implement another set of abstractions to emulate the sensing functions.

Note that the applications are not simulated in the HiFi mode, but are replaced with traffic generators that reflect the traffic behavior of the applications.

A. Simulation Methodology

In the CORASMA program, several partners are independently developing their cognitive solutions. Therefore, we had to find solutions for the two following problems: first, how to enable each partner to implement its own solution in the common simulator, and, second, how to assess performance enhancement brought by each cognitive solution. The answer to these two questions leads to: first, the definition of a common reference waveform, which is called *basic waveform* in CORASMA, and, second, the definition of a specific simulator architecture. These two aspects are detailed in the following sections.

Notice that in this paper, *waveform* designates the features of the communication system from layer 1 to layer 3.

B. Basic Waveform

We give here an overview of the BW without detailing in-depth its structure due to the lack of space.

The BW is a reference waveform with no cognition. It is supposed to represent an average state of the art waveform that is shared among the partners. The BW serves as a reference for performance evaluation in order to assess the enhancement (or degradation) that each cognitive solution brings to the system.

The BW is basically a multi-user access clustered *ad hoc* network, based on a slotted time division multiple access frame structure, along with a single-carrier frequency division multiple access scheme, including multiple modulation and coding schemes (MCS). Each cluster selects one transmit channel among a list of given frequency bands. The BW implements a dynamic algorithm called greedy-based dynamic channel assignment (GBDCA) that was inspired from the solution proposed in [3]. The assignment is done at each cluster, based upon information collected through a specific message sent in the HELLO packet where each node advertises the channel it is operating.

The network organization distinguishes three kinds of nodes: cluster head (CH), gateway node (GN) and regular node (RN). The CH is a dedicated node in the cluster that elaborates the resource allocation for the nodes that belong to the cluster. GNs are nodes that belong to multiple clusters. They enable communications between different clusters by alternately switching from one cluster to another. Nodes that are neither CH nor GN are called RNs. Note that this structure allows peer to peer communications between RNs of the same cluster without relaying the traffic through the CH.

The frame structure is composed of three consecutive parts:

1) Cluster head signaling slots (CHSS), which serves as a beacon that is broadcast from the CH;
2) Random access slots (RAS) based upon a contention access scheme that enables transmission of "Hello" messages for neighbor detection, and allows the nodes to query the CH for allocating the resource.
3) Data slots (DS), which are used for transmitting data packets in between nodes.

C. Basic Waveform Architecture

The BW can be presented along the conventional data plane (DP) and control plane (CtrlP) as illustrated in Fig. 1. The DP processes the data flow from the IP datagram to the signal over the air (and conversely). It encompasses three blocks:

1) The network that forwards the IP datagrams according to the routing algorithm;
2) The radio access that encompasses a segmentation and reassembly block to adapt the IP packet size to the MAC ones, several queues in parallel to manage different scheduling priorities, a MAC that combines the packets from the different queues to fit the frame format and the MCS, and a physical layer that channel encode the bits and modulate them in base band;
3) The radio frequency (RF) block that translates the base band modulated signal to a carrier frequency to an operating channel (although the whole simulation is done at base band).

All the blocks in the CtrlP are interconnected through a common interface called Cross-Layer Interface (XLI) thus they can exchange information which allows implementing cross-layer solutions.

The CtrlP implements the various algorithms that set the parameters used in the DP. For the network block we have the routing algorithm that is based on the proactive optimal link state routing (OLSR). For the clustered network organization, the neighbor manager elaborates a list neighbor nodes through the received RAS "Hello" messages, and the clustering manager decides the nodes specification (CH, GN, RN) according to the information collected by the neighbor manager. The RAS manager manages the triggering of RAS transmissions. The slot allocation performs the resource allocation selecting the transmit power along with the modulation and coding scheme for each of the activated links per slot. The cluster graph coloring selects the operating channel value in the cluster, which can be one single frequency band or a set of frequency hops when frequency hopping is used.

It was decided that each of the partner of the CORASMA program would be free to work on their own cognitive solutions, seen as an extension to the existing BW. Thus, in order to be flexible, each partner could select any CtrlP block in Fig. 1 (one or many) and modify it to implement its own solution. To allow the different partners to implement their cognitive

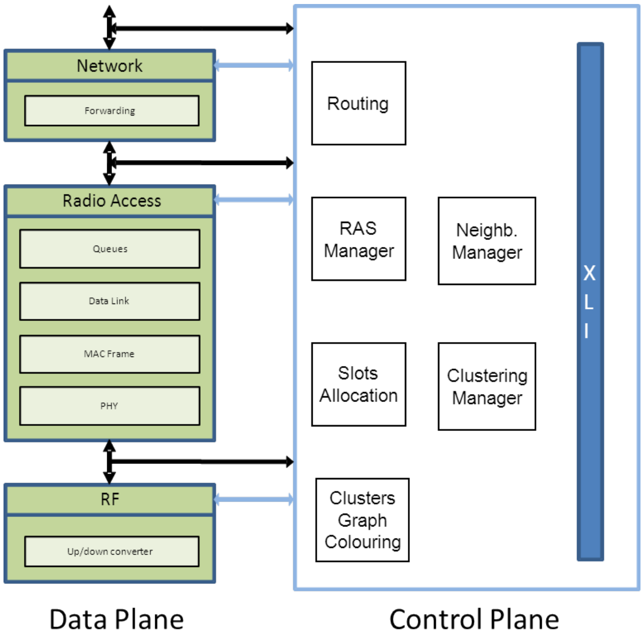

Fig. 1. Basic waveform: data plane and control plane.

solutions in a smooth and user-friendly way, we created a *cognitive plane* (CogP) as in Fig. 2. This CogP is composed of two main blocks. The first one called basic waveform mirror blocks (BWMB) is the replication of the CtrlP, where we can substitute all or part of the CtrlP blocks inside the CogP. We have complemented the CogP with another block that includes a database, a sensing block where all the sensing algorithms will be placed and a block called supervisor that can host any feature that is not yet available in the other blocks. In particular, it allows the implementation of algorithms that need to coordinate several blocks for joint or cross-layer solutions.

The interaction between the blocks inside the CogP and in between the CtrlP and the CogP is done through generic interfaces developed on purpose, and practical implementation is done through specific messages using the interfaces.

Note that we have also implemented, but not detailed here, a set of over-the-air interfaces to enable the exchange of messages between blocks in the cognitive plane of different nodes, enabling collaborative schemes that include several nodes in the decision-making process.

D. Metrics

The evaluation of simulation results is a key step in the study of the system performance. The simulator should provide features that enable to measure performance figures that we call *metrics* in the sequel. The CORASMA simulator implements three different kinds of metrics: 1) layer-based metrics for PHY/MAC/NET such as conventional packet loss, packet delay, ..., 2) cognitive metrics, which are specific to each cognitive solution, and 3) operational metrics that are *mission-oriented*.

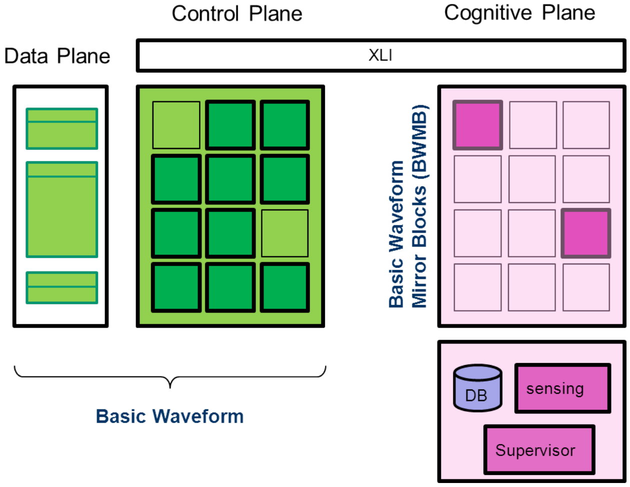

Fig. 2. Cognitive plane structure of the CORASMA simulator.

The two first kinds of metrics are devoted to detailed analysis of the simulation for technical people who are interested in engineering matters. It is worth noticing that for realistic scenarios with tens of nodes, the number of possible links at MAC layer, and source to destination links at NET layer, may be huge. Hence, something else is needed to answer the basic questions that operational people ask: *Does this waveform perform good*? *Does this cognitive solution perform better than my BW, and how much do I gain*? For this purpose, we have introduced some operational metrics that are able to synthesize the whole simulation in order to give precise answers to the previous questions. These metrics are linked to the operational scenario that depicts a set of communication services (push-to-talk, voice over IP, blue force tracking, ...) along the time for each node. Thus, from the technical NET metrics, we have defined rules based upon quality of service figures (end-to-end delay, packet loss rate, ...) in order to decide whether each service is performed satisfactorily or not. It is then possible to compute scores or figures of merit thus obtaining the average success for each service over the whole simulation duration. A global simulation score can be obtained by averaging the per service scores using a weighted sum, the weights being chosen according to the operational priorities of the corresponding services.

III. COGNITIVE SOLUTIONS

Aside from the HiFi simulator, one of the main contribution of the CORASMA program is the study and implementation of cognitive solutions. For this purpose we used a two-step approach. First, study of theoretical solutions inspired from the scientific literature in order to validate concepts/algorithms adapted to the CORASMA context. In this phase, each partner validates its work using its own simulation tool, and the corresponding target TRL is around three. Second, each of the partners implements at least one of its cognitive solution inside the HiFi simulator as presented in Section II. These implementations are constrained by the BW, which requires an important effort in order to adapt the solutions to its characteristics. More specifically, the implementation needs to cope with the HiFi constraints and use the signaling and interfaces offered by the BW complemented with the CogP.

As a matter of fact, all the partners have chosen to work at least on the cluster graph coloring algorithm. This appears natural, since this activity falls into the dynamic frequency management topic that is often seen as one of the major challenges that CR is envisioned to solve.

In the following sections, we first review the DFA topic in the context of tactical military systems, we then describe the solutions proposed by the authors for dynamic channel allocation derived in CORASMA, and finally we illustrate the results of the algorithms using simulator displays for a few metrics.

A. Dynamic Frequency Allocation

In standard military communication, a phase of mission preparation, called *mission planning*, sets the portion of the spectrum that must be used by the devices in a network. This portion of the spectrum is then shared by these devices in a flat fashion, i.e., all the devices use all the resources. Furthermore, each device utilizes for the transmission the maximum power allowed from the transceivers. However, this solution presents two weak points. The first one is its scalability, in fact the availability of transmission slots is inversely proportional to the number of transmitting devices. The second one is linked with its rigidity as fixed communication channels do not permit to account for interference, jamming and eavesdropping and a fixed (maximum) transmission power naturally leads to excess of battery drain (for instance if the receiver is close to the transmitter) and an increase in electromagnetic pollution, which, in turn, may disturb friendly communications and facilitates eavesdropping.

To overcome these limits, one possibility is to partition the network into subnetworks named clusters, each cluster being a group of devices sharing the same communication parameters. In this way, it is possible to subdivide the spectrum among the clusters. When the resource is large enough, an orthogonal assignment among the different cluster can be established. When the resource is not enough compared to the need (increasing number of nodes for instance), then the application of the frequency reuse concept among the clusters can dramatically increase the scalability of the network. Moreover, this subdivision might allow the networks to skip the mission planning. In fact, if each cluster in each network is able to efficiently select its transmission channel among the available ones, there is no need for the first subdivision of the spectrum.

For these reasons, it is envisaged the use of CRs and DFA [4], [5] as enabling technologies to improve the performance of tactical networks. According to this paradigm, the transmission channel is not set in advance, rather it is decided, following a certain behavioral rule, during the transmission evaluating the solution that better fits the communications' needs.

Notice that by employing CRs, the selection of the communication channel is not the only parameter that is possible to dynamically set during the transmission. Other parameters, such as transmission power, coding and modulation scheme, can be chosen to meet various and varying constraints. For instance, in military operations there might be phases in which prolonging battery life is more important than reaching an high throughput, and phases in which high performance must be achieved at all cost. However, the largest part of the technical literature mainly focuses in the DFA since this naturally arises as the first parameter to enable any communications.

We highlight that this problem is similar to the one of resource allocation in heterogeneous networks, such as small cells, pico-cells and femto-cells. However, in these contexts it is realistic to assume the presence of a backhaul that can be used to exchange useful information in order to help the network to self-configure its parameters [6].

In other cognitive environments, for instance in primary/secondary users context, CRs can exploit a common control channel to synchronize their access and to exchange information to avoid to interfere with the primary users. However, the presence of a such a channel results in higher risk in a military context, presenting several vulnerabilities [7], [8] both in terms of eavesdropping and of denial of service.

In clustered ad hoc networks, performing the DFA function can be translated into solving a graph coloring problem. Indeed, the set of clusters can be seen as a graph, each node representing a cluster. The links (or edges) between the nodes figure the property that these two nodes may interfere if they are operating on the same frequency channel. The problem is then to distribute the channels (to color the nodes) in such way that any pair of adjacent nodes in the graph have different colors.

To perform the function of DFA, mainly three approaches can be followed: centralized, collaborative, distributed. In the centralized one, a device (which can be one of the device in the network or an external dedicated hardware) collects the necessary informations and allocates the resources for the communicating nodes. The main drawbacks of this approach are linked with the amount of information exchange and the lack of flexibility. For instance, if the centralizing entity needs to be chose among the devices, this function must be completed every time in case of splitting or merging clusters.

In the collaborative approach, the devices exchange information in order to collectively assess the configuration. The main drawbacks of this approach are linked with the amount of (possibly sensible) information that must be exchanged among the devices in the network, which leads to security and network scalability issues.

In the distributed approach, each entity selects its own configuration relying only on locally available information. This approach is highly scalable and flexible, but it may suffer from performance issues.

Due to these characteristics, the authors focused on the third approach, aiming at defining a behavioral rule that could let the clusters, which in the network considered in CORASMA are the deciding entities, autonomously set the transmission channel and the power level.

In the technical literature, several methods have been proposed to efficiently accomplish this process of channel selection, for instance the iterative water filling, the greedy autonomous dynamic interference avoidance [9]–[15]. The interested reader, is referred to [11], [16] for a more comprehensive analysis of the state of the art.

B. Learning Solution for Cluster Frequency and Power Allocation

Here, we discuss the cognitive solution proposed by the authors for the CORASMA program. As stated in the previous sections, we aim to implement a solution that is able to assign to each cluster a transmission channel and a transmit power to be used by all the transmitters belonging to the cluster in an efficient way. Here, we mean by efficient that this solution should satisfy the QoS constraints for the largest possible set of links by employing the minimum amount of power at the global level. Therefore, each CH is responsible for choosing autonomously its communication configuration, which corresponds in our setting to the transmission channel c_k and the transmit power level p_k. Here, both c_k and p_k are assumed to be common parameters for all the transmitters belonging to cluster k. Summarizing, we rely on the following requirements:

1) Each CH must take its decisions based strictly on intra-cluster available information acquired through sensing, measurements or cooperation among the nodes within the cluster;
2) The chosen configuration should guarantee the respect of the transmission constraints (e.g., SINR) for the largest possible amount of links in the network;
3) The chosen configuration should drain the minimum amount of power from the batteries.

Our proposed solution takes the name of trial and error (TE) learning algorithm. The original TE algorithm is introduced in the seminal paper [17] in the Economic field. There, the purpose was to show that a relatively simple behavioral rule that mimes human behaviors is able to stochastically[1] steer an economic system to a Nash equilibrium. Later on, the behavioral rule was slightly modified in [18] to let the algorithm select among the NE the one with highest global performance. This rule was first adapted by the authors for single-link wireless networks in [19], and then generalized to ad hoc wireless networks in [20]. This adaptation requires the definition of a particular utility function that links the NE concept with the networking practical constraints. That is, the NE with the highest performance is a configuration setting that satisfies the constraints for the largest amount of links in the field and drains the minimum amount of power from the batteries in order to achieve this results.

Briefly, the algorithm is composed of a state machine, which runs in every CH. This state machine takes as an input the aggregate level of *satisfaction* of the links in the cluster, i.e., a one-bit feedback information representing whether a link is respecting its transmission constraints or not. There are several way to obtain this information, one is the estimation of the SINR level at the receiver side. This level can then be compared with a threshold and the result is sent to the CH (namely the feedback). Alternatively, a CRC is run on the received packet, and the in-built ACK/NACK system of the network can be exploited to obtain the information on the *satisfaction* of the links. Based on this *satisfaction*, the CH decides whether to experiment a new channel-power couple or not.

However, the basic formulation of TE was instable from a DFA point of view, i.e., the CH was switching from channel to channel too quickly for the algorithm to be efficiently be employed in a wireless network. In order to stabilize the cluster channel and power adaptation, the authors proposed a new solution based upon some heuristics in [16], [21].

First of all, the random process to select a new experiment for he channel and the power has been decoupled and processed independently. Second, the probability density functions driving the experiments have been made adaptive along time. For the channel, probability of experimenting is decreased gradually as long as satisfaction is achieved. For the power, the maximum value that can be drawn is monotonically decreased as long as satisfaction is achieved. The effect of these enhancements is to increase the average number of satisfied links (which can transmit), and to strongly reduce the amount of channel switches.

IV. SIMULATION RESULTS

In this section, we aim at assessing the performance of the proposed cognitive solution. First, we provide Matlab simulation results, showing the ability of TE to efficiently set the channel and power for a mobile network with high level of abstraction. Later, we show the simulation results obtained using the CORASMA simulator for both the BW and the TE.

In our first experiment we simulate the scenario plot in Fig. 3. Here, four static clusters are aligned together, and a fifth cluster is far apart. After 1500 iterations, the fifth cluster begins to move at a constant speed towards the aligned clusters. It becomes close enough to be creating interference around 1750 iterations, it is aligned around 2250 iterations and it becomes far apart around 2750 iterations.

In Fig. 4, we plot the result of the experiment. Here we plot the channel and power selection as a function of the iterations. Each color represents a channel, and the dimension of the line represents the amount of power used for transmission. Notice that the four static clusters select quite promptly (less than 50 iterations) an optimal configuration while the fifth is far apart. After 1750 iterations, the mobile cluster begins to interfere with cluster number 2 and 4. Here, it switches almost immediately its transmission channel, achieving an orthogonal channel assignment.

When implementing a similar scenario in the CORASMA simulator, it is possible to evaluate how the good behavior seen on the previous simulation by the TE impacts the upper layers, and it is also possible to compare the frequency channels set

---

[1] Here, stochastically means that the system implement a Nash equilibrium (NE) for a large proportion of the time with high probability.

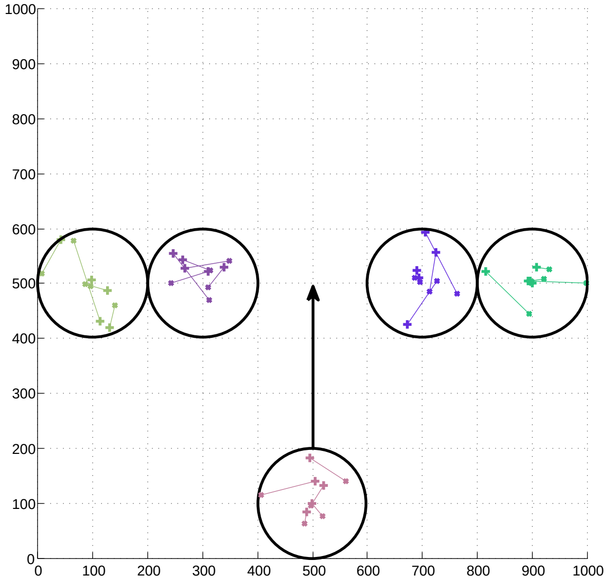

Fig. 3. Mobile scenario with four static clusters and a mobile one. The mobile cluster, begin to move after 1500 iterations at a constant speed, and it is aligned to the other clusters at 2250 iterations.

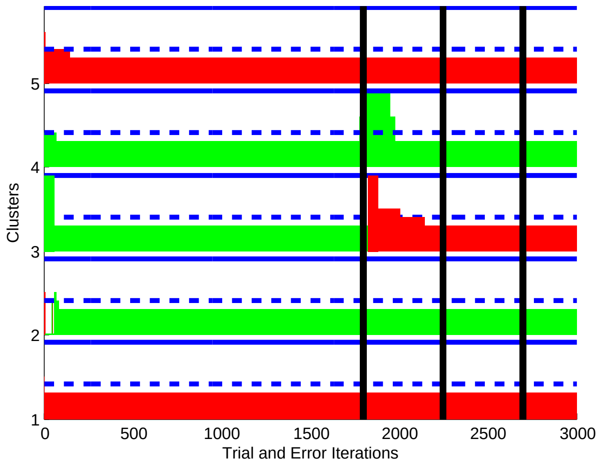

Fig. 4. Channel and power allocation for the scenario of Fig. 3 with two channel frequencies (green and red), the ordinates representing the transmit power.

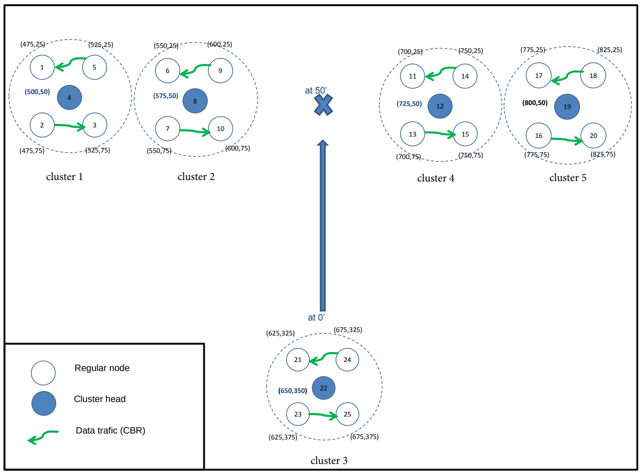

Fig. 5. Scenario description used in the CORASMA simulator (distances in meter).

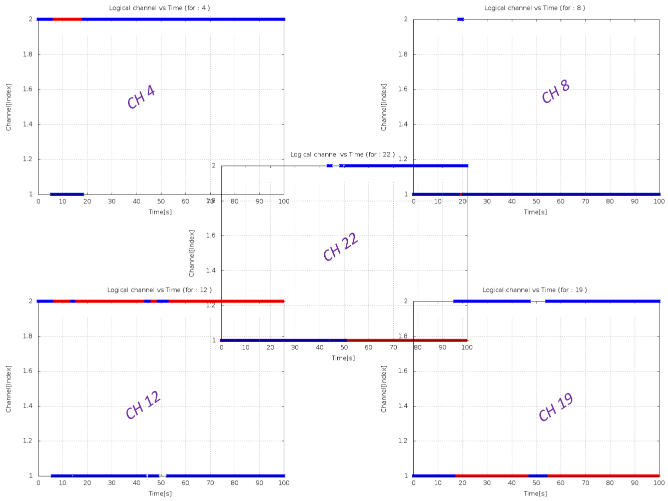

Fig. 6. Five clusters' logical channel along time for the two solutions, BW (static frequency) and TE - Only two available logical channels.

by TE with the one of GBDCA. Following the Matlab scenario given in Fig. 3, another equivalent scenario is defined for the CORASMA simulator as depicted in Fig. 5. In this scenario, a UDP constant bit rate traffic of 6500 bytes/s is implemented between nodes and indicated with green arrows.

In order to analyze and compare the performance between BW and TE, we make use of the statistical metric display tool developed with the CORASAMA simulator, namely the *result display*. Note that in the following figures, the red curves and blue curves represent the BW and the TE respectively. Fig. 6 provides the frequency selection for each CH along time for both the BW and TE.

One can observe that the BW does not change the channel during the simulation whereas the TE solution does. In particular, one can observe that the frequency selection starts varying around 40 seconds. This is due to the fact that the mobile cluster becomes close to the other clusters and starts interfering. Then, after around 55 seconds (i.e., 15 seconds for convergence), the channel selection stabilizes. The final frequency selection is $\{2, 1, 1, 2, 1\}$ and $\{2, 1, 2, 1, 2\}$ for the BW and the TE, respectively. Therefore, in the BW case, clusters 2 and 5 with CH 8 and 22 respectively, interfere with each other since they are using the same logical channel 1. This illustrates one drawback of the GBDCA algorithm that is not based upon interference measurements, and that can be stuck in an interfering configuration without being able to resolve it.

Now, thanks to the CORASMA simulator, we can analyze the performance of the system at various layers, and more particularly at the IP layer. We selected the IP throughput metric in the result display for three communication links,

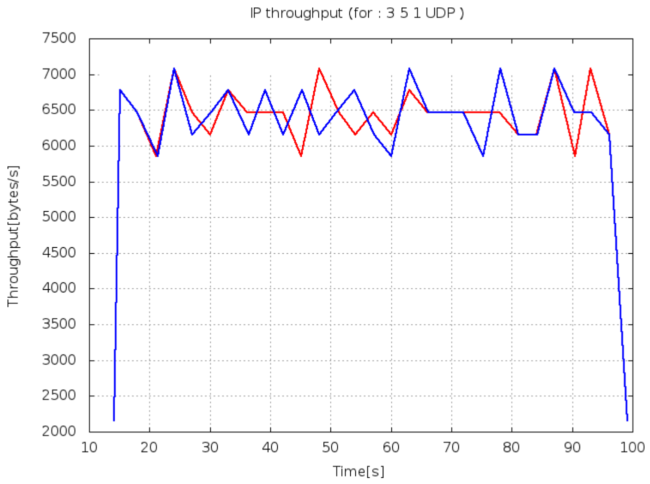

Fig. 7. IP throughput at node 5 received from node 1.

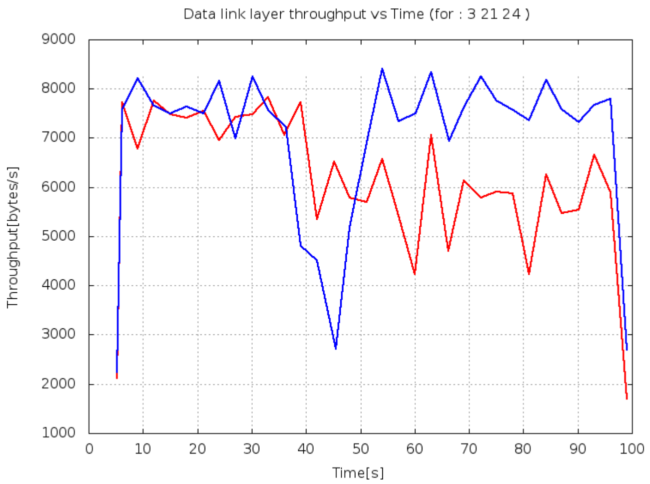

Fig. 8. IP throughput at node 24 received from node 21.

$5 \rightarrow 1$, $24 \rightarrow 21$ and $7 \rightarrow 10$, which are displayed in Fig. 7, Fig. 8, and Fig. 9 respectively.

In Fig. 7 we can observe that for the link $5 \rightarrow 4$ the throughput is the same for the BW and TE solutions. This shows that when that the TE succeeded to adapt the power such that the configuration $\{2, 1, 2, 1, 2\}$ does not create significant interference between cluster 1 and cluster 3. The performance is the same as for the BW even though the configuration $\{2, 1, 1, 2, 1\}$ is more favorable for this particular link.

For the two other links, in Figs. 8-9, the BW throughput drops after around 40 seconds. This traffic drop is coherent with the channel frequency solution of the BW described before, i.e., communications between clusters 2 and 5 are interfering each other.

Figures 10-11, and Figs. 12-13 represent the throughout metric and the packet error rate respectively at the data link layer for the the two interfered links.

One can observe that the TE solution has errors concentrated around 50 seconds only, whereas for the BW the errors remain

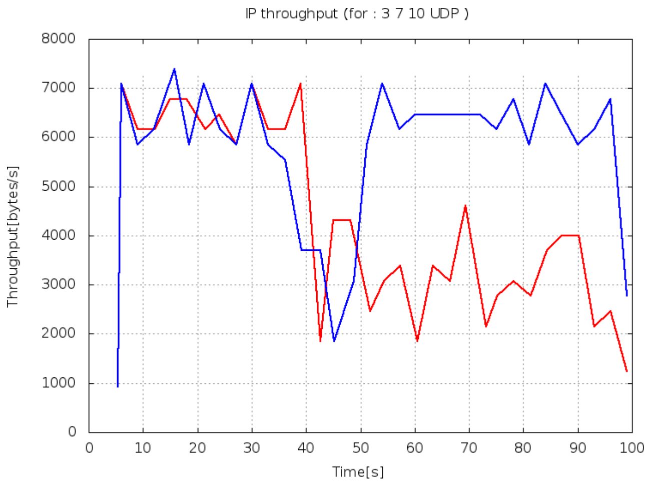

Fig. 9. IP throughput at node 10 received from node 7.

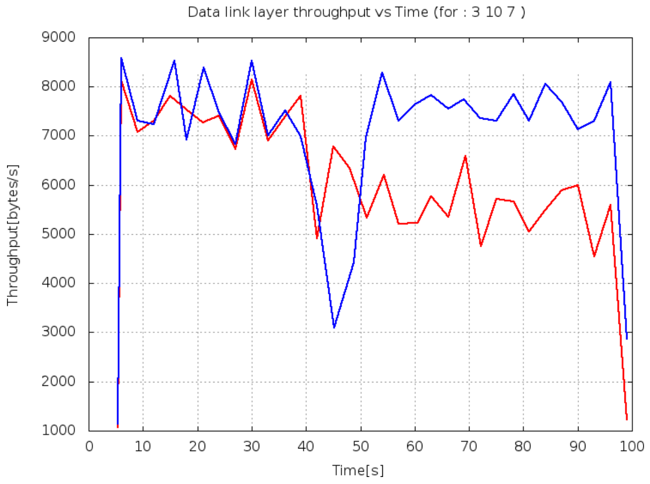

Fig. 10. MAC throughput at node 21 from node 24.

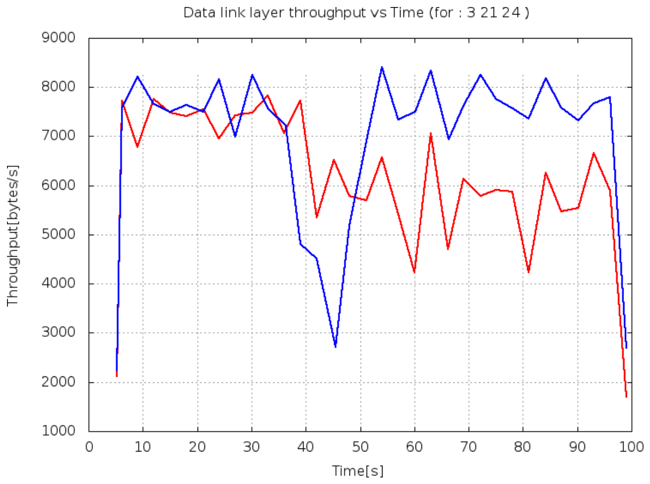

Fig. 11. MAC throughput at node 7 from node 10.

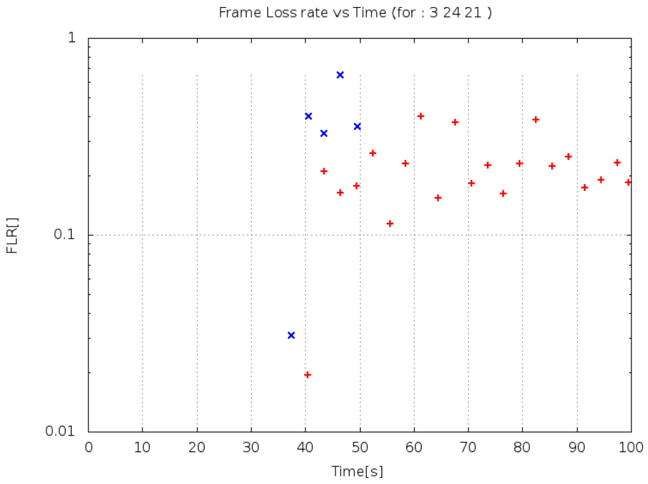

Fig. 12. Mac Frame Loss Rate at node 21 for data from node 24.

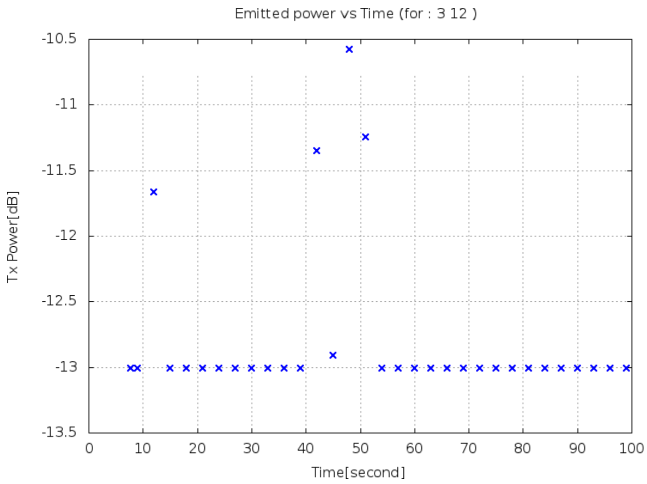

Fig. 14. Transmit power along time for the TE solution for CH 12.

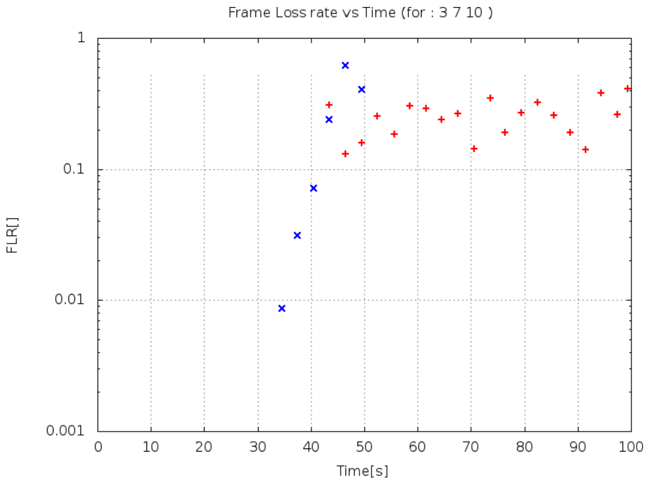

Fig. 13. Mac Frame Loss Rate at node 10 for data from node 7.

till the end. This actually confirms the behavior seen at IP layer. One can note that the decrease of throughput at the IP layer is much larger than the one at data link layer, which shows the ”amplification” on the performance between two adjacent layers of the interference effect. Finally, Fig. 14 displays the transmit power for the TE solution along time in dBW. While the BW transmit power is fixed and equal to -10 dBW, the graph shows that the TE achieves a lower transmit power and succeeds to meet the objective of setting the smallest transmit power while fulfilling the required QoS.

V. CONCLUSION

In this paper, the latest advancement of the ongoing CORASMA program have been reported. In this program, cognitive solutions are studied and compared in a military wireless network context. A HiFi simulator, in which communications' details, from the physical layer to the network layer, are implemented without any level of abstraction, has been developed in order to assess the advantages and drawbacks of the proposed cognitive solutions. A basic waveform at the state of the art has been designed to serve as a reference for comparison. As a cognitive solution, the trial and error learning algorithm has been suggested as a possible candidate to allocate communication channels and transmission power within the network, and its ability to efficiently configure the network has been detailed through comprehensive simulations.

The TE was implemented in the CORASMA simulator and performance results were presented on a similar scenario stimulated by UDP traffic. Thanks to the simulator result display, we were able to assess the performance of the system at IP layer and to verify the coherence of the results with lower layers performance and also channel assignment information. Although the simulator is not fully finalized, preliminary results are already promising, and the next step should include the operational metrics.

VI. ACKNOWLEDGMENT

This research work was carried out in the frame of the ”CORASMA - EDA Project B-0781-IAP4-GC”.

REFERENCES

[1] J. Mittag, S. Papanastasiou, H. Hartenstein, and E. Strom, “Enabling Accurate Cross-Layer PHY/MAC/NET Simulation Studies of Vehicular Communication Networks,” *Proceedings of the IEEE*, vol. 99, no. 7, pp. 1311–1326, 2011.

[2] R. Massin, C. Lamy-Bergot, C. J. Le Martret, and R. Fracchia, “OMNeT++ based cross-layer simulator for content transmission over wireless ad hoc networks,” *EURASIP Journal on Wireless Communications and Networking (JWCN)*, vol. 2010, no. ID 2502549, 2010.

[3] T.-C. Hou and T.-J. Tsai, “On the cluster based dynamic channel assignment for multihop ad hoc networks,” *IEEE Journal of Communications and Networks*, vol. 4, no. 1, pp. 40–47, March 2002.

[4] Q. Zhao and B. M. Sadler, “A survey of dynamic spectrum access,” *IEEE Signal Processing Magazine*, vol. 24, no. 3, pp. 79–89, 2007.

[5] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, “Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey,” *Journal of Computer networks (Elsevier)*, vol. 50, pp. 2127–2159, 2006.

[6] D. Lopez-Perez, I. Guvenc, G. De La Roche, M. Kountouris, T. Q. Quek, and J. Zhang, “Enhanced intercell interference coordination challenges in heterogeneous networks,” *IEEE Wireless Communications, IEEE*, vol. 18, no. 3, pp. 22–30, 2011.

[7] K. Bian and J.-M. Park, “Mac-layer misbehaviors in multi-hop cognitive radio networks,” in *2006 US-Korea Conference on Science, Technology, and Entrepreneurship (UKC2006)*, 2006.

[8] T. X. Brown and A. Sethi, “Potential cognitive radio denial-of-service vulnerabilities and protection countermeasures: a multi-dimensional analysis and assessment,” *Jounral of Mobile Networks and Applications*, vol. 13, no. 5, pp. 516–532, 2008.

[9] G. Foschini and Z. Miljanic, “A simple distributed autonomous power control algorithm and its convergence,” *IEEE Transaction on Vehicular Technology*, vol. 42, no. 4, pp. 641–646, 1993.

[10] P. Sastry, V. Phansalkar, and M. Thathachar, “Decentralized learning of Nash equilibria in multi-person stochastic games with incomplete information,” *IEEE Transactions on Systems, Man and Cybernetics*, vol. 24, no. 5, pp. 769–777, May 1994.

[11] L. Rose, S. Lasaulce, S. M. Perlaza, and M. Debbah, “Learning equilibria with partial information in decentralized wireless networks,” *IEEE Communications Magazine*, vol. 49, no. 8, pp. 136 –142, Aug. 2011.

[12] B. Babadi and V. Tarokh, “GADIA: A greedy asynchronous distributed interference avoidance algorithm,” *IEEE Transaction on Information Theory*, vol. 56, pp. 6228–6252, Dec. 2010.

[13] V. Le Nir and B. Scheers, “Autonomous dynamic spectrum management for coexistence of multiple cognitive tactical radio networks,” in *Proceedings of the Fifth International Conference on Cognitive Radio Oriented Wireless Networks Communications (CROWNCOM)*, Jun. 2010.

[14] V. L. Nir and B. Scheers, “Improved Coexistence between Multiple Cognitive Tactical Radio Networks by an Expert Rule based on Subchannel Selection,” in *Wireless Innovation Forum European Conference on Communications Technologies and Software Defined Radio SDR’11-WInnComm-Europe, Brussels, Belgium*, Jun. 2011.

[15] J.-S. Pang, G. Scutari, D. P. Palomar, and F. Facchinei, “Design of cognitive radio systems under temperature-interference constraints: A variational inequality approach,” *IEEE Transaction on Signal Processing*, vol. 58, no. 6, pp. 3251–3271, Jun. 2010.

[16] L. Rose, S. M. Perlaza, C. J. Le Martret, and M. Debbah, “Self-Organization in Decentralized Networks: A Trial and Error Learning Approach,” *submitted to IEEE Transaction on Wireless Communication*, 2013.

[17] H. P. Young, “Learning by trial and error,” University of Oxford, Department of Economics, Economics Series Working Papers 384, 2008.

[18] J. R. Marden, H. P. Young, and L. Y. Pao, “Achieving pareto optimality through distributed learning,” 2011, under submission.

[19] L. Rose, S. M. Perlaza, M. Debbah, and C. L. Martret, “Distributed power allocation with SINR constraints using trial and error learning,” in *IEEE Wireless Communications and Networking Conference, WCNC, Paris, France*, Apr. 2012.

[20] L. Rose, M. Debbah, and C. L. Martret, “Distributed power allocation with sinr constraints using trial and error learning,” in *Military Communications and Information Systems Conference, MCC*, Gdańsk, Poland, Oct. 2012.

[21] L. Rose, C. J. L. Martret, and M. Debbah, “Joint channel and power allocation in tactical cognitive networks: Enhanced trial and errors,” in *submitted to the Military Communications and Information Systems Conference (MCC)*, Saint–Malo, France, Oct. 2013.