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**Research Article**

# Learning System for Proactive Pre-emptive Unified Spectrum Handoff (PRO-PUSH) in Cognitive Radio Mobile Ad Hoc Networks

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**Abstract:** The aim of this study is to introduce a conceptual framework for the new approach Intelligent Proactive Pre-emptive Unified Spectrum Handoff (IP PRO-PUSH) algorithm is presented, which is a highly potential intelligent technology to intelligently address the spectrum scarcity challenges in Cognitive Radio Mobile Ad hoc Networks (CR-MANETs). The fact that spectrum is a limited natural resource poses technology challenge to ensure the available frequency is used efficiently and able to cope with new services which definitely requires more bandwidth in the future. However, over the past years, traditional approaches to spectrum management have been challenged by new insights into actual use of spectrum. In order to improve the utilization of the overall radio spectrum, the Cognitive Radio (CR) is a useful solution to this low utilization of the radio spectrum. The variation in spectrum band is called spectrum mobility. The objective of the current study is to investigate the Intelligent-Based (IB) cognitive radio learning for IP Pro-PUSH and local routing based on spectrum mobility in mobile Cognitive Radio Ad hoc Networks (CR-MANET) along with a conceptual framework and its connections.

**Keywords:** Cognitive radio, dynamic spectrum allocation, handoff management, intelligent systems, learning

## INTRODUCTION

The fixed spectrum assignment has led to poor spectrum efficiency. According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15 to 85% (FCC, 2003). Therefore, the dynamic spectrum access was proposed to increase the spectrum efficiency by an opportunistic spectrum usage. The low efficiency is due to the underutilized spectrum usage by the licensed user or Primary Users (PUs) most of the time. The Cognitive Radio (CR) users or Secondary Users (SUs) can use these empty channels in an opportunistic manner. CR implies on an adaptive and intelligent radio which is aware of its surrounding environment (Mitola and Maguire, 1999).

Spectrum handoff refers to changing the operation frequency of a SU. The spectrum handoff happens when the status of the current channel does not satisfy the quality of service or a PU appears in a licensed band. SU performs spectrum handoff in order to capture a better channel or evacuate the current channel for the PU.

The available frequency bands show different characteristics in CR networks. Therefore, the radio conditions and PU activities must be considered for spectrum band characterization. In addition, a dynamic decision scheme is also needed, which considers the spectrum sensing and channel characteristics for maximizing the efficient CR transmission (Duan and Li, 2011). Available spectrum bands vary over time as well as with the SUs movements. The PUs activities, SUs mobility and channel heterogeneity must be considered in spectrum handoff and mobility management protocols. Therefore the integrated mobility and handoff management is essential to have a reliable, fast and smooth spectrum handoff and transition (Nejatian *et al*., 2012a). Integrated mobility function must consider the spectrum mobility in both time and space domain. In other words, for designing a mobility management protocol, the spectrum mobility, user mobility and channel quality degradation must be considered jointly (Lee and Akyildiz, 2012).

As mentioned previously, the learning is one of the main aspects of the CR. In learning process, the CR collects the knowledge based on evaluation of the output in the decision-making process. CR uses this knowledge for better orientation in the future. In this study, we emphasize the Intelligent-Based (IB) cognitive radio learning for Intelligent Proactive Pre-emptive Unified Spectrum Handoff (IP PRO-PUSH). Based on spectrum

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mobility in CR-MANET, segments and connections are highlighted for intelligent integrated spectrum handoff management in CR-MANETs. A conceptual model for the new approach IP PRO-PUSH algorithm is presented, which is a highly potential intelligent technology to intelligently address the spectrum scarcity challenges in Cognitive Radio Mobile Ad hoc Networks (CR-MANETs).

## LITERATURE REVIEW

Mobility is an essential function in cognitive radio networks because of its effect on network properties such as channel capacity, routing, connectivity and coverage (Nejatian *et al*., 2012b).

The existence of available spectrum holes is random due to the randomness PU's presence and unpredictability of SUs' demands. Therefore, the spectrum holes are shifting over time because of the PUs activities and over space because of the SUs mobility. The spectrum holes shifting is defined the as spectrum mobility. Spectrum mobility leads to spectrum handoff, which refers to evacuating the operation frequency of a SU. During the spectrum mobility, PU reclaims the special licensed band occupied by the SU. The SU's ongoing data transmission is transferred to another empty band of the spectrum. Mobility function guarantees a fast channel evacuation with minimum network performance degradation. Spectrum handoff management is challenging in ad hoc networks due to the lack of a central entity for managing and controlling the spectrum handoff procedure.

In Duan and Li (2011), a handoff management scheme is proposed. This scheme determines the optimal spectrum band based on a multi criteria decision making strategy, which considers the estimated transmission time, the PU presence probability and spectrum availability time. The authors of Song and Xie (2011a, b) proposed a proactive spectrum handoff scheme which is based on the statistics of channel utilization. The collision among SUs is also deleted using a distributed channel allocation scheme. Nejatian *et al*. (2012c), an established route from a source node to a destination node is considered. Different scenarios, which lead to the handoff initiation in this route, are also introduced. Considering these events, which are node mobility and spectrum mobility, the authors introduced a conceptual model for unified handoff management in CR-MANETs. The authors of Nejatian *et al*. (2012b) have characterized the availability of spectrum bands in CR-MANETs. The authors proved that the channel heterogeneity must be considered in terms of transmission range, because it increases the blocking probability of spectrum handoff. Based on their findings, a unified system, which considers the spectrum mobility in time and space domain as well as topology changing, must be investigated.

Nejatian *et al*. (2013a, 2014, 2013b) proposed Pre-emptive Unified Spectrum Handoff (PUSH) scheme in Cognitive Radio Mobile Ad hoc Networks (CR-MANETs) through an established route in which the Channel availability depends on the PU's activity, the SU's mobility and the channel heterogeneity. First, they introduced an analytical model for Unified Spectrum Handoff (USH) scheme in which the Secondary Users (SUs) will move to another unused spectrum band, giving priority to a Primary User (PU) (Nejatian *et al*., 2013c, 2013d). Then, they proposed the PUSH method in which a handoff threshold is used to start the handoff pre-emotively. When a channel handoff cannot be performed due to the SU's mobility, a Local Flow Handoff (LFH) is performed. The proposed PUSH algorithm uses the cognitive link availability prediction while considering the interference to the PUs to estimate the maximum link accessibility period with the PU's interference avoidance. Based on the analytical model, the channel heterogeneity and the SU's mobility affected the performance of the handoff management method rather than the PU's activity.

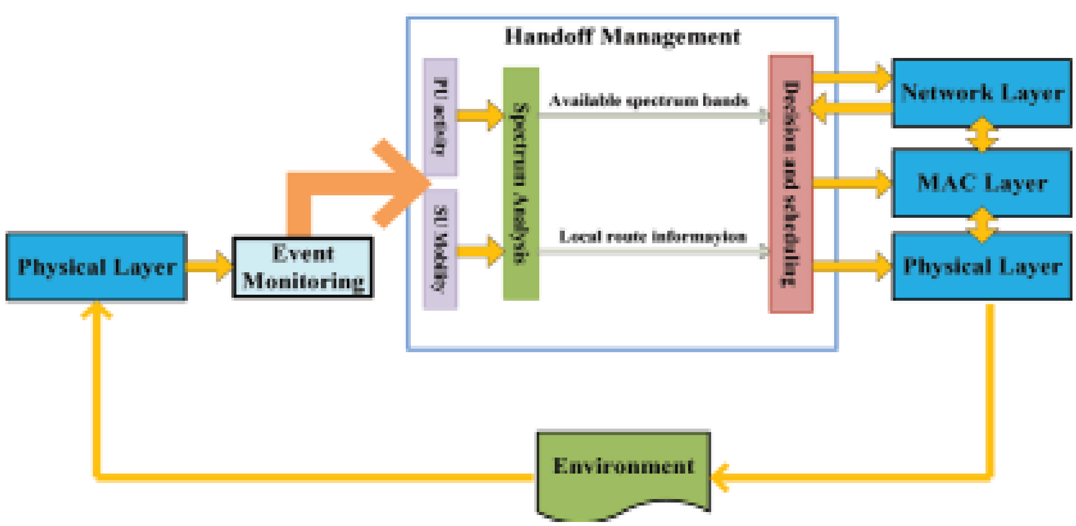


Fig. 1: Proposed PUSH method in Nejatian *et al*. (2013a)

As illustrated in Fig. 1, the proposed PUSH framework considers the spectrum-aware handoff management based on interactions between routing (layer 3) and the physical layer (layer 1). The proposed scheme is equipped with an algorithm to identify appropriate channel based on the channel qualities, the spectrum and the node mobility. The spectrum analysis provides information about the environment condition and the mobility of the SUs. Thus, a precise and cooperative environment and a location aware mechanism are used in the PUSH. The spectrum analysis segment requires information about the situations of the SUs as well as the PUs' activities. Hello packets in neighbour discovery message are modified to provide or share the information regarding free channel at each node to its neighbour nodes. The neighbours can also obtain information about the situation of the node based on the Received Signal Strength Indicator (RSSI) and other appropriate parameters. In a heterogeneous channel conditions in which different channels have different transmission and broadcasting ranges, channel availability time depends on the channel transmission range. On the other hand, channel availability time varies rapidly due to SU's mobility. Hence, the integrated spectrum handoff management system considers the mentioned factors along with SINR and power management schemes to avoid interference with PUs. When a channel handoff cannot be performed due to the SUs mobility, a pre-emptive local flow handoff is performed. The motivation of this mechanism is to maintain end-to-end connectivity once a route is established for the purpose of sending data and increase the route maintenance probability. The PUSH algorithm also predicts the cognitive link availability and estimates the maximum link availability time considering the interference to the PUs. The motivation of this mechanism is to reduce the number of spectrum handoff and the number of route error requests.

Although, both the simulation and analytical results demonstrated an improvement of route maintenance probability based on the LFH and cognitive link

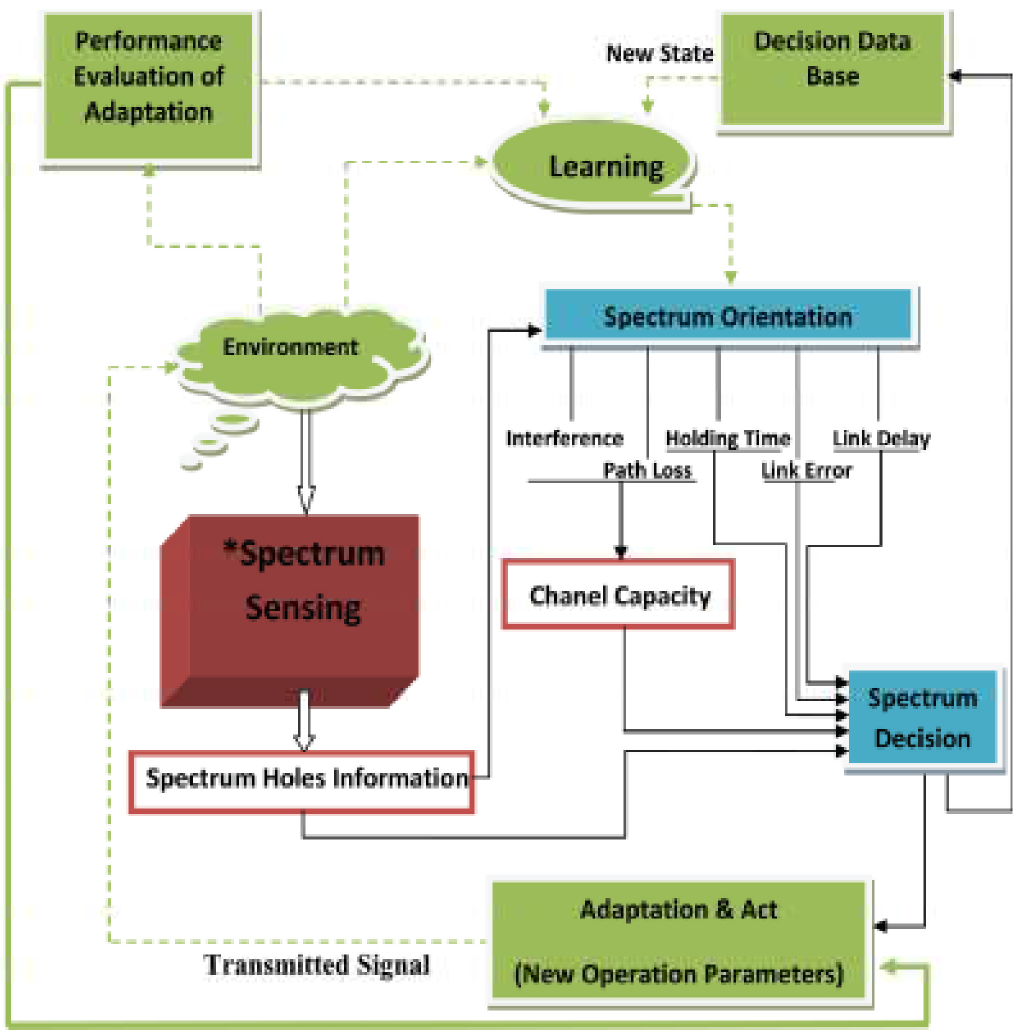


Fig. 2: Elements of cognitive cycle and their connections

availability prediction mechanisms in PUSH, the learning area of PUSH algorithm is still in a nascent stage. Further work on PUSH algorithm may proceed along the improvement of the learning algorithms that allow a fast, appropriate and accurate converging on the decision-making process. Using the intelligent systems such as neural networks, fuzzy sets and systems and Bayesian networks can be a good solution to improve the learning algorithms.

This research introduces the IB cognitive radio learning for PUSH. The new approach IP PRO-PUSH algorithm is presented, which is a highly potential intelligent technology to address the spectrum scarcity challenges in CR-MANETs. Based on the literature, as far as we are concerned, there is no work which considers intelligent integrated spectrum handoff management in CR-MANETs. Current study leads to optimization of CR-MANETs by exploiting intelligent efficient usage of the available wireless spectrum and it can be used potentially for further development and commercialization. In the next section we introduce the concept of the IP PRO-PUSH and its main connections.

## INTELLIGENT-BASED COGNITIVE RADIO LEARNING FOR INTELLIGENT PROACTIVE PRE-EMPTIVE UNIFIED SPECTRUM HANDOFF

**Cognitive cycle in cognitive radio:** CRs are intelligent wireless radios that are able to adapt and configure themselves to satisfy the quality of service. In order to achieve this goal, they must observe the environment, adapt to the spectrums, make a decision, perform necessary actions and learn from their experiences (Maqbool *et al*., 2013a, b, 2014). These activities form a cycle which is famously known as cognitive cycle. The cognitive cycle elements and their relations are illustrated in Fig. 2. As it can be seen, the last stage in cognitive cycle is related to the learning aspect of this cycle. In this stage, the CR collects the knowledge based on evaluation of the output in the decision-making process. CR uses this knowledge for better orientation in the future. Therefore, using an IB learning part can improve the performance of the CR.

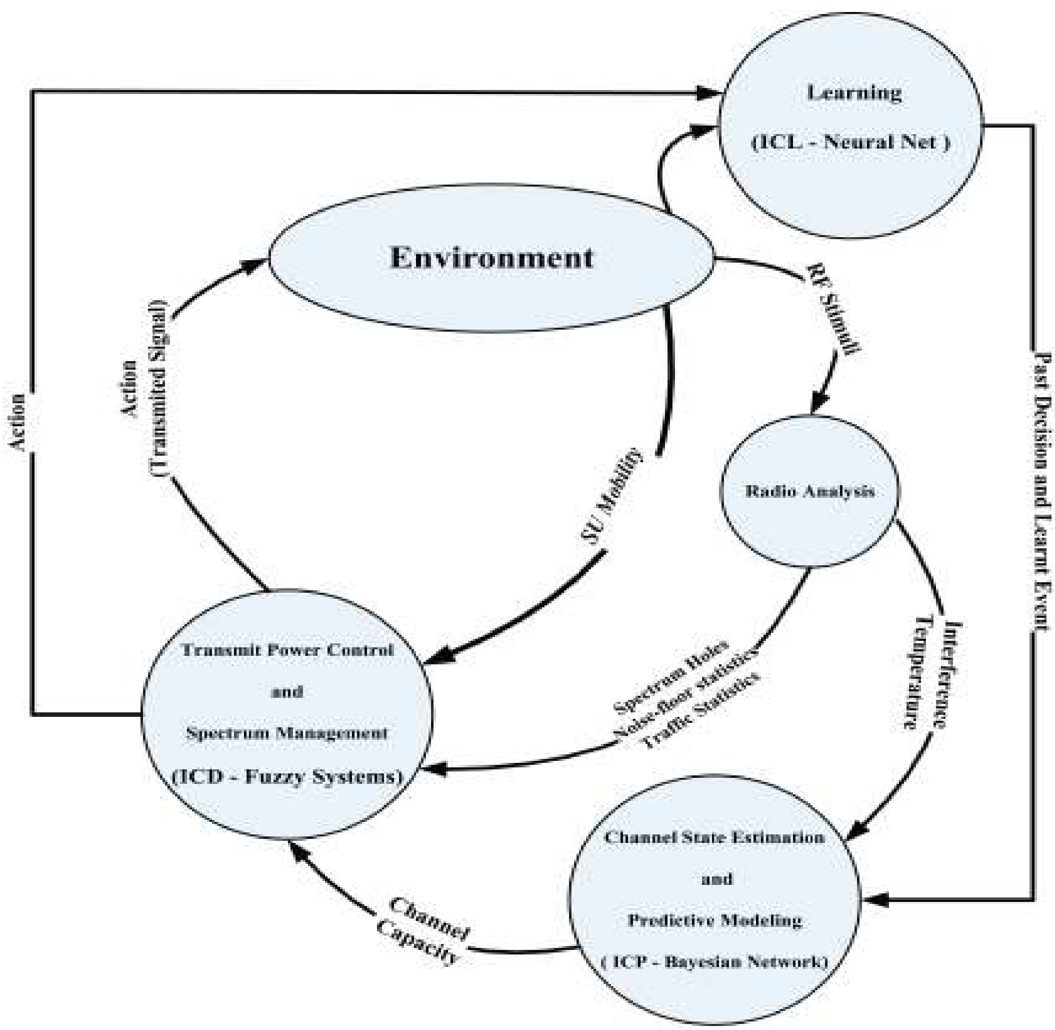


Fig. 3: Intelligent based learning for proactive pre-emptive unified spectrum handoff management scheme

**Intelligent learning cycle for proactive pre-emptive unified spectrum handoff:** Considering the cognitive cycle in CR, the IB learning part for PUSH algorithm is proposed. Figure 3 illustrates the cognitive cycle with IB learning part for PUSH. Here, each SU is equipped with an Intelligent Core (IC) that is an adaptive and intelligent decision-making unit. The IC improves the spectrum handoff performance of the SU by learning how to choose the optimal action from a set of actions through repeated interactions with a random and time varying environment in which spectrum availability varies over time as well as over space.

The action is chosen by the Decision-making part of the IC (ICD) based on a probability distribution kept over the actions set learnt by the learning part of the IE (ICL) and an estimation of channel state predicted by the Predictive part of the IC (ICP). At each instant the given action is served as the input to the random and time varying environment. The environment responds the taken action in turn with a reinforcement signal. The action probability vector is updated based on the reinforcement learning feedback from the environment. The objective of using the IC is to find the optimal action from the finite action-set so that the average penalty received from the environment is minimized. The IC is also used to recognize the parameters of an unknown traffic distribution and to find the optimal action in pre-emptive unified spectrum handoff strategy.

The influence of different parameters and events on channel availability is considered in learning part, prediction part and decision part of the IC in order to obtain an IB unified model for channel availability and spectrum handoff in CR-MANETs.

**Intelligent proactive pre-emptive unified spectrum handoff framework:** Based on the IB learning cycle introduced in the previous subsection, the Intelligent Proactive Pre-emptive Unified Spectrum Handoff (IP PRO-PUSH) framework is proposed. Figure 4 illustrates the proposed framework for the IP PRO-PUSH.

As illustrated in Fig. 4, the proposed IP PRO-PUSH framework considers the spectrum-aware handoff management based on interactions between routing (layer 3) and the physical layer (layer 1). The proposed scheme is equipped with an IC to manage the unified spectrum handoff intelligently. The IC consists of three different segments ICL, ICD and ICP segments.

In this IB framework, the neural network is used in the ICL segment. In this segment, the CR collects the knowledge based on the evaluation of the output of the decision-making process. CR uses this knowledge for better orientation in the future. Here, an Adaptive Neuro-Fuzzy Inference System (ANFIS) is used to

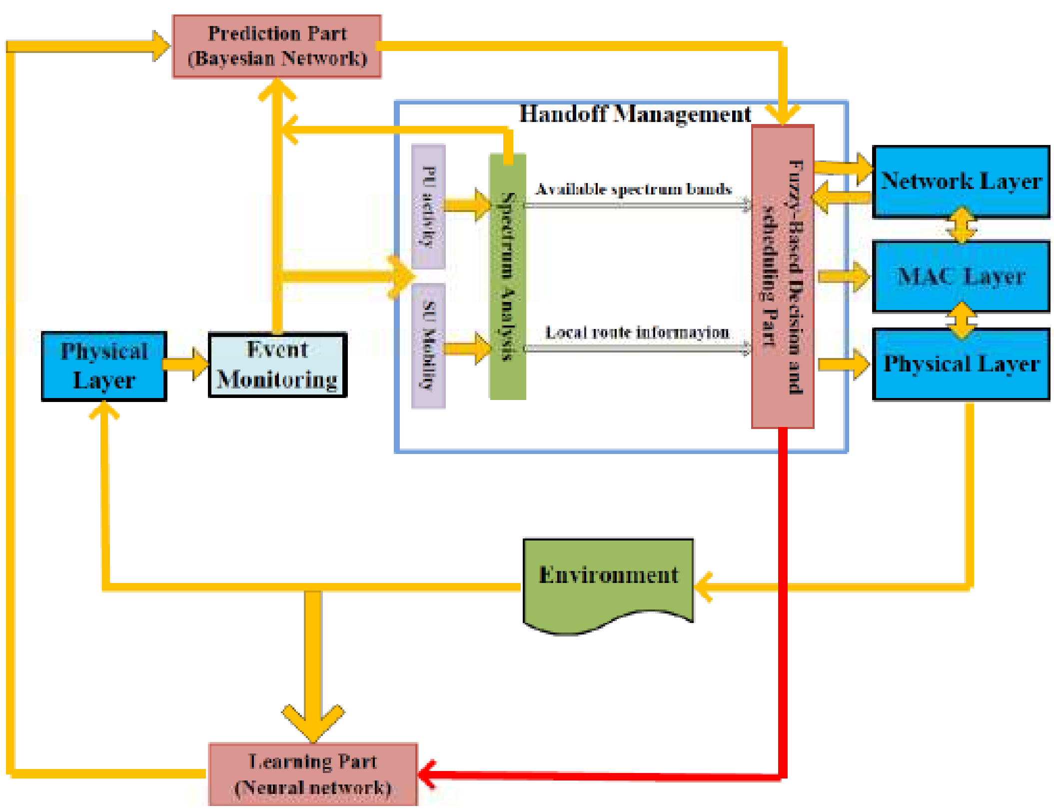


Fig. 4: The proposed framework for IP PRO PUSH

improve the learning capabilities of the cognitive cycle. It combines the neural network adaptive capabilities and the fuzzy qualitative approach.

In the prediction segment the Bayesian network is used as the predictive tool. Bayesian inference allows informative priors so that prior knowledge or results of the previous experiences learnt by the ICL can be used to inform the current state of the system to the ICD. CR observes and senses the radio environment by sensing. Interference information, which is the output of radio analysis part, is sent to the prediction segment. The ICP predicts the channel capacity based on the interference information and also the experiences learnt from the learning stage and sends this information to the ICD.

Spectrum holes information is sent to the decision-making segment by the spectrum analysis part. For decision-making, the spectrum holes information, the time varying properties of the radio environment and channel capacity are needed. In the decision-making segment the Fuzzy system is used as the ICD tool. The Fuzzy decision-making algorithm is capable of adapting to the network conditions and traffic changes. It can also incorporate the uncertain conflicting metrics to make a comprehensive decision with a low cost. In this stage, CR determines the data rate and transmission mode to provide the QoS. Therefore, CR must change its parameters according to the decision before transmitting the signal. CR must learn from its experiences and gather the knowledge for better spectrum orientation in the future.

The presented IP PRO-PUSH algorithm is a highly potential intelligent technology to intelligently address the spectrum scarcity challenges in Cognitive Radio Mobile Ad hoc Networks (CR-MANETs). It can also intelligently reduce the handoff blocking and link failure probabilities due to user mobility. Additionally, IP PRO-PUSH reduces the route request frequency, hence maintaining end to end connectivity. It is also expected to intelligently decrease the number of spectrum handoff in these networks considering the effects of different mobility events and parameters on spectrum handoff. Above all, IP PRO-PUSH algorithm is expected to improve the performance of bandwidth utilization of CR-MANETs.

## CONCLUSION

The last stage in cognitive cycle is related to the learning aspect of this cycle. In this stage, the CR collects the knowledge based on evaluation of the output in the decision making process. CR uses this knowledge for better orientation in the future. This area is still in a nascent stage. IP PRO-PUSH may proceed along the improvement of the learning algorithms that allow a fast, appropriate and accurate converging on the decision-making process. Using the intelligent systems such as neural networks, fuzzy sets and systems and Bayesian networks is a good solution to improve the learning algorithms for PUSH. In this study, we emphasize the Intelligent-Based (IB) cognitive radio learning for IP PRO-PUSH based on spectrum mobility in CR-MANET, highlighting those segments and connections for intelligent integrated spectrum handoff management in CR-MANETs. A conceptual framework for the new approach IP PRO-PUSH algorithm is presented, which is a highly potential intelligent technology to intelligently address the spectrum scarcity challenges in Cognitive Radio Mobile Ad hoc Networks (CR-MANETs).

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